

# GRADE 2 ENGINEERING & PHYSICS

First edition

8 units

32 lessons + Toy Lab

A video for every lesson

FIRST EDITION

## COURSE GUIDE

This course follows the eight strands of engineering through one school year for second graders: motion and machines, bridges, buildings, electricity, water, power and roads, boats, flight, and robots. Every lesson begins with a true story from history. Children watch workers in old Egypt pour water in front of a giant statue's sledge, Russian builders roll a rock as big as a house on bronze balls, Samuel Morse tap out "What hath God wrought," Elisha Otis cut the rope on his own elevator, and Wilbur and Orville Wright lift off the sand at Kitty Hawk.

Each lesson follows the same simple path, written in short sentences to read aloud. First comes **the story**. Then **how they figured it out**: what they tried, what went wrong and what they changed. Then **the physics**, explained for a seven-year-old, and **the engineering**: how people turn the idea into something safe and useful today. Last, the child builds a small version with cardboard, paper, pennies, string and batteries, guesses what will happen, tests it fairly, writes down the numbers, and makes it better.

God made an orderly world that can be measured and understood, and He made people in His image to be makers. Engineering, rightly done, is a way of loving our neighbors: a bridge that stays up, clean water, a light in the dark. The old Latin saying *Fabricando fit faber*, "by making, one becomes a maker," is the heart of this course. An optional ninth unit, the Toy Lab, looks at the physics of the Slinky, Lincoln Logs, the swing and the little red wagon, for the summer or any week that needs something fun.

Most videos come from trusted teaching channels and museums: SciShow Kids, Free School, Design Squad, Science Buddies, the Smithsonian Channel, BBC Studios, Science Channel, Fun Kids Learn (made with the Royal Academy of Engineering) and a few others chosen lesson by lesson. Every video was previewed for content and

accuracy and most are two to eight minutes long. Some channels end with an invitation to subscribe or a short sponsor message; you can stop the video when the teaching ends. A few lessons have a short parent note about something to watch for. Watch together, and pause to let your child guess what will happen next.

**Start with Lesson 1.1 →**

## WHO IT IS FOR

Written for children in second grade (about ages 7–8), usually read aloud by a parent. Children should be able to count to 100, measure with a ruler with help, and draw and label a simple picture; a parent writes down answers when needed and handles scissors, sharp points and hot glue. No kits are required: every build uses household or inexpensive craft-store materials. Optional kits are listed in some units for families who want them.

## HOW TO USE THIS COURSE

1. **The weekly rhythm.** The year has 32 lessons, one a week. Session 1 (30–40 minutes) is the warm-up, the story, the video and the picture study. Session 2 (30–40 minutes) is the build and the engineer’s notebook. In the last week of each unit, add a short third session for the oral unit review and the portfolio build.
2. **Reading the lesson aloud.** The core ideas are written to be read aloud. Read one paragraph at a time: *The story*, *How they figured it out*, *The physics* and *The engineering*. After each one, ask your child to tell it back in his or her own words. Keep the key terms in front of you and use them often.
3. **Picture study.** Each lesson has one historic photograph, drawing, patent or painting. Look at it quietly together for two minutes. Then put it away and let your child tell everything he or she remembers. Bring it back and work through the “look for” items and the questions, which point to the physics and engineering in the picture.
4. **The engineer’s notebook.** Use a graph-paper composition book for the whole year. For every build, your child draws a picture with labels, writes a guess, fills in a simple table of numbers (you may write while your child tells you), and finishes with one sentence about what to change. Date every page. Honest records matter more than perfect results: “a just weight is his delight” (Proverbs 11:1).

5. **Fair tests and improving.** Most builds change only one thing at a time and test it more than once. Every build ends with an “improve it” step. A bridge that sags and is then made stronger teaches more than one that worked the first time.
6. **Optional kits.** Some units list kits such as KiwiCo crates, K’NEX, KEVA planks or Snap Circuits Jr. They are extras for families who enjoy them. Every lesson can be done without them.
7. **Unit review and portfolio.** Each unit ends with an oral review of five or six questions. There are no points: ask the questions aloud, and let your child answer by telling, pointing, drawing or showing a build. Then do the portfolio build, which pulls the unit together. Keep photos and notebook pages in a folder for the year.
8. **Safety.** Read the safety box before each build. Electricity in this course comes only from AA, C or D batteries, never from the outlets in the wall. A grown-up handles scissors on hard materials, sharp points and any hot glue, and stays nearby whenever there is a tub of water. Wear safety glasses for anything that can snap or fly. Fly kites only in open places far from power lines.
9. **The family engineering fair.** In the last week, set out the best build from each unit with its notebook pages, invite family or friends, and let your child explain how each one works and what was changed to make it better.
10. **Toy Lab (optional Unit 9).** Four bonus lessons on the physics and design of toys: the Slinky, Lincoln Logs and Tinkertoys, the swing and the seesaw, and the little red wagon. Use them after the fair, over the summer, or whenever a week needs something fun.

# SCOPE AND SEQUENCE

## UNIT 1 • WEEKS 1–4

### Motion and Machines

Friction and the engineer's five steps, from the Egyptian statue sledges; gravity and Galileo's rolling balls; wheels and rollers that moved the Thunder Stone; and Archimedes and the lever.

- 1.1 Think Like an Engineer: Moving a Giant Statue
- 1.2 Gravity: Galileo's Rolling Balls
- 1.3 Wheels and Rollers: Moving the Thunder Stone
- 1.4 Archimedes and the Lever

## UNIT 3 • WEEKS 9–12

### Buildings

The wise builder's foundation and the Leaning Tower of Pisa; snow-block domes and igloos; castle walls, round towers and the treadwheel crane; and Otis's safe elevator and the first skyscraper.

- 3.1 The Wise Builder: Foundations and the Leaning Tower
- 3.2 Domes and Igloos
- 3.3 Castles: Thick Walls, Round Towers and a Giant Wheel
- 3.4 Skyscrapers and Otis's Safe Elevator

## UNIT 2 • WEEKS 5–8

### Bridges

Beam, arch, truss and suspension bridges; why triangles are strong in covered-bridge trusses; Roman arches and the Pont du Gard; and the cables and towers of the Golden Gate Bridge.

- 2.1 Four Kinds of Bridges
- 2.2 Why Triangles? Covered Bridges and Trusses
- 2.3 Arches and the Pont du Gard
- 2.4 The Golden Gate Bridge

## UNIT 4 • WEEKS 13–16

### Electricity

Static electricity with William Gilbert; Volta's battery and the closed circuit; switches and Samuel Morse's telegraph; and Joseph Henry's electromagnet.

- 4.1 Static Electricity: William Gilbert and the Amber
- 4.2 Volta's Battery and the Closed Circuit
- 4.3 Switches and Samuel Morse's Telegraph
- 4.4 Joseph Henry's Electromagnet

## **UNIT 5 • WEEKS 17–20**

### **Water, Power and Roads**

Water from the rain to the tap through the Croton Aqueduct and the water tower; wells, pumps and farm windmills; waterwheels and dams that make power; and McAdam's roads and the first traffic lights.

- 5.1 From the Rain to the Tap: The Croton Aqueduct
- 5.2 Wells and Pumps
- 5.3 Waterwheels and Dams Make Power
- 5.4 Roads, Signs and Traffic Lights

## **UNIT 7 • WEEKS 25–28**

### **Flight**

The four forces of flight with Sir George Cayley; kites and Alexander Graham Bell's triangle kites; the Wright brothers' first flight; and helicopters, Igor Sikorsky and spinning maple seeds.

- 7.1 The Four Forces of Flight
- 7.2 Kites and Alexander Graham Bell
- 7.3 The Wright Brothers Fly
- 7.4 Helicopters and Spinning Maple Seeds

## **UNIT 6 • WEEKS 21–24**

### **Boats**

Archimedes and the king's crown; hull shape and load, from the ark to the foil boat; Viking longships and the keel; and Robert Fulton's paddle-wheel steamboat.

- 6.1 Archimedes and the King's Crown
- 6.2 Hull Shape and Load: The Ark and the Foil Boat
- 6.3 Viking Longships
- 6.4 Robert Fulton's Steamboat

## **UNIT 8 • WEEKS 29–32**

### **Robots and Inventions**

The machines inside robots, from al-Jazari's elephant clock; programming a path like the drivers of the Sojourner rover; sensors and Grey Walter's robot tortoises; and drones, the Ingenuity Mars helicopter and the family engineering fair.

- 8.1 Machines Inside Robots: Al-Jazari's Elephant Clock
- 8.2 Programming a Path: Driving a Rover on Mars
- 8.3 Robot Sensors: Grey Walter's Tortoises
- 8.4 Drones, the Mars Helicopter and Our Engineering Fair

## UNIT 9 • WEEKS 33–36

### Toy Lab: The Physics of Play

Optional Toy Lab: springs and the Slinky; notches and triangles in Lincoln Logs and Tinkertoys; the pendulum swing and the seesaw lever; and wheels, axles and bearings in the little red wagon.

9.1 The Slinky: A Spring That Walks

9.2 Lincoln Logs and Tinkertoys

9.3 The Swing and the Seesaw

9.4 The Little Red Wagon

## WEEKLY PACING CALENDAR

| WEEK | PLAN                                                                                                                                                                                                                                                                                                                                                                                                 |
|------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1    | <ul style="list-style-type: none"><li>• Session 1: Lesson 1.1 Think Like an Engineer: Moving a Giant Statue: warm-up, video, teaching and picture study</li><li>• Session 2: Lesson 1.1 build project and engineer's notebook</li></ul> <p><i>Two sessions a week is the usual rhythm. Younger children can split a long session in two; older students can do both sessions in one sitting.</i></p> |
| 2    | <ul style="list-style-type: none"><li>• Session 1: Lesson 1.2 Gravity: Galileo's Rolling Balls: warm-up, video, teaching and picture study</li><li>• Session 2: Lesson 1.2 build project and engineer's notebook</li></ul>                                                                                                                                                                           |
| 3    | <ul style="list-style-type: none"><li>• Session 1: Lesson 1.3 Wheels and Rollers: Moving the Thunder Stone: warm-up, video, teaching and picture study</li><li>• Session 2: Lesson 1.3 build project and engineer's notebook</li></ul>                                                                                                                                                               |
| 4    | <ul style="list-style-type: none"><li>• Session 1: Lesson 1.4 Archimedes and the Lever: warm-up, video, teaching and picture study</li><li>• Session 2: Lesson 1.4 build project and engineer's notebook</li><li>• Session 3: Unit 1 review and portfolio project</li></ul>                                                                                                                          |
| 5    | <ul style="list-style-type: none"><li>• Session 1: Lesson 2.1 Four Kinds of Bridges: warm-up, video, teaching and picture study</li><li>• Session 2: Lesson 2.1 build project and engineer's notebook</li></ul>                                                                                                                                                                                      |
|      |                                                                                                                                                                                                                                                                                                                                                                                                      |

| WEEK | PLAN                                                                                                                                                                                                                                                                                        |
|------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 6    | <ul style="list-style-type: none"> <li>• Session 1: Lesson 2.2 Why Triangles? Covered Bridges and Trusses: warm-up, video, teaching and picture study</li> <li>• Session 2: Lesson 2.2 build project and engineer's notebook</li> </ul>                                                     |
| 7    | <ul style="list-style-type: none"> <li>• Session 1: Lesson 2.3 Arches and the Pont du Gard: warm-up, video, teaching and picture study</li> <li>• Session 2: Lesson 2.3 build project and engineer's notebook</li> </ul>                                                                    |
| 8    | <ul style="list-style-type: none"> <li>• Session 1: Lesson 2.4 The Golden Gate Bridge: warm-up, video, teaching and picture study</li> <li>• Session 2: Lesson 2.4 build project and engineer's notebook</li> <li>• Session 3: Unit 2 review and portfolio project</li> </ul>               |
| 9    | <ul style="list-style-type: none"> <li>• Session 1: Lesson 3.1 The Wise Builder: Foundations and the Leaning Tower: warm-up, video, teaching and picture study</li> <li>• Session 2: Lesson 3.1 build project and engineer's notebook</li> </ul>                                            |
| 10   | <ul style="list-style-type: none"> <li>• Session 1: Lesson 3.2 Domes and Igloos: warm-up, video, teaching and picture study</li> <li>• Session 2: Lesson 3.2 build project and engineer's notebook</li> </ul>                                                                               |
| 11   | <ul style="list-style-type: none"> <li>• Session 1: Lesson 3.3 Castles: Thick Walls, Round Towers and a Giant Wheel: warm-up, video, teaching and picture study</li> <li>• Session 2: Lesson 3.3 build project and engineer's notebook</li> </ul>                                           |
| 12   | <ul style="list-style-type: none"> <li>• Session 1: Lesson 3.4 Skyscrapers and Otis's Safe Elevator: warm-up, video, teaching and picture study</li> <li>• Session 2: Lesson 3.4 build project and engineer's notebook</li> <li>• Session 3: Unit 3 review and portfolio project</li> </ul> |
| 13   | <ul style="list-style-type: none"> <li>• Session 1: Lesson 4.1 Static Electricity: William Gilbert and the Amber: warm-up, video, teaching and picture study</li> <li>• Session 2: Lesson 4.1 build project and engineer's notebook</li> </ul>                                              |
| 14   | <ul style="list-style-type: none"> <li>• Session 1: Lesson 4.2 Volta's Battery and the Closed Circuit: warm-up, video, teaching and picture study</li> <li>• Session 2: Lesson 4.2 build project and engineer's notebook</li> </ul>                                                         |
|      |                                                                                                                                                                                                                                                                                             |

| WEEK | PLAN                                                                                                                                                                                                                                                                                   |
|------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15   | <ul style="list-style-type: none"> <li>• Session 1: Lesson 4.3 Switches and Samuel Morse's Telegraph: warm-up, video, teaching and picture study</li> <li>• Session 2: Lesson 4.3 build project and engineer's notebook</li> </ul>                                                     |
| 16   | <ul style="list-style-type: none"> <li>• Session 1: Lesson 4.4 Joseph Henry's Electromagnet: warm-up, video, teaching and picture study</li> <li>• Session 2: Lesson 4.4 build project and engineer's notebook</li> <li>• Session 3: Unit 4 review and portfolio project</li> </ul>    |
| 17   | <ul style="list-style-type: none"> <li>• Session 1: Lesson 5.1 From the Rain to the Tap: The Croton Aqueduct: warm-up, video, teaching and picture study</li> <li>• Session 2: Lesson 5.1 build project and engineer's notebook</li> </ul>                                             |
| 18   | <ul style="list-style-type: none"> <li>• Session 1: Lesson 5.2 Wells and Pumps: warm-up, video, teaching and picture study</li> <li>• Session 2: Lesson 5.2 build project and engineer's notebook</li> </ul>                                                                           |
| 19   | <ul style="list-style-type: none"> <li>• Session 1: Lesson 5.3 Waterwheels and Dams Make Power: warm-up, video, teaching and picture study</li> <li>• Session 2: Lesson 5.3 build project and engineer's notebook</li> </ul>                                                           |
| 20   | <ul style="list-style-type: none"> <li>• Session 1: Lesson 5.4 Roads, Signs and Traffic Lights: warm-up, video, teaching and picture study</li> <li>• Session 2: Lesson 5.4 build project and engineer's notebook</li> <li>• Session 3: Unit 5 review and portfolio project</li> </ul> |
| 21   | <ul style="list-style-type: none"> <li>• Session 1: Lesson 6.1 Archimedes and the King's Crown: warm-up, video, teaching and picture study</li> <li>• Session 2: Lesson 6.1 build project and engineer's notebook</li> </ul>                                                           |
| 22   | <ul style="list-style-type: none"> <li>• Session 1: Lesson 6.2 Hull Shape and Load: The Ark and the Foil Boat: warm-up, video, teaching and picture study</li> <li>• Session 2: Lesson 6.2 build project and engineer's notebook</li> </ul>                                            |
| 23   | <ul style="list-style-type: none"> <li>• Session 1: Lesson 6.3 Viking Longships: warm-up, video, teaching and picture study</li> <li>• Session 2: Lesson 6.3 build project and engineer's notebook</li> </ul>                                                                          |
| 24   | <ul style="list-style-type: none"> <li>• Session 1: Lesson 6.4 Robert Fulton's Steamboat: warm-up, video, teaching and picture study</li> </ul>                                                                                                                                        |

| WEEK | PLAN                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
|------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|      | <ul style="list-style-type: none"> <li>• Session 2: Lesson 6.4 build project and engineer's notebook</li> <li>• Session 3: Unit 6 review and portfolio project</li> </ul>                                                                                                                                                                                                                                                                                                                  |
| 25   | <ul style="list-style-type: none"> <li>• Session 1: Lesson 7.1 The Four Forces of Flight: warm-up, video, teaching and picture study</li> <li>• Session 2: Lesson 7.1 build project and engineer's notebook</li> </ul>                                                                                                                                                                                                                                                                     |
| 26   | <ul style="list-style-type: none"> <li>• Session 1: Lesson 7.2 Kites and Alexander Graham Bell: warm-up, video, teaching and picture study</li> <li>• Session 2: Lesson 7.2 build project and engineer's notebook</li> </ul>                                                                                                                                                                                                                                                               |
| 27   | <ul style="list-style-type: none"> <li>• Session 1: Lesson 7.3 The Wright Brothers Fly: warm-up, video, teaching and picture study</li> <li>• Session 2: Lesson 7.3 build project and engineer's notebook</li> </ul>                                                                                                                                                                                                                                                                       |
| 28   | <ul style="list-style-type: none"> <li>• Session 1: Lesson 7.4 Helicopters and Spinning Maple Seeds: warm-up, video, teaching and picture study</li> <li>• Session 2: Lesson 7.4 build project and engineer's notebook</li> <li>• Session 3: Unit 7 review and portfolio project</li> </ul>                                                                                                                                                                                                |
| 29   | <ul style="list-style-type: none"> <li>• Session 1: Lesson 8.1 Machines Inside Robots: Al-Jazari's Elephant Clock: warm-up, video, teaching and picture study</li> <li>• Session 2: Lesson 8.1 build project and engineer's notebook</li> </ul>                                                                                                                                                                                                                                            |
| 30   | <ul style="list-style-type: none"> <li>• Session 1: Lesson 8.2 Programming a Path: Driving a Rover on Mars: warm-up, video, teaching and picture study</li> <li>• Session 2: Lesson 8.2 build project and engineer's notebook</li> </ul>                                                                                                                                                                                                                                                   |
| 31   | <ul style="list-style-type: none"> <li>• Session 1: Lesson 8.3 Robot Sensors: Grey Walter's Tortoises: warm-up, video, teaching and picture study</li> <li>• Session 2: Lesson 8.3 build project and engineer's notebook</li> </ul>                                                                                                                                                                                                                                                        |
| 32   | <ul style="list-style-type: none"> <li>• Session 1: Lesson 8.4 Drones, the Mars Helicopter and Our Engineering Fair: warm-up, video, teaching and picture study</li> <li>• Session 2: Lesson 8.4 build project and engineer's notebook</li> <li>• Session 3: Unit 8 review and portfolio project</li> </ul> <p><i>Last week. Hold a family engineering fair: set out the best build from each unit with its notebook pages, and let the student show guests how one of them works.</i></p> |

| WEEK | PLAN                                                                                                                                                                                                                                                                                                                                                                 |
|------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 33   | <ul style="list-style-type: none"> <li>Session 1: Lesson 9.1 The Slinky: A Spring That Walks: warm-up, video, teaching and picture study</li> <li>Session 2: Lesson 9.1 build project and engineer's notebook</li> </ul> <p><i>Optional bonus unit: Toy Lab. Do it after the fair, over the summer, or slip a lesson in whenever a week needs something fun.</i></p> |
| 34   | <ul style="list-style-type: none"> <li>Session 1: Lesson 9.2 Lincoln Logs and Tinkertoys: warm-up, video, teaching and picture study</li> <li>Session 2: Lesson 9.2 build project and engineer's notebook</li> </ul>                                                                                                                                                 |
| 35   | <ul style="list-style-type: none"> <li>Session 1: Lesson 9.3 The Swing and the Seesaw: warm-up, video, teaching and picture study</li> <li>Session 2: Lesson 9.3 build project and engineer's notebook</li> </ul>                                                                                                                                                    |
| 36   | <ul style="list-style-type: none"> <li>Session 1: Lesson 9.4 The Little Red Wagon: warm-up, video, teaching and picture study</li> <li>Session 2: Lesson 9.4 build project and engineer's notebook</li> <li>Session 3: Unit 9 review and portfolio project</li> </ul>                                                                                                |

## MATERIALS

### **Engineer's notebook (graph-paper composition book)**

One for the whole year: labeled drawings, guesses, number tables and “what I would change.”

### **Ruler, tape measure and a smartphone or stopwatch**

Measuring and timing are part of almost every build.

### **Cardboard, card stock, printer paper, masking tape, clear tape and white glue**

The main building materials all year. Save cereal boxes, shoeboxes and paper-towel tubes.

### **Drinking straws, craft sticks, wooden skewers (tips cut off), string, rubber bands and paper clips**

For trusses, carts, levers, kites and gliders.

### **About 150 pennies and a few small paper cups**

Standard weights for load tests on bridges, boats and levers.

### **Modeling clay**

For holding wheels on axles, floating-and-sinking tests and stick-and-spool frames.

**A D-cell battery in a holder (or two AA batteries in a holder), two small flashlight bulbs in holders, and four alligator clip leads**

For all of Unit 4 and the sensor build in Unit 8. Batteries only; never the outlets in the wall.

**An iron nail and about 6 feet of thin insulated or magnet wire**

For the electromagnet in Lesson 4.4.

**Aluminum foil and a tub, sink or bathtub**

For the boat builds in Unit 6. A grown-up stays nearby.

**Sand or soil, small gravel and a few foil baking pans**

For the foundation test, the model well and the model road.

**Three or four raw eggs**

For the eggshell dome test in Lesson 3.2 (eat the insides for breakfast).

**A small fan**

For the keel test in Lesson 6.3. A grown-up sets it up away from water.

**Safety glasses**

For load tests, rubber bands and anything that can snap or fly.

**Free software: ScratchJr ([scratchjr.org](http://scratchjr.org)) on a tablet**

Optional, for Lesson 8.2.

**Optional: one kit, such as a KiwiCo Kiwi Crate, K'NEX or Snap Circuits Jr.**

Never required. See the kits listed in each unit.

## GRADING

There are no letter grades in second grade. Progress is shown by what your child can do, tell and build, and by a growing portfolio of notebook pages and build photographs.

- After each unit, write two or three sentences of narrative feedback: what your child built and tested well, what he or she can now explain, and one habit to keep working on (for example, changing only one thing at a time, or writing down every number).
- Keep a portfolio folder with the best notebook pages and a photograph of each unit's portfolio build. Look back through it at the end of each unit and at the

family engineering fair.

- Use the mastery checklist at the start of each unit as your guide. When your child can show or tell each item, the unit is done well.
- Praise careful guessing, fair testing, honest records and trying again more than a build that worked the first time.

## **A NOTE TO PARENTS**

You do not need to be an engineer to teach this course. Read the story aloud, watch the video together, and then be your child's helper at the build: hold the ruler, write down the numbers, and ask two questions over and over: "What do you think will happen?" and "Why do you think that happened?" Those two questions are most of what a good engineering teacher does.

Expect things to fail. Bridges will sag, towers will tip and gliders will dive. The Wright brothers crashed gliders for three summers before they flew. Failure, carefully looked at, is how engineers learn, so cheer for the second try. *Fabricando fit faber*: by making, one becomes a maker.

Some lessons touch on hard moments in history, such as the leaning tower or a great fire. They are told gently and briefly, with the focus on what people learned and built so that others would be safe.

## UNIT 1

# MOTION AND MACHINES

Every machine starts with a push or a pull. In this unit you will learn how engineers think, by following people long ago who had very hard jobs to do. Workers in Egypt dragged a giant stone statue across the sand. Galileo rolled balls down a ramp to learn how things fall. Builders in Russia rolled a rock as big as a house on bronze balls. And Archimedes showed that a long bar can lift what your arms cannot.

You will learn about friction, gravity, wheels and levers. You will also learn the engineer's way of working: ask, imagine, plan, build, and improve. At every build you will guess first, test, write down what happened, and then make it better.

### PREREQUISITES

- Can measure with a ruler to the nearest inch or centimeter, with help
- Can count pennies to 50
- Can draw a simple picture and label it with help

### MASTERY CHECKLIST

- ☐ I can name the five steps engineers use: ask, imagine, plan, build, improve.
- ☐ I can tell how the Egyptian workers made a giant statue easier to pull.
- ☐ I can tell what friction is and what gravity is.
- ☐ I can show how wheels or rollers make moving things easier.
- ☐ I can find the fulcrum on a lever and show that a long lever makes lifting easier.

### OPTIONAL KITS FOR THIS UNIT

- **KiwiCo Kiwi Crate**: Ages 5–8. A monthly box with one hands-on build and a short story about the science. Many crates use ramps, wheels and levers, which fit Lessons 1.1–1.4.
- **K'NEX building sets**: Ages 7 and up. Rods, connectors and wheels for building carts, levers and simple machines. Fits Lessons 1.3 and 1.4 and Unit 2.

Not required. Every project in this unit can be built with household materials. School Launch has no ties to these companies.

## LESSONS IN THIS UNIT

|                                                          |                             |
|----------------------------------------------------------|-----------------------------|
| <b>1.1 Think Like an Engineer: Moving a Giant Statue</b> | 2 sessions of 30–40 minutes |
| <b>1.2 Gravity: Galileo’s Rolling Balls</b>              | 2 sessions of 30–40 minutes |
| <b>1.3 Wheels and Rollers: Moving the Thunder Stone</b>  | 2 sessions of 30–40 minutes |
| <b>1.4 Archimedes and the Lever</b>                      | 2 sessions of 30–40 minutes |

## UNIT 1 REVIEW

A parent asks these questions aloud. Your child may answer by telling, pointing, drawing or showing with the builds from this unit. There are no points. Listen for understanding and praise careful answers.

1. Say the five steps engineers use. Can you show them on your fingers?
2. Why did the worker in Egypt pour water in front of the statue’s sledge?
3. Drop a crumpled paper ball and a flat sheet of paper. Why does the ball land first?
4. Show me with your cart: is it easier to slide a load or roll it? Why?
5. Point to the fulcrum on your lever. Where should it go to lift a heavy rock with a small push?
6. Name a lever, a wheel and a ramp you can find in our house or yard.

#### ANSWER KEY

1. Ask, imagine, plan, build, improve.
2. Wet sand made less friction, so the sledge was easier to pull.
3. Air pushes up on the flat sheet and slows it. Gravity pulls both the same way.
4. Rolling is easier, because wheels and rollers make much less friction than sliding.
5. Close to the heavy rock, so the side you push is long.
6. Any good examples, such as scissors or a bottle opener (lever), a wagon or chair wheels (wheel), and a slide or the driveway (ramp).

#### PORTFOLIO PIECE: A CART THAT CARRIES THE HEAVIEST LOAD

Use all you learned in this unit to make your cardboard cart carry a heavy load down the ramp and roll as far as it can. Test it with 10, 20 and 30 pennies and write each distance. Then improve one thing, test again, and show your cart and your notebook pages to your family.

| LOOK FOR                    | WHAT IT MEANS                                                              |
|-----------------------------|----------------------------------------------------------------------------|
| <b>The engineer's steps</b> | Told or drew the ask, imagine, plan, build and improve steps for the cart. |
| <b>Fair testing</b>         | Let the cart go from the same spot each time and measured each roll.       |
| <b>Notebook</b>             | Kept a table of loads and distances, with a date on the page.              |
| <b>Improving</b>            | Found a problem, changed one thing, and tested again.                      |

# 1.1 THINK LIKE AN ENGINEER: MOVING A GIANT STATUE

## OBJECTIVES

- Name the engineer's five steps: ask, imagine, plan, build, improve.
- Tell how workers in old Egypt made a giant statue easier to pull.
- Measure how hard it is to pull a load across different surfaces.

**Warm-up.** Rub your hands together fast for ten seconds. What do you feel? Now put a drop of hand lotion or water on them and rub again. Is it easier or harder? Tell what you notice.

## WATCH

### Think Like an Engineer: Let's Design a Solution! | SciShow Kids

SciShow Kids · 5:35

<https://www.youtube.com/watch?v=M6t26J-Bbkg>

## WHEN TO WATCH

After the story, before the build. Listen for each step the friends use to make their raft.

## BACKUP VIDEO

### Introduction to Friction for Children - Friction for Kids: FreeSchool

Free School · 3:58

<https://www.youtube.com/watch?v=lkmAnLmXENo>

With the paragraph on friction.

## KEY TERMS

### **engineer**

A person who uses science and careful testing to solve a problem by making something.

### **friction**

A force that rubs against a moving thing and slows it down.

### **sledge**

A big wooden sled for dragging heavy loads.

### **test**

Trying something out to see if it works, and watching carefully.

## CORE IDEAS

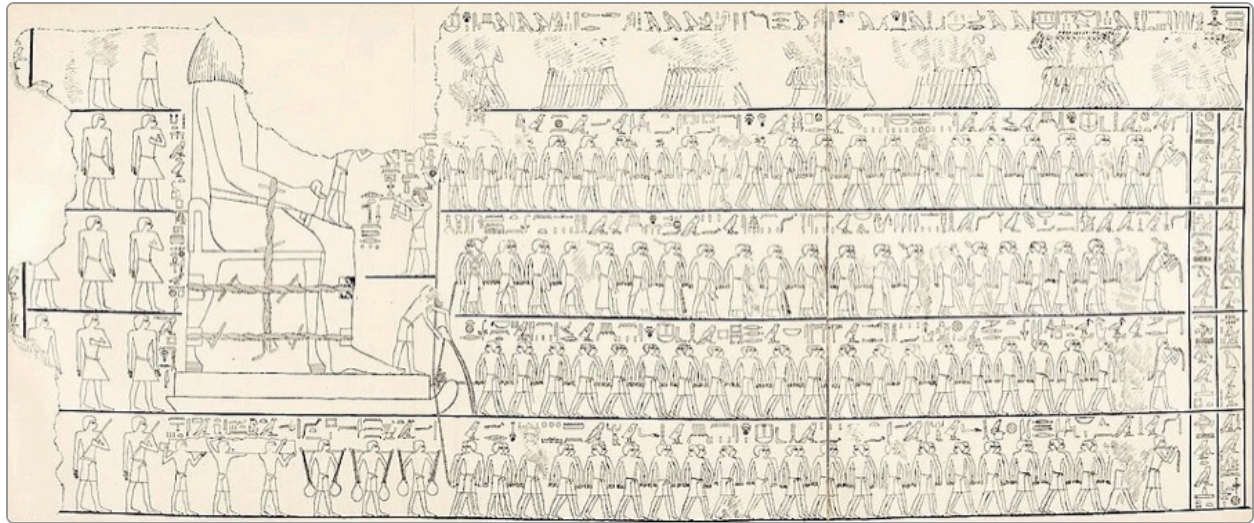
**The story.** Long ago in Egypt, almost four thousand years ago, a ruler named Djehutihotep wanted a giant stone statue of himself. It was taller than three grown men stacked up. It was heavier than many elephants. How could people move it? They had no trucks and no cranes. A painting on the wall of his tomb shows how they did it.

**How they figured it out.** The workers tied the statue onto a big wooden sledge. Long rows of men pulled the ropes. But the sledge rubbed hard on the sand. So one man stood at the front of the sledge and poured water on the sand. For a long time, people wondered why. Not long ago, scientists tested it with a little sledge and a tray of sand. Wet sand was much easier to pull across than dry sand. Wet sand is firm, and it does not pile up in front of the sledge. The Egyptian workers had found a smart answer.

**The physics.** When two things rub together, there is a force called **friction**. Friction pushes against things that slide. Rough things have lots of friction. Smooth and slippery things have less. Friction is not always bad. It keeps your shoes from slipping and lets you hold a pencil.

**The engineering.** Engineers solve problems in steps. First they **ask**: what is the problem? Then they **imagine** many ideas. They **plan** one idea with a drawing. They **build** it and test it. Then they **improve** it and test again. The Egyptian workers did all five steps. You will do them too, in every build this year.

## PICTURE STUDY



*Moving the Statue of Djehutihotep*, Copied from the tomb wall by Percy E. Newberry, Tomb painting about 1850 B.C.; drawing published 1895 · Drawing of a wall painting · Tomb of Djehutihotep, Deir el-Bersha, Egypt

Image: [Wikimedia Commons](#), public domain

This drawing was copied from a wall painting in an Egyptian tomb. It shows workers pulling a giant statue. Look closely, and you will find the clever trick that made it easier.

### Look closely

- Find the giant statue. What is it sitting on?
- Find the ropes. How many rows of men are pulling?
- Find the small man at the front of the sledge. What is he pouring on the ground?
- Look under the sledge. Is there a wheel anywhere?

### Talk about it

1. Why do you think the workers poured water on the sand?
2. Why did they need so many people to pull?
3. What could you use today to move something this heavy?

## BUILD

### The Sledge-Pulling Test

You will be like the Egyptian workers. You will pull a heavy load on a little sledge across different floors. A rubber band will show how hard you pull. The more it stretches, the more friction there is.

#### You will need

- A small shoebox lid or a piece of stiff cardboard for the sledge
- A heavy load, such as a full can of soup
- A rubber band and a paper clip
- A ruler
- Three or four surfaces: a carpet, a wooden or tile floor, a sheet of wax paper, and a towel
- Engineer's notebook and a pencil

#### Steps

1. **Ask.** Which floor will be easiest to pull the sledge across? Write your guess in your notebook.
2. Poke a small hole in the front of the sledge with help. Hook the paper clip through it. Hook the rubber band onto the paper clip.
3. Put the can on the sledge. Set the sledge on the first surface.
4. Hold the end of the rubber band next to the ruler. Pull slowly and steadily. Have a helper read how long the rubber band stretches just as the sledge starts to slide.
5. Write the number in a table. Do it three times on each surface. Use the same can every time. Only the floor changes. That makes it a fair test.
6. Circle the surface with the smallest stretch. That surface has the least friction.
7. **Improve.** Can you make the sledge easier to pull on the carpet? Try taping wax paper under it, or laying two pencils under it as rollers. Test it again and write the new number.

#### Tips

- Pull slowly. A fast jerk gives a different number each time.
- A helper can hold the ruler flat on the floor next to the rubber band.

#### Check your work

- ☐ I can name the five engineering steps.
- ☐ I can tell which surface had the most friction and how I know.
- ☐ I can tell why the Egyptian worker poured water in front of the sledge.

#### ENGINEER'S NOTEBOOK

1. Draw your sledge and label the load, the rubber band and the floor.
2. Make a table with two columns: surface and stretch. Fill it in.
3. Write one sentence: "The floor with the least friction was \_\_\_\_."

**From history.** The drawing of the statue was copied from the tomb by English scholars in the 1890s, before parts of the wall were damaged. In 2014 scientists in the Netherlands built a small sledge and showed that the right amount of water in the sand cut the pulling force about in half.

#### COMMON MISTAKES

- Changing the load and the floor at the same time. Change only one thing.
- Thinking friction is always bad. We need it to walk and to hold things.

**Make it a game • Five Steps Sledge Pull.** Pull a heavy box across the floor with a string, first on the bare floor and then on rolled towels or marker pens. Feel the friction. Between each try, shout one of the engineer's five steps: ask, imagine, plan, build, improve. Tell your parent how Egyptian workers pulled a giant statue on a sledge. Name all five steps in order.

**Scripture.** "For which of you, intending to build a tower, sitteth not down first, and counteth the cost, whether he have sufficient to finish it?" (Luke 14:28, KJV)

Jesus said a wise builder sits down and plans before he builds. That is the "plan" step that every engineer uses.

## 1.2 GRAVITY: GALILEO'S ROLLING BALLS

### OBJECTIVES

- Tell what gravity does.
- Tell how Galileo used a ramp to study falling things.
- Measure how far a ball rolls from ramps of different heights.

**Warm-up.** Hold a book in one hand and a crumpled ball of paper in the other at the same height. Which will land first if you let go together? Guess, then try it. Now try a flat sheet of paper and a crumpled one. What changed?

### WATCH

#### Introduction to Gravity for Children: Gravity, Weight, and Mass for Kids - FreeSchool

Free School · 4:40

<https://www.youtube.com/watch?v=L1Xw9QMxaiQ>

### WHEN TO WATCH

After the physics paragraph.

### KEY TERMS

#### **gravity**

The pull that makes things fall down toward the earth.

#### **ramp**

A slanted path. Things roll down it more slowly than they fall.

#### **speed up**

To go faster and faster.

### CORE IDEAS

**The story.** About four hundred years ago in Italy lived a teacher named Galileo Galilei. He wanted to know how things fall. Most people then believed that heavy things fall faster than light things. Galileo was not sure. He wanted to test it.

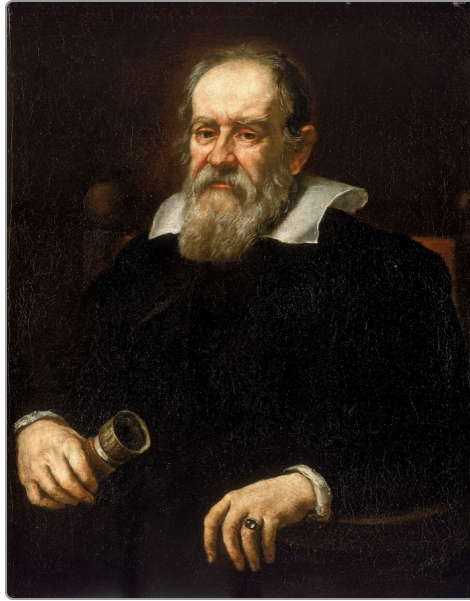
**How he figured it out.** Things fall too fast to watch. So Galileo had a clever idea. He made a long wooden ramp with a smooth groove in it. He rolled bronze balls down the groove. On the ramp, the balls moved slowly enough to time. He had no stopwatch, so he let water drip out of a bucket while the ball rolled, and then he

weighed the water. He did it again and again, about a hundred times. He found that the balls went faster and faster all the way down. He also found that a heavy ball and a lighter ball rolled down together.

**The physics.** Gravity is the pull that brings things down to the earth. It pulls on everything. When something falls, gravity makes it speed up. Heavy things and light things fall at the same speed, unless air gets in the way. A flat sheet of paper falls slowly because air pushes up on it. A crumpled ball of the same paper falls fast.

**The engineering.** Engineers use gravity every day. Water flows downhill through pipes. Playground slides and roller coasters use gravity to go fast. Builders use ramps to slow things down, the way Galileo did. God made gravity steady and the same every day, so engineers can count on it. “By him all things consist.”

## PICTURE STUDY



*Portrait of Galileo Galilei*, Justus Sustermans, 1636 · Oil on canvas · Uffizi Gallery, Florence, Italy

Image: [Wikimedia Commons](#), public domain

This portrait was painted when Galileo was about seventy years old. By then he had spent his whole life testing how things move and fall, and looking at the sky through telescopes he built himself.

### Look closely

- Find the telescope in Galileo's hand. He built his own and made them better and better.
- Look at his face. Does he look like a person who thinks carefully?
- Look at his clothes. What kind of work do you think he did?

### Talk about it

1. Galileo tested ideas instead of just believing what people said. Why is that a good habit for an engineer?
2. What tools would Galileo need to measure how fast a ball rolls down a ramp?
3. If you could ask Galileo one question about gravity, what would it be?

## BUILD

### Ramp Races

You will build a ramp like Galileo's. You will roll a ball down it from different heights and measure how far it rolls across the floor.

#### You will need

- A long piece of cardboard or a cardboard tube cut in half, about 3 feet long
- A stack of books
- A marble, a golf ball or a small toy car
- A tape measure
- Masking tape and a pencil
- Engineer's notebook

#### Steps

1. Lay the cardboard on one book to make a low ramp. Tape the bottom end to a smooth floor.
2. Make a tape mark at the top of the ramp. Always let the ball go from this mark. Do not push it.
3. **Predict.** Will the ball roll farther from a low ramp or a high ramp? Write your guess.
4. Let the ball go. Put a piece of tape where it stops. Measure from the end of the ramp to the tape.
5. Roll it three times from one book. Then use two books, then three books. Write each distance in a table.
6. Look at your table. Did a higher ramp make the ball roll farther?
7. **Improve.** Try one change, such as a towel on the floor or a heavier ball, and test it from three books. Change only one thing.

#### Tips

- Let go of the ball. Do not push it, or the test will not be fair.

- If the ball rolls under a couch, use a hallway or a long table with books at the end.

#### Check your work

- ☐ I can tell what gravity does.
- ☐ I can tell why Galileo used a ramp.
- ☐ I can tell what my ramp test showed.

#### ENGINEER'S NOTEBOOK

1. Draw your ramp from the side. Draw an arrow showing which way gravity pulls.
2. Fill in a table: number of books, distance rolled.
3. Draw a flat sheet of paper and a crumpled one falling. Which lands first? Why?

**From history.** A famous story says Galileo dropped two balls from the Leaning Tower of Pisa. His student told the story, but nobody knows for sure if it happened. We do know about his ramps, because Galileo wrote about them in his book. In 1971 an astronaut on the moon, where there is no air, dropped a hammer and a feather together. They landed at the same time.

#### COMMON MISTAKES

- Thinking heavy things always fall faster. Without air in the way, they fall together.
- Pushing the ball at the start. That adds speed and ruins the fair test.

**Make it a game • Ramp Race Predictions.** Make two ramps with different heights from books and a board. Race two toy cars, one on each, and shout your guess before the cars go. Count the points for correct guesses against your parent. Then tell what gravity does, and how Galileo used a ramp to slow down falling so he could study it.

**Scripture.** “And he is before all things, and by him all things consist.” (Colossians 1:17, KJV)

The whole world holds together because God holds it. That is why gravity works the same way every day.

# 1.3 WHEELS AND ROLLERS:

## MOVING THE THUNDER STONE

### OBJECTIVES

- Tell how workers in Russia moved a giant rock on bronze balls.
- Show that rolling has much less friction than sliding.
- Build a cart with wheels and axles and test it.

**Warm-up.** Push a heavy book across a table. Now lay four round pencils under it and push again. Which was easier? Why do you think so?

### WATCH

#### Let's Get Rolling! | Physics for Kids

SciShow Kids · 3:18

<https://www.youtube.com/watch?v=YIV9IUHqW3A>

### WHEN TO WATCH

After the physics paragraph, before the build.

### KEY TERMS

#### **roller**

A round log or ball put under a heavy load so it rolls instead of slides.

#### **wheel**

A round disk that turns.

#### **axle**

The rod in the middle of a wheel that the wheel turns on.

#### **ball bearing**

Little balls that let one part roll smoothly against another.

### CORE IDEAS

**The story.** About 250 years ago, Empress Catherine of Russia wanted a great statue of a horse and rider in the city of St. Petersburg. The statue needed a giant rock to stand on. Workers found one in a swamp, a few miles out of the city. People called it the Thunder Stone. It was as big as a house. It weighed more than a thousand tons. That is heavier than two hundred elephants!

**How they figured it out.** No sledge could slide a rock that heavy. An engineer named Marinos Carburi had an idea. He had workers build a long track out of logs with

grooves on top. In the grooves he put bronze balls, each about as big as a grapefruit. The rock sat on a wooden platform on top of the balls. When the workers pulled with ropes and big turning winches, the platform rolled on the balls. Workers kept moving the track pieces from the back to the front. They worked all winter, when the ground was frozen hard. After many months the rock reached the edge of the sea, and a big barge carried it the rest of the way. It still stands in St. Petersburg today.

**The physics.** Sliding makes lots of friction, because the whole bottom rubs on the floor. Rolling makes much less friction. A roller or a wheel touches the ground at only a small spot, and it turns instead of rubbing. That is why rolling a heavy thing is so much easier than dragging it.

**The engineering.** A wheel turns on a rod called an **axle**. Together they make a simple machine. Wheels and axles are in wagons, bikes, cars and trains. Carhuri's bronze balls were like the **ball bearings** that are inside bike wheels and skateboard wheels today. Engineers still use them to make wheels turn smoothly.

## PICTURE STUDY



*Moving the Thunder Stone*, Engraving after a drawing by Yuri Felten, About 1770 · Colored engraving · St. Petersburg, Russia

Image: [Wikimedia Commons](#), public domain

This print was made at the time the Thunder Stone was moved. Crowds came out in the snow to watch. Look for how the workers made the giant rock roll.

### Look closely

- Find the wooden platform under the rock. Can you see the track beneath it?
- Find the long ropes. Follow them to the teams of workers turning the winches.
- Find the people standing on top of the rock. Why might workers be up there?
- Look at the ground. What season is it?

### Talk about it

1. Why did the workers move the rock in winter?
2. Why was rolling better than dragging?
3. Where do you see wheels or rollers in your house?

**Safety first.** Keep fingers clear when a loaded cart rolls down the ramp, and have an adult poke any holes in the cardboard.

## BUILD

### A Cardboard Cart with Wheels and Axles

First you will test sliding against rolling. Then you will build a small cart with wheels and axles, roll it down a ramp, and make it roll farther.

#### You will need

- A small box or a piece of cardboard about the size of your hand, for the cart
- Two drinking straws and two wooden skewers (with the sharp tips cut off by an adult)
- Four bottle caps or cardboard circles for wheels
- Tape, modeling clay, and a few pennies for a load
- Your ramp from Lesson 1.2 and a tape measure
- Six round pencils
- Engineer's notebook

#### Steps

1. **Slide or roll?** Pull a heavy book with your rubber band from Lesson 1.1. Write how far it stretches. Now set the book on six round pencils and pull again. Write the new number.
2. **Build.** Tape two straws across the bottom of the cart. Slide a skewer through each straw. These are your axles.
3. Have an adult poke a hole in the center of each bottle cap. Push a cap onto each end of each skewer. Hold them with a bit of clay.
4. Spin a wheel with your finger. Does it turn easily? The straw lets the axle turn with little rubbing.
5. Put 10 pennies in the cart. Let it roll down the ramp from three books. Measure how far it goes. Do it three times.
6. **Improve.** Find what slows your cart down. Are the wheels crooked? Do they rub the box? Fix one thing and test again.
7. Write your best distance in your notebook.

#### Tips

- Make the wheels as round and straight as you can. Wobbly wheels waste energy.
- Keep the wheels from touching the sides of the cart.

#### Check your work

- ☐ I can tell how the Thunder Stone was moved.
- ☐ I can show that rolling is easier than sliding.
- ☐ I can point to the wheels and axles on my cart.

#### ENGINEER'S NOTEBOOK

1. Draw your cart from the side and from below. Label the wheels, the axles and the straws.
2. Write two numbers: how far the rubber band stretched for sliding, and for rolling.
3. Draw one thing you changed and how far the cart rolled after.

**From history.** The statue that stands on the Thunder Stone is called the Bronze Horseman. It shows Peter the Great, who built the city of St. Petersburg. Workers trimmed the rock as it traveled, so it was a little smaller when it arrived.

#### COMMON MISTAKES

- Taping the axle tight so the wheel cannot turn. The axle must spin freely in the straw.
- Testing with a push. Let the cart go from the same spot each time.

**Make it a game • Roller Versus Slide.** Push a heavy book across a table, then set it on three pencils and push again. Tell your parent which took less push, and say friction. Then tell how workers in Russia moved the Thunder Stone on bronze balls. Quiz each other: roller, wheel, axle, ball bearing. Who can use all four in one sentence?

## 1.4 ARCHIMEDES AND THE LEVER

### OBJECTIVES

- Tell who Archimedes was and what he said about the lever.
- Name the parts of a lever: the bar, the fulcrum, the load and the push.
- Test how moving the fulcrum changes how hard it is to lift a load.

**Warm-up.** Try to open a paint can lid or a jar lid with your fingers. Now ask a grown-up to show you how a spoon handle or a coin can pry it up. Why is that easier?

### WATCH

#### Super Simple Machines: Levers

SciShow Kids · 3:20

<https://www.youtube.com/watch?v=lueqE0lxLyc>

### WHEN TO WATCH

After the story.

### KEY TERMS

#### **lever**

A stiff bar that turns on a point to help lift or move a load.

#### **fulcrum**

The point a lever rests and turns on.

#### **load**

The thing you want to lift or move.

#### **simple machine**

A simple tool, like a lever, wheel or ramp, that makes work easier.

### CORE IDEAS

**The story.** More than two thousand years ago, a great thinker named Archimedes lived on the island of Sicily. He studied numbers, water and machines. He loved levers. He is remembered for saying, “Give me a place to stand, and I will move the earth.” He meant that a long enough lever could lift anything at all.

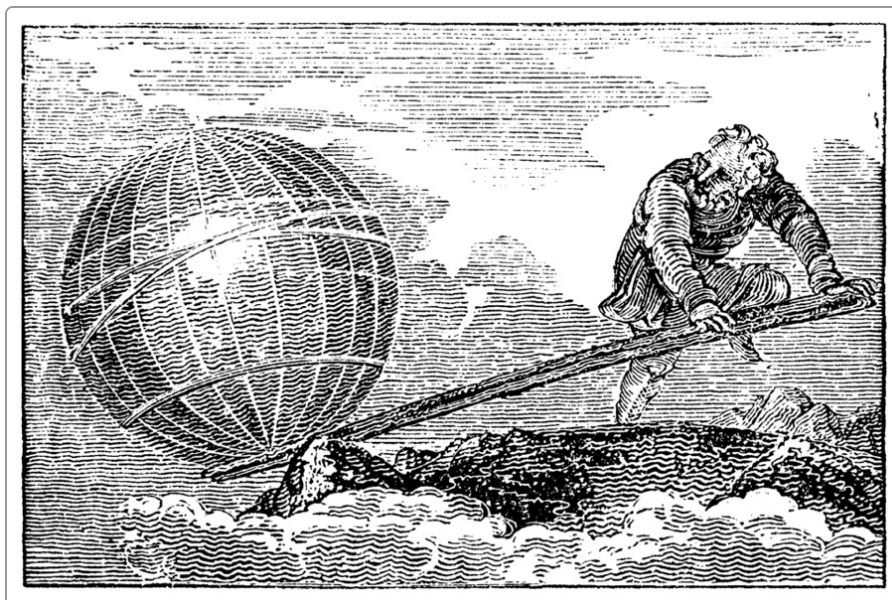
**How he figured it out.** Archimedes did not just guess. He tested levers with weights. He found a rule. If the load is close to the fulcrum and you push far away, you can lift a heavy load with a small push. An old story says that he showed the king how it

works. With levers and ropes, Archimedes pulled a big loaded ship onto the shore all by himself.

**The physics.** A lever is a stiff bar that turns on a point called the **fulcrum**. A seesaw is a lever. When the fulcrum is near the heavy load, your side of the bar is long. A long side makes your push stronger. But you have to push your end down a long way to lift the load a little way. You trade a long push for a strong push.

**The engineering.** Levers are all around us. A crowbar, a bottle opener, a wheelbarrow and a pair of scissors are all levers. Big cranes on building sites work like levers too. Engineers choose where to put the fulcrum so that people can lift heavy things safely.

## PICTURE STUDY



*Archimedes Moving the Earth*, Unknown engraver, from *Mechanics Magazine*, 1824 · Wood engraving · *Mechanics Magazine*, London

Image: [Wikimedia Commons](#), public domain

This old print is a joke picture of Archimedes' famous words. Of course no one can really move the earth. But the picture shows how a lever works.

### Look closely

- Find the long bar. That is the lever.
- Find the rock under the bar. That is the fulcrum.
- Find the load. Is it close to the fulcrum or far away?
- Find where Archimedes pushes. Is it close to the fulcrum or far away?

### Talk about it

1. Why does Archimedes push at the far end of the bar?
2. What would happen if the rock were right next to Archimedes?

**Safety first.** Wear safety glasses if you use a ruler or board as a lever, in case a load slips and flips.

## BUILD

### The Penny Lever Test

You will make a lever with a ruler and a pencil. You will put a load on one end and add pennies to the other end until the load lifts. Then you will move the fulcrum and test again.

#### You will need

- A flat 12-inch ruler
- A round or six-sided pencil for the fulcrum
- Two small paper cups and tape
- A load, such as a small rock or a roll of coins
- About 50 pennies
- Engineer's notebook

#### Steps

1. Tape one cup to each end of the ruler. Put the load in one cup.
2. Lay the pencil under the middle of the ruler (the 6-inch mark). This is the fulcrum.
3. **Predict.** How many pennies will lift the load? Write your guess.
4. Add pennies one at a time to the other cup until the load lifts. Write the number.
5. Move the pencil closer to the load, to the 4-inch mark. Count the pennies again. Then try the 3-inch mark and the 2-inch mark.
6. Make a table: where the fulcrum is, and how many pennies it took.
7. **Improve.** Find the spot where the fewest pennies lift the load. Then try putting the fulcrum close to the pennies instead. What happens?

#### Tips

- Keep the load the same every time. Only the fulcrum moves.
- Hold the pencil still with a bit of tape or clay so it does not roll.

#### Check your work

- ☐ I can point to the fulcrum, the load and the push on my lever.

- ☐ I can tell where the fulcrum should go to lift a heavy load with a small push.
- ☐ I can name three levers I use at home.

#### ENGINEER'S NOTEBOOK

1. Draw your ruler lever. Label the fulcrum, the load and the pennies.
2. Fill in your table of fulcrum places and penny counts. Circle the smallest number.
3. Draw a seesaw with a big person and a small child. Show where the fulcrum should go so they balance.

**From history.** Archimedes lived in the city of Syracuse. He also invented a screw-shaped pump for lifting water, which you may meet in Unit 5, and he discovered why things float, which you will learn in Unit 6.

#### COMMON MISTAKES

- Thinking the fulcrum should always be in the middle. Move it toward the heavy load to lift it more easily.
- Changing the load while moving the fulcrum. Change only one thing.

**Make it a game • Archimedes Says Lever.** Build a ruler lever on a pencil with pennies. Move the fulcrum closer to the heavy side and see what happens. Say bar, fulcrum, load and push as you point to each. Then play teacher: tell your parent what Archimedes said about moving the world with a lever. Your parent sneaks in one wrong fact to catch.

**Scripture.** “And I have filled him with the spirit of God, in wisdom, and in understanding, and in knowledge, and in all manner of workmanship, To devise cunning works, to work in gold, and in silver, and in brass, And in cutting of stones, to set them, and in carving of timber, to work in all manner of workmanship.” (Exodus 31:3-5, KJV)

God gave Bezalel skill to build and to make. Our skill to make good things is a gift from God too.

## UNIT 1

# MOTION AND MACHINES

Every machine starts with a push or a pull. In this unit you will learn how engineers think, by following people long ago who had very hard jobs to do. Workers in Egypt dragged a giant stone statue across the sand. Galileo rolled balls down a ramp to learn how things fall. Builders in Russia rolled a rock as big as a house on bronze balls. And Archimedes showed that a long bar can lift what your arms cannot.

You will learn about friction, gravity, wheels and levers. You will also learn the engineer's way of working: ask, imagine, plan, build, and improve. At every build you will guess first, test, write down what happened, and then make it better.

### PREREQUISITES

- Can measure with a ruler to the nearest inch or centimeter, with help
- Can count pennies to 50
- Can draw a simple picture and label it with help

### MASTERY CHECKLIST

- ☐ I can name the five steps engineers use: ask, imagine, plan, build, improve.
- ☐ I can tell how the Egyptian workers made a giant statue easier to pull.
- ☐ I can tell what friction is and what gravity is.
- ☐ I can show how wheels or rollers make moving things easier.
- ☐ I can find the fulcrum on a lever and show that a long lever makes lifting easier.

### OPTIONAL KITS FOR THIS UNIT

- **KiwiCo Kiwi Crate**: Ages 5–8. A monthly box with one hands-on build and a short story about the science. Many crates use ramps, wheels and levers, which fit Lessons 1.1–1.4.
- **K'NEX building sets**: Ages 7 and up. Rods, connectors and wheels for building carts, levers and simple machines. Fits Lessons 1.3 and 1.4 and Unit 2.

Not required. Every project in this unit can be built with household materials. School Launch has no ties to these companies.

## LESSONS IN THIS UNIT

|                                                          |                             |
|----------------------------------------------------------|-----------------------------|
| <b>1.1 Think Like an Engineer: Moving a Giant Statue</b> | 2 sessions of 30–40 minutes |
| <b>1.2 Gravity: Galileo’s Rolling Balls</b>              | 2 sessions of 30–40 minutes |
| <b>1.3 Wheels and Rollers: Moving the Thunder Stone</b>  | 2 sessions of 30–40 minutes |
| <b>1.4 Archimedes and the Lever</b>                      | 2 sessions of 30–40 minutes |

## UNIT 1 REVIEW

A parent asks these questions aloud. Your child may answer by telling, pointing, drawing or showing with the builds from this unit. There are no points. Listen for understanding and praise careful answers.

1. Say the five steps engineers use. Can you show them on your fingers?
2. Why did the worker in Egypt pour water in front of the statue’s sledge?
3. Drop a crumpled paper ball and a flat sheet of paper. Why does the ball land first?
4. Show me with your cart: is it easier to slide a load or roll it? Why?
5. Point to the fulcrum on your lever. Where should it go to lift a heavy rock with a small push?
6. Name a lever, a wheel and a ramp you can find in our house or yard.

#### ANSWER KEY

1. Ask, imagine, plan, build, improve.
2. Wet sand made less friction, so the sledge was easier to pull.
3. Air pushes up on the flat sheet and slows it. Gravity pulls both the same way.
4. Rolling is easier, because wheels and rollers make much less friction than sliding.
5. Close to the heavy rock, so the side you push is long.
6. Any good examples, such as scissors or a bottle opener (lever), a wagon or chair wheels (wheel), and a slide or the driveway (ramp).

#### PORTFOLIO PIECE: A CART THAT CARRIES THE HEAVIEST LOAD

Use all you learned in this unit to make your cardboard cart carry a heavy load down the ramp and roll as far as it can. Test it with 10, 20 and 30 pennies and write each distance. Then improve one thing, test again, and show your cart and your notebook pages to your family.

| LOOK FOR                    | WHAT IT MEANS                                                              |
|-----------------------------|----------------------------------------------------------------------------|
| <b>The engineer's steps</b> | Told or drew the ask, imagine, plan, build and improve steps for the cart. |
| <b>Fair testing</b>         | Let the cart go from the same spot each time and measured each roll.       |
| <b>Notebook</b>             | Kept a table of loads and distances, with a date on the page.              |
| <b>Improving</b>            | Found a problem, changed one thing, and tested again.                      |

## UNIT 2

# BRIDGES

A bridge carries people over a place they could not cross: a river, a valley or a busy road. In this unit you will meet four kinds of bridges. A beam bridge is a plank on posts. An arch bridge is a curve of stones. A truss bridge is made of triangles. A suspension bridge hangs from long cables. You will visit a wooden bridge in old Japan, the covered bridges of New England, a Roman bridge that has stood for two thousand years, and the Golden Gate Bridge in California.

In every build you will put pennies on a bridge until it bends or falls. You will guess first, count carefully, and write the number down. Then you will make the bridge stronger and test it again. A bridge must be safe for everyone who crosses it, so engineers test and test before anyone walks on it.

### PREREQUISITES

- Knows the five engineering steps: ask, imagine, plan, build, improve (Unit 1)
- Can count pennies by fives or tens
- Can tape and fold paper with some help

### MASTERY CHECKLIST

- ☐ I can name and draw four kinds of bridges: beam, arch, truss and suspension.
- ☐ I can show that folding paper makes a beam stronger.
- ☐ I can show why a triangle holds its shape better than a square.
- ☐ I can tell how the Romans built the Pont du Gard with arches.
- ☐ I can tell how the Golden Gate Bridge hangs from its cables.

### OPTIONAL KITS FOR THIS UNIT

- **KEVA Planks**: All ages. Plain wooden planks that are all the same size, with no glue or connectors. Good for building arches and beam bridges, and fits Lessons 2.1 and 2.3 and Unit 3.
- **K’NEX building sets**: Ages 7 and up. Rods and connectors make it easy to build truss and suspension bridges and then load them. Fits Lessons 2.2 and 2.4.

Not required. Every project in this unit can be built with household materials. School Launch has no ties to these companies.

## LESSONS IN THIS UNIT

### 2.1 Four Kinds of Bridges

2 sessions of 30–40 minutes

### 2.2 Why Triangles? Covered Bridges and Trusses

2 sessions of 30–40 minutes

### 2.3 Arches and the Pont du Gard

2 sessions of 30–40 minutes

### 2.4 The Golden Gate Bridge

2 sessions of 30–40 minutes

## UNIT 2 REVIEW

A parent asks these questions aloud. Your child may answer by telling, pointing, drawing or showing with the bridges from this unit. There are no points. Listen for understanding and praise careful answers.

1. Draw or build the four kinds of bridges. Say each one's name.
2. Show me a flat paper beam and a folded one. Which is stronger, and why?
3. Push on a square and a triangle made of sticks. Why do builders use triangles?
4. Why did old wooden bridges in New England have roofs?
5. Show me with your paper arch: what does an arch need at its feet?
6. On the Golden Gate Bridge, what holds up the road, and what holds down the cables?

### ANSWER KEY

1. Beam (flat deck on supports), arch (a curve), truss (triangles), suspension (road hanging from cables over towers).
2. The folded one, because folding makes the beam deeper and stiffer, so it does not bend as easily.
3. The triangle keeps its shape. The square can be pushed flat.
4. To keep the rain off the wooden truss so it would not rot.
5. Strong supports (abutments) to keep the feet from sliding apart.
6. The road hangs from the cables, which go over the towers. Big concrete anchors at the ends hold the cables down.

### PORTFOLIO PIECE: MY BEST BRIDGE

Choose one kind of bridge from this unit and build the strongest one you can across an 8-inch gap, using paper, straws, card stock, tape and string. Test it with pennies, improve it, and test it again. Show your family your bridge, your drawing and your table, and tell them which kind of bridge it is and why it is strong.

| LOOK FOR              | WHAT IT MEANS                                                      |
|-----------------------|--------------------------------------------------------------------|
| <b>Kind of bridge</b> | Named the kind of bridge and pointed to its main parts.            |
| <b>Fair test</b>      | Kept the gap the same and put the pennies in the middle each time. |
| <b>Improving</b>      | Tried again after the first bridge sagged and wrote both numbers.  |
| <b>Telling</b>        | Explained to the family why the shape makes the bridge strong.     |

## 2.1 FOUR KINDS OF BRIDGES

### OBJECTIVES

- Name and draw four kinds of bridges: beam, arch, truss and suspension.
- Tell what makes a beam bridge bend.
- Test flat and folded paper beams with pennies.

**Warm-up.** Lay a ruler across two books with a gap between them. Press gently on the middle. What does it do? Now turn the ruler on its edge and press again. What changed?

### WATCH

**What Makes Bridges So Strong? | Engineering for Kids | STEAM | SciShow Kids**

SciShow Kids · 3:45

<https://www.youtube.com/watch?v=oVOnRPefcno>

### WHEN TO WATCH

After the story, before the physics.

### BACKUP VIDEO

**Paper Bridges STEM Activity**

Science Buddies · 2:05

<https://www.youtube.com/watch?v=CqYGVW2Eu6Y>

Before the build, to see the paper bridge test.

### KEY TERMS

#### **beam bridge**

A bridge made of a flat, strong beam resting on posts or banks.

#### **arch bridge**

A bridge held up by a curved arch.

#### **truss bridge**

A bridge held up by a frame of triangles.

#### **suspension bridge**

A bridge whose road hangs from long cables held up by tall towers.

## **span**

The distance a bridge reaches across,  
from one support to the next.

### **CORE IDEAS**

**The story.** The first bridge was probably a log that fell across a creek. People walked across it to the other side. Later, people learned to build better bridges. About 170 years ago, in the city of Edo in Japan (now called Tokyo), there was a long wooden bridge called the Great Bridge. It crossed a wide river. It was a beam bridge. A beam bridge is a flat deck that rests on posts. The posts of the Great Bridge stood in the river like the legs of a long table.

**How they figured it out.** Bridge builders learned that a long beam sags in the middle. The longer the gap, the more it sags. So the builders of the Great Bridge put rows of posts all the way across the river. Each piece of beam only had to reach a short way, from one row of posts to the next. Short spans do not sag much.

**The physics.** When you press on a beam, the top of it gets squeezed and the bottom gets stretched. A thin, flat beam bends easily. But if you fold it or stand it on its edge, it gets much stiffer. Engineers learned other shapes too. An **arch** pushes the weight out to its ends. A **truss** uses triangles. A **suspension bridge** hangs its road from cables. These four kinds of bridges are beam, arch, truss and suspension.

**The engineering.** Engineers choose the kind of bridge that fits the place. A short creek needs only a beam. A deep valley may need an arch. A very wide bay needs a suspension bridge. They also think about what the bridge is made of, how much it costs, and how many cars and people it must carry.

## PICTURE STUDY



*Sudden Shower over Shin-Ōhashi Bridge and Atake*, Utagawa Hiroshige, 1857 · Woodblock print · From *One Hundred Famous Views of Edo*

Image: [Wikimedia Commons](#), public domain

Hiroshige was a Japanese artist who made prints of the places in his city. In this print a sudden rain shower has caught people on the Great Bridge.

### Look closely

- Find the posts under the bridge. How many rows can you see?
- Find the flat deck where people walk. That is the beam.
- Look at the diagonal pieces between the posts. What do you think they do?
- Find the raft on the river. Why must the posts leave space between them?

### Talk about it

1. What kind of bridge is this: beam, arch, truss or suspension?
2. Why do you think the builders used so many posts?
3. What would happen to the bridge if there were posts only at the two ends?

## BUILD

### The Paper Beam Test

You will make bridges out of a single sheet of paper. You will lay each one across a gap and add pennies until it sags to the table. You will find out which shape makes the strongest beam.

#### You will need

- Several sheets of plain printer paper, all the same
- Two stacks of books the same height
- A small paper cup
- About 100 pennies
- A ruler and tape
- Engineer's notebook

#### Steps

1. Set the two book stacks 6 inches apart. Measure the gap with a ruler. Keep it the same for every test.
2. **Flat bridge.** Lay one flat sheet across the gap. Set the cup in the middle. Add pennies one at a time until the paper sags and the cup touches the table. Write the number.
3. **Predict.** Which folded shape will be strongest? Write your guess.
4. **Folded bridges.** Fold a new sheet in half the long way. Test it. Then fold another sheet into a "U" channel with its sides up, and tape it so it does not open. Test it. Then fold a sheet back and forth like a fan, all the long way. Test it.
5. Write every result in a table: shape, number of pennies.
6. **Improve.** Design your own paper beam using only one sheet and some tape. Test it. Can you beat your best number?

#### Tips

- Use the same kind of paper and the same gap for every test. Only the shape changes.
- Set the pennies down gently. Do not drop them.

### Check your work

- ☐ I can name four kinds of bridges.
- ☐ I can tell which paper shape held the most pennies.
- ☐ I can tell why a folded beam is stronger than a flat one.

### ENGINEER'S NOTEBOOK

1. Draw the four kinds of bridges: beam, arch, truss and suspension. Label each one.
2. Make a table of your paper shapes and how many pennies each held. Circle the winner.
3. Draw the end of your strongest paper beam, as if you were looking straight into it.

**From history.** Hiroshige's print was so loved that the Dutch painter Vincent van Gogh made his own painted copy of it in 1887. The wooden Great Bridge was later replaced by stronger bridges of iron and steel.

### COMMON MISTAKES

- Moving the books farther apart between tests. A longer gap makes any beam weaker.
- Thinking a bridge is strong because it is big. Its shape matters most.

**Make it a game • Name That Bridge.** Draw four bridges in one minute: beam, arch, truss and suspension. Hold up each drawing, and your parent names the kind. Switch roles, and your parent draws while you guess. Then explain what makes a beam bridge bend. Whoever names the most correct bridges out of eight wins. Beat your last score.

## 2.2 WHY TRIANGLES? COVERED BRIDGES AND TRUSSES

### OBJECTIVES

- Show that a triangle keeps its shape and a square does not.
- Tell how Ithiel Town built bridges from a lattice of boards.
- Build a straw truss bridge and test it with pennies.

**Warm-up.** Make a square out of four craft sticks or straws, with a pushpin or a bit of clay at each corner. Push on one corner. What happens? Now make a triangle out of three. Push it. Which one keeps its shape?

### WATCH

#### Strong Structures with Triangles | Design Squad

Design Squad · 5:02

<https://www.youtube.com/watch?v=mBHJtWbsiaA>

### WHEN TO WATCH

After the warm-up, before the story.

### KEY TERMS

#### **triangle**

A shape with three sides. It cannot be squashed into a different shape unless a side breaks or bends.

#### **truss**

A frame made of triangles joined together.

#### **lattice**

A crisscross pattern of strips, like a garden trellis.

#### **covered bridge**

A wooden bridge with a roof and walls to keep the rain off its wooden frame.

### CORE IDEAS

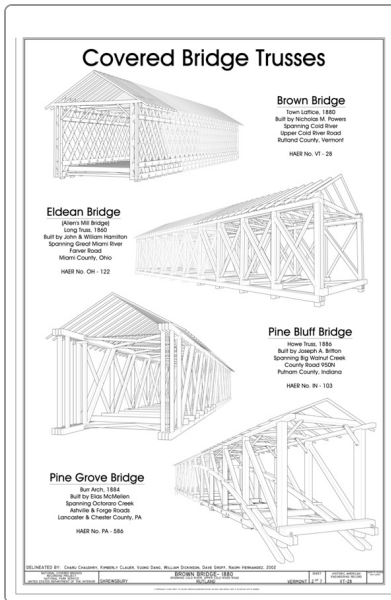
**The story.** Two hundred years ago, America was full of rivers and creeks, and people needed bridges for their wagons. Big logs were hard to find and hard to move. In 1820 a builder named Ithiel Town from Connecticut came up with an idea. He nailed lots of plain, flat boards together in a crisscross pattern, like a garden fence. He called it a **lattice truss**. Any good carpenter could build one with ordinary boards and wooden pegs.

**How they figured it out.** Builders had found that wooden bridges rotted when rain soaked into the joints. So they put a roof and walls over the truss. That is why so many old bridges in New England are **covered bridges**. The roof was not for the travelers. It was to keep the wooden frame dry, so the bridge would last a long time. Some covered bridges are more than 150 years old and still carry cars today.

**The physics.** A square made of four sticks can be pushed flat, because its corners can bend. A **triangle** cannot be pushed into a new shape unless one of its sides breaks. So a frame of triangles is stiff and strong. In a truss, some pieces get squeezed and some get pulled. Each piece only has to do a little of the work.

**The engineering.** Engineers use triangles everywhere: in bridges, roofs, cranes, towers and bicycle frames. A truss is strong but light, because it is mostly empty space. That saves wood or steel and saves money. Look for triangles the next time you drive over a bridge or see a power-line tower.

## PICTURE STUDY



*Covered Bridge Trusses*, Historic American Engineering Record, 2002 · Measured drawing · Library of Congress

Image: [Wikimedia Commons](#), public domain

Engineers who study old bridges made this careful drawing. They drew four covered bridges as if you could see right through the walls. The top one, Brown Bridge in Vermont, uses Ithiel Town's lattice truss.

### Look closely

- Find the Brown Bridge at the top. Can you see the crisscross lattice?
- Find the roof on each bridge. What is it for?
- Find triangles in each of the four trusses. Which bridge has the most?
- Find the bottom of each bridge, where the road goes.

### Talk about it

1. Why did the builders put a roof on a wooden bridge?
2. Why are the boards set on a slant instead of straight up and down?
3. Which of the four trusses would you choose to build? Why?

**Safety first.** Have an adult cut straws or sticks with scissors. Wear safety glasses for the load test, in case a straw snaps.

## BUILD

### A Straw Truss Bridge

You will build two bridges from straws: one made of squares and one made of triangles. You will test which one holds more pennies.

#### You will need

- About 40 plastic or paper drinking straws
- Masking tape or a box of large paper clips to join straws
- Two stacks of books the same height
- A strip of card stock for the road, about 3 inches wide and 10 inches long
- A small paper cup and about 100 pennies
- Engineer's notebook

#### Steps

1. Set the book stacks 8 inches apart.
2. **Square bridge.** Build two side walls, each a row of squares made from straws, about 10 inches long. Join the walls with straws across the top and bottom. Lay the card-stock road on the bottom.
3. **Predict.** Will the triangle bridge hold more or fewer pennies? Write your guess.
4. Set the square bridge across the gap. Set the cup on the middle of the road. Add pennies until the bridge sags or leans. Write the number.
5. **Triangle bridge.** Build two new side walls, this time with a slanted straw across each square to make triangles. Join and test them the same way.
6. Write both numbers in a table.
7. **Improve.** Look where your triangle bridge bent first. Add one or two straws there to make more triangles. Test it again.

#### Tips

- Tape every joint tightly. Most straw bridges fail at a loose joint.
- Use the same number of straws in the walls of both bridges if you can, so the test is fair.

### Check your work

- ☐ I can show why a triangle is stronger than a square.
- ☐ I can tell why covered bridges have roofs.
- ☐ I can point to the triangles in my bridge.

### ENGINEER'S NOTEBOOK

1. Draw a square and a triangle made of sticks. Draw what happens when you push on each corner.
2. Draw your triangle bridge from the side and color each triangle.
3. Write both penny counts and one sentence about what you learned.

**From history.** Many covered bridges were painted red, because red barn paint was cheap. Vermont alone still has about one hundred covered bridges, and families drive many miles to visit them.

### COMMON MISTAKES

- Leaving the joints loose. Even triangles wobble if the corners slip.
- Putting the pennies near one end instead of the middle.

**Make it a game • Triangle Truss Challenge.** Build a square and a triangle from straws and push on each one. Say which keeps its shape. Then race the clock: in three minutes, add triangles to a straw bridge and lay a toy across it. Tell your parent how Ithiel Town built covered bridges from a lattice of boards, using the word truss.

## 2.3 ARCHES AND THE PONT DU GARD

### OBJECTIVES

- Tell how the Romans built the Pont du Gard to carry water.
- Explain that an arch pushes out on its ends, so it needs strong supports.
- Build a paper arch and test it with and without supports at its feet.

**Warm-up.** Stand facing a partner with your hands pressed together over your heads, making an arch with your arms. Lean in a little. What do your feet have to do so you don't slide apart?

### WATCH

#### Fun with Arches

Engineering Models • 5:48

<https://www.youtube.com/watch?v=CP3fMa9iq8w>

#### WHEN TO WATCH

After the physics paragraph. Pause before each test and guess what will happen.

**Note:** Made by an engineering professor at the University of Waterloo with simple models. Good for watching together.

### BACKUP VIDEO

#### Pont du Gard (Roman Aqueduct) (UNESCO/NHK)

UNESCO • 2:18

<https://www.youtube.com/watch?v=zQqtiwlq9gw>

With the story, to fly around the real Pont du Gard and look inside its water channel.

### KEY TERMS

#### **arch**

A curved shape that carries weight down and out to its two ends.

#### **keystone**

The wedge-shaped stone at the very top of an arch.

**aqueduct**

A long channel that carries water from far away, sometimes on a bridge.

**abutment**

The strong support at each end of an arch that keeps the ends from spreading apart.

**CORE IDEAS**

**The story.** About two thousand years ago, the Romans built a city called Nemausus, in the land we now call France. The city needed fresh water. There was a good spring far away, but a river valley lay in between. So the Roman engineers built a water channel, called an **aqueduct**, about 30 miles long. To carry it over the river, they built a giant bridge of stone. We call it the Pont du Gard. It is as tall as a 15-story building. It has three rows of arches, one on top of another. The water flowed in a covered channel along the very top.

**How they figured it out.** The water had to flow downhill all the way to the city, but only a tiny bit. So the engineers had to measure the land very carefully. They built the bridge with huge blocks of stone. Many of the blocks were fitted so well that they needed no mortar to hold them. To build each arch, the workers first built a curved wooden frame. They laid the stones on top of the frame. Last of all they set the **keystone** at the top. Then they took the frame away, and the arch held itself up.

**The physics.** An arch is made of wedge-shaped stones. When weight presses down on the arch, the stones squeeze against each other. The squeeze travels around the curve, down to the two ends. But the ends also push outward. If nothing holds them, they slide apart and the arch falls. So every arch needs strong supports at its ends, called **abutments**. In the Pont du Gard, each arch leans against the arch next to it, and the ends push against the hillsides.

**The engineering.** Stone is very strong when it is squeezed, but it cracks easily when it is bent. An arch keeps every stone squeezed, so it is the perfect shape for stone. That is why the Pont du Gard still stands after two thousand years. Engineers still build arch bridges today, out of stone, concrete and steel.

## PICTURE STUDY



*The Pont du Gard*, Detroit Publishing Company, Between 1890 and 1900 · Photochrom (a colored photograph) · Library of Congress

Image: [Wikimedia Commons](#), public domain

This is an old colored photograph of the Pont du Gard, taken more than a hundred years ago. Count the arches and look for the clues that tell how it was built.

### Look closely

- Count the rows of arches. How many are there?
- Compare the big arches at the bottom with the small ones at the top. Why might the top ones be small?
- Find the very top of the bridge. That is where the water flowed.
- Look for stones that stick out from the side of the bridge. The builders may have used them to hold up their wooden frames.

### Talk about it

1. Why did the Romans need such a tall bridge?
2. What holds up the end of each arch?
3. Why do you think this bridge has lasted so long?

## BUILD

### The Paper Arch Test

You will make an arch out of card stock and put a load on it. First you will let its feet slide. Then you will hold its feet with “abutments” and test it again.

#### You will need

- Two strips of card stock, about 3 inches wide and 11 inches long
- Four heavy books
- A flat sheet of paper for a road
- A small paper cup and about 100 pennies
- A ruler
- Engineer’s notebook

#### Steps

1. Set two books 7 inches apart.
2. **No abutments.** Bend a card-stock strip into an arch and set it between the books so its feet rest on the table, but do not let the feet touch the books. Set the cup on top. Add pennies until the arch flattens. Write the number.
3. **Predict.** What will happen if the books hold the feet of the arch? Write your guess.
4. **With abutments.** Push the books in until they press firmly against both feet of the arch. Test again with pennies. Write the number.
5. **Arch plus beam.** Lay a flat sheet of paper across the books on top of the arch, like a road. Put the cup on the road and test again.
6. Make a table of your three tests.
7. **Improve.** Try a taller, rounder arch and a lower, flatter arch, both with abutments. Which holds more?

#### Tips

- Put the cup right on top of the arch, in the middle.
- If the card stock is floppy, use two strips together.

#### Check your work

- ☐ I can tell why the Romans built the Pont du Gard.
- ☐ I can show that an arch needs strong supports at its feet.
- ☐ I can name the keystone and the abutments.

#### ENGINEER'S NOTEBOOK

1. Draw an arch made of wedge-shaped stones. Color the keystone. Draw arrows showing the push going down to the abutments.
2. Write your three penny counts in a table.
3. Draw the Pont du Gard with its three rows of arches and the water channel on top.

**From history.** In the Middle Ages, after the aqueduct stopped carrying water, people used the Pont du Gard as a road bridge. In 1743 a new road bridge was built right beside it. Today it is one of the most visited Roman buildings in the world.

#### COMMON MISTAKES

- Forgetting the abutments. An arch with nothing at its feet spreads and falls.
- Thinking the keystone holds the whole arch by itself. Every stone in the arch works together.

**Make it a game • Arch Pushes Out.** Make an arch from a folded paper strip and press down on top. Watch the ends spread. Now hold the ends in with books and press again. Say abutment. Then explain how the Romans built the Pont du Gard, and why the keystone matters. Whoever explains it best in 30 seconds wins a paper chip.

## 2.4 THE GOLDEN GATE BRIDGE

### OBJECTIVES

- Tell the story of how the Golden Gate Bridge was built.
- Explain how a suspension bridge hangs from cables held up by towers and anchors.
- Build a string suspension bridge and test it with pennies.

**Warm-up.** Hold a jump rope or a long string between two people, loose in the middle. Hang a small toy from the middle. Now pull the ends tighter. What happens to the toy? What do your hands feel?

### WATCH

#### The Golden Gate Bridge for Kids: Famous Landmarks for Children - FreeSchool

Free School · 3:43

<https://www.youtube.com/watch?v=WKphjf3VZhA>

### WHEN TO WATCH

After the story.

### BACKUP VIDEO

#### Golden Gate Bridge for Kids

Homeschool Pop · 4:08

<https://www.youtube.com/watch?v=bPBTx97pMDs>

After the engineering paragraph.

### KEY TERMS

#### **cable**

A thick, strong rope made of many steel wires.

#### **anchor**

A huge block of concrete at each end that holds the cables down tight.

#### **tower**

A tall support that holds the cables up high.

#### **tension**

A pulling force that stretches something, like the pull in a tight rope.

## CORE IDEAS

**The story.** The city of San Francisco sits at the tip of a long piece of land. Across the water to the north is more land. For years, the only way across was by ferry boat. The gap of water is called the Golden Gate. It is more than a mile wide and very deep. The wind is strong, the water rushes in and out with the tides, and thick fog rolls in. Many people said no bridge could ever be built there.

**How they figured it out.** An engineer named Joseph Strauss led the work. Another engineer, Charles Ellis, did many careful pages of math. Workers began in 1933. The hardest part was the south tower, which had to stand in the open sea. Workers built a great concrete wall in the water around the spot first, to keep the waves out. Then they built two steel towers taller than any bridge towers in the world. Next they spun the two main cables, wire by wire, back and forth across the gap. Each cable holds more than 27,000 thin wires bundled together, and it is about three feet thick. Safety was important. Workers wore hard hats, and a big net hung under the bridge to catch anyone who slipped. The bridge opened in May 1937. On the first day, people walked across it.

**The physics.** In a suspension bridge, the road hangs from the cables by long steel ropes. The cables are pulled tight. That pull is called **tension**. The cables pass over the tops of the two tall towers. They push the towers straight down into the ground. At each end, the cables are tied into huge concrete **anchors** buried in the land, so they cannot pull loose.

**The engineering.** Steel wire is very strong when it is pulled. So a suspension bridge can reach farther than any other kind of bridge. When the Golden Gate Bridge opened, its middle span was the longest in the world, 4,200 feet. Today painters and ironworkers take care of the bridge every day. They keep its orange paint fresh so the salty sea air cannot rust the steel.

## PICTURE STUDY



*The Golden Gate Bridge*, Jet Lowe, Historic American Engineering Record, 1984 · Photograph · Library of Congress

Image: [Wikimedia Commons](#), public domain

A photographer who records great American bridges for the Library of Congress took this picture. It shows how the road hangs from the cables.

### Look closely

- Find the two tall towers.
- Follow a main cable with your finger from the top of a tower down to the middle of the bridge and back up.
- Find the thin ropes that hang straight down from the main cable to the road.
- Find the truss under the road. What shape do you see?

### Talk about it

1. What holds up the main cables?
2. What would happen if the anchors at the ends let go?
3. Why do you think the bridge has a truss under its road?

**Safety first.** Wear safety glasses during the load test, and keep your face away from the string when it is tight.

## BUILD

### A String Suspension Bridge

You will build a suspension bridge between two chairs, using string for the cables and cardboard for the road. Then you will test how many pennies it can hold, and make it stronger.

#### You will need

- Two chairs with backs, set about 2 feet apart
- Two paper towel tubes for towers
- Strong string or yarn, about 12 feet
- A strip of cardboard about 3 inches wide and 24 inches long for the road
- A hole punch, tape and several heavy books for anchors
- A small paper cup and about 100 pennies
- Engineer's notebook

#### Steps

1. Tape a paper towel tube upright to the front of each chair seat. These are your towers.
2. Lay two long strings over the tops of both towers. Tie or tape the ends of each string under a stack of heavy books on the floor beyond each chair. These are your cables and anchors.
3. Punch three holes along each side of the cardboard road. Tie short pieces of string from each hole up to the main cable above it, so the road hangs level between the towers.
4. **Predict.** How many pennies will your bridge hold before the road sags 1 inch? Write your guess.
5. Set the cup on the middle of the road. Add pennies, ten at a time, and measure the sag with a ruler. Write each number.
6. **Improve.** Add more hanging strings, pull the main cables tighter, or add more books to the anchors. Change one thing and test again.

#### Tips

- If the towers tip over, tape them more firmly or add a book on each chair seat.
- Make all the hanging strings the same length so the road is level.

#### Check your work

- ☐ I can point to the towers, cables, anchors and road on my bridge.
- ☐ I can tell what tension means.
- ☐ I can tell one hard problem the Golden Gate builders solved.

#### ENGINEER'S NOTEBOOK

1. Draw your suspension bridge and label the towers, cables, hangers, road and anchors.
2. Make a table: number of pennies and how far the road sagged.
3. Draw an arrow on a cable to show which way it is pulled.

**From history.** The color of the bridge is called International Orange. The architect Irving Morrow chose it because it shows up well in the fog and looks good against the hills, the sky and the sea.

#### COMMON MISTAKES

- Forgetting the anchors. Without them, the cables pull the towers over.
- Hanging the road from only one string in the middle. Spread the load over many hangers.

**Make it a game • Cable Tension Pull.** Hang a string between two chairs with a small toy hanging from the middle. Pull on each end like a tower and an anchor. Feel tension. Say cable, tower and anchor and point to each one. Tell your parent how the Golden Gate Bridge was built. Then try to explain why the cables must be anchored well.

**Scripture.** “And if one prevail against him, two shall withstand him; and a threefold cord is not quickly broken.” (Ecclesiastes 4:12, KJV)

One thin wire is weak, but thousands twisted together hold up a whole bridge. People are stronger together too.

## UNIT 2

# BRIDGES

A bridge carries people over a place they could not cross: a river, a valley or a busy road. In this unit you will meet four kinds of bridges. A beam bridge is a plank on posts. An arch bridge is a curve of stones. A truss bridge is made of triangles. A suspension bridge hangs from long cables. You will visit a wooden bridge in old Japan, the covered bridges of New England, a Roman bridge that has stood for two thousand years, and the Golden Gate Bridge in California.

In every build you will put pennies on a bridge until it bends or falls. You will guess first, count carefully, and write the number down. Then you will make the bridge stronger and test it again. A bridge must be safe for everyone who crosses it, so engineers test and test before anyone walks on it.

### PREREQUISITES

- Knows the five engineering steps: ask, imagine, plan, build, improve (Unit 1)
- Can count pennies by fives or tens
- Can tape and fold paper with some help

### MASTERY CHECKLIST

- ☐ I can name and draw four kinds of bridges: beam, arch, truss and suspension.
- ☐ I can show that folding paper makes a beam stronger.
- ☐ I can show why a triangle holds its shape better than a square.
- ☐ I can tell how the Romans built the Pont du Gard with arches.
- ☐ I can tell how the Golden Gate Bridge hangs from its cables.

### OPTIONAL KITS FOR THIS UNIT

- **KEVA Planks**: All ages. Plain wooden planks that are all the same size, with no glue or connectors. Good for building arches and beam bridges, and fits Lessons 2.1 and 2.3 and Unit 3.
- **K’NEX building sets**: Ages 7 and up. Rods and connectors make it easy to build truss and suspension bridges and then load them. Fits Lessons 2.2 and 2.4.

Not required. Every project in this unit can be built with household materials. School Launch has no ties to these companies.

## LESSONS IN THIS UNIT

|                                                       |                             |
|-------------------------------------------------------|-----------------------------|
| <b>2.1 Four Kinds of Bridges</b>                      | 2 sessions of 30–40 minutes |
| <b>2.2 Why Triangles? Covered Bridges and Trusses</b> | 2 sessions of 30–40 minutes |
| <b>2.3 Arches and the Pont du Gard</b>                | 2 sessions of 30–40 minutes |
| <b>2.4 The Golden Gate Bridge</b>                     | 2 sessions of 30–40 minutes |

## UNIT 2 REVIEW

A parent asks these questions aloud. Your child may answer by telling, pointing, drawing or showing with the bridges from this unit. There are no points. Listen for understanding and praise careful answers.

1. Draw or build the four kinds of bridges. Say each one's name.
2. Show me a flat paper beam and a folded one. Which is stronger, and why?
3. Push on a square and a triangle made of sticks. Why do builders use triangles?
4. Why did old wooden bridges in New England have roofs?
5. Show me with your paper arch: what does an arch need at its feet?
6. On the Golden Gate Bridge, what holds up the road, and what holds down the cables?

### ANSWER KEY

1. Beam (flat deck on supports), arch (a curve), truss (triangles), suspension (road hanging from cables over towers).
2. The folded one, because folding makes the beam deeper and stiffer, so it does not bend as easily.
3. The triangle keeps its shape. The square can be pushed flat.
4. To keep the rain off the wooden truss so it would not rot.
5. Strong supports (abutments) to keep the feet from sliding apart.
6. The road hangs from the cables, which go over the towers. Big concrete anchors at the ends hold the cables down.

### PORTFOLIO PIECE: MY BEST BRIDGE

Choose one kind of bridge from this unit and build the strongest one you can across an 8-inch gap, using paper, straws, card stock, tape and string. Test it with pennies, improve it, and test it again. Show your family your bridge, your drawing and your table, and tell them which kind of bridge it is and why it is strong.

| LOOK FOR              | WHAT IT MEANS                                                      |
|-----------------------|--------------------------------------------------------------------|
| <b>Kind of bridge</b> | Named the kind of bridge and pointed to its main parts.            |
| <b>Fair test</b>      | Kept the gap the same and put the pennies in the middle each time. |
| <b>Improving</b>      | Tried again after the first bridge sagged and wrote both numbers.  |
| <b>Telling</b>        | Explained to the family why the shape makes the bridge strong.     |

## UNIT 3

# BUILDINGS

Jesus told a story about two builders. One built his house on the rock, and the other built on the sand. When the storm came, only the house on the rock stood. Every engineer who builds a building starts the same way: with the ground underneath. In this unit you will see what happened to a famous tower in Italy that was built on soft ground. You will learn how Inuit builders make strong snow domes with no wood at all, how castle builders lifted heavy stones with a giant wheel, and how a safe elevator made tall skyscrapers possible.

You will test towers on sand and on rock, load eggshell domes with books, compare paper columns of different shapes, and build a skyscraper frame with a working elevator. As always, guess first, test fairly, write it down, and make it better.

### PREREQUISITES

- Knows that triangles are strong and that arches push out at their feet (Unit 2)
- Knows what a wheel and axle and a lever are (Unit 1)
- Can count and record numbers in a simple table

### MASTERY CHECKLIST

- ☐ I can tell why a building needs a strong foundation, and tell what happened to the Leaning Tower of Pisa.
- ☐ I can tell how an igloo is built and why a dome is strong.
- ☐ I can tell how castle builders lifted heavy stones, and show which column shape is strongest.
- ☐ I can tell how Elisha Otis made elevators safe, and why that let people build skyscrapers.

### OPTIONAL KITS FOR THIS UNIT

- **KEVA Planks:** All ages. Plain wooden planks that stack without glue. Children can build towers, domes and castle walls and test how tall they can go. Fits Lessons 3.1–3.4.
- **LEGO Education:** Ages 6 and up for the early sets. Bricks, beams and simple gears for building towers, cranes and a crank-lifted elevator. Fits Lessons 3.3 and 3.4.

Not required. Every project in this unit can be built with household materials. School Launch has no ties to these companies.

## LESSONS IN THIS UNIT

**3.1 The Wise Builder: Foundations and the Leaning Tower** 2 sessions of 30–40 minutes

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**3.2 Domes and Igloos** 2 sessions of 30–40 minutes

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**3.3 Castles: Thick Walls, Round Towers and a Giant Wheel** 2 sessions of 30–40 minutes

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**3.4 Skyscrapers and Otis’s Safe Elevator** 2 sessions of 30–40 minutes

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## UNIT 3 REVIEW

A parent asks these questions aloud. Your child may answer by telling, pointing, drawing or showing with the builds from this unit. There are no points. Listen for understanding and praise careful answers.

1. Tell the story of the wise and foolish builders. Which house stood, and why?
2. Why does the Tower of Pisa lean? What did engineers do to help it?
3. Show me with a drawing how an igloo is built. Why is a dome strong?
4. How did castle builders lift heavy stones high up the wall?
5. Show me your three paper columns. Which held the most, and why?
6. What did Elisha Otis invent, and how did he show it was safe?

#### ANSWER KEY

1. The house on the rock stood, because its foundation was strong. The house on the sand fell.
2. The ground under one side is soft, and the foundation was not deep enough, so one side sank. Engineers took a little soil from under the high side so the tower leaned a bit less.
3. Snow blocks go around in a spiral, each leaning in more, until the last block closes the top. The weight spreads all around the dome and squeezes it, and snow is strong when squeezed.
4. With a treadwheel crane. People walked inside a giant wheel, which wound the rope around the axle and lifted the stone.
5. Usually the round one. It has no corners, so the weight spreads evenly.
6. A safety brake for elevators. He rode his lift high up and had the rope cut, and the brake caught and held it.

#### PORTFOLIO PIECE: A TOWER THAT STANDS

Build the tallest tower you can from paper, straws, tape and cardboard on a strong, wide foundation. Use round columns or triangles to make it strong. Test it three ways: put a book on top, blow on it with a fan or your breath, and tap the table. Improve it after each test, and show your family your tower and your notebook.

| LOOK FOR             | WHAT IT MEANS                                                       |
|----------------------|---------------------------------------------------------------------|
| <b>Foundation</b>    | Built a wide, firm base and could explain why it matters.           |
| <b>Strong shapes</b> | Used round columns, triangles or a dome, and could tell why.        |
| <b>Testing</b>       | Tested the tower three ways and wrote down what happened each time. |
| <b>Improving</b>     | Fixed the weak spot after a test and tried again.                   |

## 3.1 THE WISE BUILDER: FOUNDATIONS AND THE LEANING TOWER

### OBJECTIVES

- Tell Jesus’ story of the wise and foolish builders.
- Tell why the Tower of Pisa leans and how engineers kept it from falling.
- Test towers on sand and on a firm base, and record what happens.

**Warm-up.** Stand on a soft pillow on one foot. Now stand on the hard floor on one foot. Which is easier? Why do you think so?

### WATCH

#### The Leaning Tower of Pisa for Kids: Famous World Landmarks for Children - FreeSchool

Free School · 4:42

<https://www.youtube.com/watch?v=OagyPEhYKxo>

### WHEN TO WATCH

After the story.

**Note:** Near the start, a stone fountain with carved cherub figures stands beside the tower for a few seconds.

### BACKUP VIDEO

#### Wise and Foolish Builder Object Lesson

Free Bible Lessons · 3:20

<https://www.youtube.com/watch?v=VT5O3WYVpFU>

Before the build, to see houses on rock and on sand.

### KEY TERMS

#### **foundation**

The strong bottom part of a building that sits in the ground and holds the building up.

#### **soil**

The ground. Some soil is soft, like mud and sand. Some is hard, like rock.

**lean**

To tip to one side.

**sink**

To slowly push down into soft ground.

**CORE IDEAS**

**The story.** Jesus told a story about two builders. A wise man built his house upon a rock. A foolish man built his house upon the sand. The rain came down, the floods came up and the wind blew. The house on the rock stood firm. The house on the sand fell with a great crash. Jesus said that people who hear His words and do them are like the wise builder.

**How builders learned it.** About 850 years ago, people in the city of Pisa, in Italy, began to build a tall, round bell tower of white marble. When they had built only three floors, the tower began to tip. The ground under it was soft clay and sand. Its foundation was not deep enough. The builders stopped for almost a hundred years. When they started again, they tried to make the new floors a little bit straighter, so the tower has a slight curve. They finished it, but it kept leaning more and more.

**How engineers saved it.** By 1990, the tower leaned so far that engineers were afraid it would fall. They closed it to visitors. They did not want to straighten it all the way, because people love the lean. Instead they slowly dug a little soil out from under the high side. The high side sank down a tiny bit, and the tower leaned a little less. Today it is safe and open again, and it still leans.

**The physics.** A building is very heavy. Its weight pushes down on the ground all the time. Hard rock can hold the weight. Soft sand and mud get squeezed and the building sinks. If one side sinks more than the other, the building leans. A wide **foundation** spreads the weight over more ground, like snowshoes spread your weight over the snow.

**The engineering.** Before a building goes up, engineers test the soil. They drill down and see what is there. On soft ground they make the foundation wider, or they drive long posts called piles deep down until they reach hard ground. The foundation is the first thing built and the part nobody sees, but everything depends on it.

## PICTURE STUDY



*The Leaning Tower, Pisa*, Detroit Publishing Company, Between 1890 and 1900 · Photochrom (a colored photograph) · Library of Congress

Image: [Wikimedia Commons](#), public domain

This colored photograph of the Leaning Tower was made more than a hundred years ago. Look closely at how it leans.

### Look closely

- Hold a pencil straight up next to the picture. Which way does the tower lean?
- Count the rows of arches. How many floors does the tower have?
- Look at the bottom of the tower. Can you tell which side has sunk lower?
- Look at the top floor. Does it look a little straighter than the rest?

### Talk about it

1. Why did the tower begin to lean?
2. What could the first builders have done differently?
3. Why did the engineers not make the tower perfectly straight?

## BUILD

### Rock or Sand? A Foundation Test

You will build two matching towers. One will stand on sand. One will stand on a flat stone or board. Then you will make it “rain” and see which tower stands.

#### You will need

- Two foil baking pans or plastic tubs
- Sand (or soil) to fill one pan about 2 inches deep
- A flat stone, brick or small wooden board for the other pan
- Building blocks, sugar cubes or plastic bricks
- A watering can or cup of water
- A piece of cardboard for a wide foundation
- A ruler and engineer’s notebook

#### Steps

1. Put sand in one pan. Put the flat stone or board in the other pan, with a little sand around it.
2. Build two towers that are exactly the same, 8 blocks tall. Set one on the sand and one on the stone.
3. **Predict.** Which tower will stand after the “storm”? Write your guess.
4. Slowly pour the same amount of water around each tower. Then tap the table five times for an “earthquake” or “wind.”
5. Watch closely. Measure how far each tower leaned or sank, with a ruler. Write it down.
6. **Improve.** Rebuild the sand tower on a wide piece of cardboard, like a foundation. Test it again the same way. Did the wide foundation help?

#### Tips

- Pour the water the same way for both towers, so the test is fair.
- Do this outside or on a tray. It gets messy.

#### Check your work

- ☐ I can tell Jesus’ story of the wise and foolish builders.

- ☐ I can tell why the Tower of Pisa leans.
- ☐ I can tell what a foundation does.

#### ENGINEER'S NOTEBOOK

1. Draw the tower on the rock and the tower on the sand after the storm.
2. Write your measurements: how far each tower leaned or sank.
3. Draw the Leaning Tower and show where the soft ground is under it.

**From history.** The Leaning Tower is a bell tower for the cathedral beside it, and it still has seven bells. The work to save it took about ten years, from 1990 to 2001. Engineers say it should stay safe for at least two hundred years.

#### COMMON MISTAKES

- Thinking the foundation does not matter because you cannot see it. It holds up everything.
- Pouring more water on one tower than the other. Keep the test fair.

**Make it a game • Leaning Tower Detective.** Build one tower on a pan of damp sand and another on a pan of hard packed rock or clay. Watch what happens as you add blocks. Say foundation, soil and lean. Tell your parent why the Tower of Pisa leans and how engineers saved it. Retell Jesus' wise builder story in three sentences.

**Scripture.** "Therefore whosoever heareth these sayings of mine, and doeth them, I will liken him unto a wise man, which built his house upon a rock: And the rain descended, and the floods came, and the winds blew, and beat upon that house; and it fell not: for it was founded upon a rock." (Matthew 7:24-25, KJV)

A good builder puts a strong foundation under a house. Jesus says a wise person builds his whole life on hearing and doing His words.

## 3.2 DOMES AND IGLOOS

### OBJECTIVES

- Tell how Inuit builders make an igloo from blocks of snow.
- Explain why a dome is a strong shape.
- Test eggshell domes with books and record how many they hold.

**Warm-up.** Hold an egg in the palm of your hand over a bowl, wrap your fingers around it, and squeeze evenly. (A grown-up should decide if you may try this!) Most eggs will not break. Why do you think such a thin shell is so strong?

### WATCH

#### How To Build An Igloo | A Boy Among Polar Bears | BBC

BBC Studios · 2:53

<https://www.youtube.com/watch?v=R-x5QOSqP3E>

### WHEN TO WATCH

After the story. Watch how each block leans in.

### BACKUP VIDEO

#### How strong are domes - from Fun Kids Inspiring Engineers

Fun Kids Learn · 4:13

<https://www.youtube.com/watch?v=D8h2DL-gWg8>

Before the build. It shows the eggshell test you will do.

### KEY TERMS

#### **dome**

A round roof shaped like half of a ball.

#### **igloo**

A dome-shaped house built from blocks of hard snow.

#### **spiral**

A line that winds around and around as it climbs, like a snail shell.

#### **compression**

A squeezing force. A dome is squeezed all over by its own weight.

### CORE IDEAS

**The story.** Far in the north, where there are no trees, the Inuit people have lived on the ice and snow for a very long time. When a hunter needs shelter on a long trip, he

can build a house out of snow in about an hour. It is called an **igloo**. He needs only a long snow knife and the right kind of snow.

**How they figured it out.** Inuit builders learned which snow to use. It must be packed hard by the wind, so it can be cut into firm blocks. The builder cuts blocks from the snow where he will stand, so the floor gets lower. He sets the first row of blocks in a circle. Then he trims the tops so the next row climbs around in a **spiral**. Each block leans in a little more than the one below. The walls curve inward and close up into a **dome**. The last block is cut to fit the hole at the very top. A small, low tunnel makes the door, so the cold wind stays out.

**The physics.** A dome is like an arch that has been spun all the way around. When weight pushes down on a dome, the push spreads out all around the curve and down to the ground. Every part of the dome gets squeezed together. Snow, stone and eggshell are all strong when they are squeezed. That is why a thin eggshell can hold up a stack of books, and why an igloo can hold the weight of a person standing on top.

**The engineering.** Builders have used domes for thousands of years. Great domes cover churches, museums and the Capitol building in Washington, D.C. A dome covers a big space with no posts in the middle. It also uses less material than a flat roof for the same space. Igloo builders and dome builders use the same idea: let the shape do the work.

## PICTURE STUDY



*Building a Snow House on Baffin Island, Frank and Frances Carpenter Collection, Early 1900s ·*

Photograph · Library of Congress

Image: [Wikimedia Commons](#), public domain

This old photograph was taken on Baffin Island in the far north of Canada. A traveler has finished a snow house for the night.

### Look closely

- Find the igloo. What shape is it?
- Find the small doorway. Why do you think it is so low?
- Find the sled. What do you think the traveler carried on it?
- Look around the igloo. Are there any trees or wood to build with?

### Talk about it

1. Why did the builder use snow instead of wood?
2. Why does a dome not need posts in the middle?
3. How is an igloo like an arch?

**Safety first.** An adult should help cut the eggshells, and everyone should wash their hands after handling raw eggs.

## BUILD

### The Eggshell Dome Test

You will make four little domes from eggshells and stack books on top of them. Then you will try to make your domes hold even more.

#### You will need

- Four raw eggs (save the insides for breakfast)
- Masking tape and small scissors
- A stack of books, paperback and hardcover, about the same size
- A kitchen scale (optional)
- Engineer's notebook

#### Steps

1. With an adult, gently crack each egg near the pointed end and pour out the inside. Rinse the shells.
2. Wrap a strip of tape around the middle of each shell. Cut through the tape all the way around, so each shell becomes a clean dome with a taped edge.
3. Set the four domes on a table, round side up, in a square about the size of a book.
4. **Predict.** How many books will the four domes hold before one cracks? Write your guess.
5. Gently lay one book at a time on top of the domes. Count the books. Stop when you hear a crack.
6. Write the number of books. If you have a scale, weigh the stack.
7. **Improve.** Try again with new domes, but change one thing: use six domes, or put a stiff piece of cardboard on top so the books press evenly. Test and write the new number.

#### Tips

- Make sure the cut edges are even, so each dome stands flat.
- Lay the books down gently. Do not drop them.

#### Check your work

- ☐ I can tell how an igloo is built.
- ☐ I can tell why a dome is strong.
- ☐ I can tell how many books my domes held.

#### ENGINEER'S NOTEBOOK

1. Draw an igloo and show the spiral of blocks going up to the top.
2. Draw your eggshell domes under the books. Write how many books they held.
3. Draw arrows on a dome showing how the weight spreads down to the ground.

**From history.** Inside a good igloo, the heat from the people and a small lamp can keep it much warmer than the air outside. A low sleeping bench is built higher than the doorway, because warm air rises and stays up near the bench.

#### COMMON MISTAKES

- Pressing the books down with your hand. Let only the weight of the books push.
- Thinking an igloo is made of ice. It is made of hard-packed snow blocks.

**Make it a game • Dome Weight Duel.** Press a half eggshell dome, a cup and a flat card with books on top, one at a time, and see how many books each holds. Count them out loud. Say dome and compression. Tell your parent how Inuit builders make an igloo from blocks of snow. Guess first, then compare your guess to the result.

## 3.3 CASTLES: THICK WALLS, ROUND TOWERS AND A GIANT WHEEL

### OBJECTIVES

- Tell how castle builders lifted heavy stones with a treadwheel crane.
- Explain why thick stone walls and round towers are strong.
- Test paper columns of different shapes and find the strongest.

**Warm-up.** Look at a cardboard paper-towel tube and an empty cereal box. Press gently on the top of each. Which one squashes more easily? Where does the box bend first?

### WATCH

#### Castles for Kids: What is a Castle? Medieval History for Children - FreeSchool

Free School • 7:25

<https://www.youtube.com/watch?v=AesgRREuCQI>

### WHEN TO WATCH

After the story.

**Note:** A few old paintings and tapestry pictures of knights in battle appear briefly. The video focuses on how castles were built and used.

### KEY TERMS

#### castle

A strong stone home with thick walls and towers, built long ago for a lord and his people.

#### treadwheel crane

A crane powered by people walking inside a giant wheel, like a hamster wheel.

#### column

A tall, upright post that holds weight up.

#### mortar

A paste that hardens between stones or bricks to hold them together.

### CORE IDEAS

**The story.** About eight hundred years ago, kings and lords in Europe built castles. A castle was a home, a storehouse and a safe place for the people nearby. Its stone

walls could be thicker than your bed is long. Building one took many years and hundreds of workers: stonecutters, masons, carpenters and blacksmiths.

**How they figured it out.** The hardest job was lifting heavy stones up high. Builders used a **treadwheel crane**. It was a giant wooden wheel, taller than a man. One or two workers walked inside it, and as the wheel turned, it wound a rope around its axle and lifted a stone. It is a wheel and axle, just like in Unit 1. Today, in a forest in France, a team of builders has been building a whole new castle called Guédelon, using only the tools and ways of eight hundred years ago. They built treadwheel cranes too. They found that one worker walking in the wheel can lift a heavy stone that he could never lift with his arms.

**The physics.** Stone is very strong when it is squeezed, so thick stone walls can hold up heavy roofs and floors. Castle builders learned that round towers were stronger than square ones. A square tower has corners, and corners are weak spots where cracks begin. A round tower has no corners. Weight and pushes spread evenly around it.

**The engineering.** Builders laid the stones in rows, with each stone sitting over the gap between two stones below, like bricks in a wall. They filled the gaps with **mortar** made of lime, sand and water. Engineers still use these ideas. Round columns hold up bridges and buildings today, and brick walls are still laid so that the joints do not line up.

## PICTURE STUDY



*Building with a Treadwheel Crane*, Unknown illuminator, 13th century · Manuscript painting (paint and gold on parchment) · A medieval French manuscript

Image: [Wikimedia Commons](#), public domain

Medieval artists painted small, bright pictures in handwritten books. This one shows a busy building site. Look for the machine that does the heavy lifting.

### Look closely

- Find the giant wheel. Who is inside it, and what are they doing?
- Follow the rope from the wheel to the load. Where is it going?
- Find the workers carrying stones up the ladders.
- Find the masons laying stones on top of the wall. How are the stones lined up?

### Talk about it

1. How is the treadwheel like the wheel and axle you built in Unit 1?
2. Why might it be easier to walk in a wheel than to lift a stone with your arms?
3. Why did builders lay each stone over the gap between two stones below?

## BUILD

### The Column Shape Test

You will make three columns from paper, each the same height: a round one, a square one and a triangle one. You will stack books on each until it crumples.

#### You will need

- Several sheets of printer paper, all the same
- Tape
- A ruler
- A stack of books about the same size, or a small board and cans of food
- Engineer's notebook

#### Steps

1. **Round column.** Roll one sheet into a tube about 2 inches across. Tape it.
2. **Square column.** Fold another sheet into a square tube with four sides the same. Tape it.
3. **Triangle column.** Fold a third sheet into a triangle tube with three sides the same. Tape it.
4. **Predict.** Which column will hold the most books? Write your guess.
5. Stand one column on the table. Gently lay books on top, one at a time, until the column crumples. Write the number. Test the other two the same way.
6. Look at where each column crumpled. Did the square one fail at a corner?
7. **Improve.** Build a castle tower with three round columns under a cardboard floor. How many books can it hold? Can you make it hold more by using four columns?

#### Tips

- Make all three columns the same height.
- Set the books on top carefully, right in the middle, so the column is pressed straight down.

#### Check your work

- ☐ I can tell how a treadwheel crane works.

- ☐ I can tell which column shape held the most and why.
- ☐ I can tell why castle walls were made thick.

#### ENGINEER'S NOTEBOOK

1. Draw the three columns and write how many books each held. Circle the winner.
2. Draw a treadwheel crane and label the wheel, the axle, the rope and the stone.
3. Draw a stone wall with each stone sitting over the gap between two below.

**From history.** The builders at Guédelon Castle in France started in 1997. They quarry their own stone, make their own mortar and forge their own iron tools. Visitors can watch them work and see the treadwheel cranes lift stones.

#### COMMON MISTAKES

- Using different amounts of paper for each column. Use one sheet for each so the test is fair.
- Thinking castles were only for fighting. They were homes, storehouses and safe places for many people.

**Make it a game • Castle Column Challenge.** Roll three paper tubes: round, square and flat. Stack books on each and count how many each holds. Predict the winner first. Say column and mortar. Then explain how a treadwheel crane lifted castle stones. Your parent plays a castle visitor and asks why the walls are thick and the towers round. Answer in two sentences.

**Scripture.** “So built we the wall; and all the wall was joined together unto the half thereof: for the people had a mind to work.” (Nehemiah 4:6, KJV)

Nehemiah led the people to rebuild the walls of Jerusalem. Big building jobs get done when many people work together with a willing heart.

## 3.4 SKYSCRAPERS AND OTIS'S SAFE ELEVATOR

### OBJECTIVES

- Tell how Elisha Otis showed that his elevator was safe.
- Explain why skyscrapers need both a strong frame and safe elevators.
- Build a tall frame with a working elevator and a safety catch.

**Warm-up.** Walk up a flight of stairs and count the steps. Now imagine living on the 20th floor with no elevator. How many steps would that be? Would you like to carry the groceries up?

### WATCH

#### Make Inventions: Otis Safety Elevator

Make: · 4:12

<https://www.youtube.com/watch?v=sSjJkCoNRk>

### WHEN TO WATCH

After the story. Watch how the safety brake catches.

**Note:** A builder makes a full-size copy of Otis's elevator and acts out the famous demonstration, standing on the platform while a helper cuts the rope. Children should never try anything like it.

### KEY TERMS

#### **elevator**

A box or platform that carries people or things up and down inside a building.

#### **safety brake**

A part that stops an elevator from falling if the rope breaks.

#### **skyscraper**

A very tall building.

#### **frame**

The inside framework of beams and columns that holds a building up.

### CORE IDEAS

**The story.** Long ago, buildings were only a few floors tall. People did not want to climb more stairs than that. There were lifts for carrying boxes, pulled up by ropes, but people were afraid to ride them. If the rope broke, the lift would crash down. In

1852 a mechanic named Elisha Otis was working in a factory in New York. He had to move heavy machines up to a higher floor, and he wanted to do it safely.

**How he figured it out.** Otis invented a **safety brake**. He put a strong spring at the top of the lift, held tight by the pull of the rope. Along each side of the shaft, he put wooden rails with teeth, like a saw. If the rope broke, the spring would snap open and push hooks into the teeth, and the lift would stop. In 1854, at a big fair in New York, Otis stood on his lift high above a crowd. Then he had the rope cut! The crowd gasped. But the lift stopped with a jerk and stayed put. People believed him, and soon elevators were carrying passengers.

**The physics.** Gravity always pulls an elevator down. The rope holds it up by pulling, which is called tension. Otis's brake turned the danger into a safety switch. As long as the rope pulls, the brake stays open. If the rope stops pulling, the brake catches at once. Engineers call this a fail-safe: when something goes wrong, the machine goes to a safe state.

**The engineering.** Safe elevators made tall buildings useful. Engineers then learned to build tall buildings with a strong **frame** of iron and steel beams, like the bones inside your body, instead of thick stone walls. In 1885 the Home Insurance Building in Chicago, designed by William Le Baron Jenney, was built with an iron and steel frame. Many people call it the first **skyscraper**. Today, elevators in tall buildings still have safety brakes, and inspectors check them every year.

## PICTURE STUDY



*The Home Insurance Building, Chicago, Unknown photographer, About the 1920s · Photograph · Chicago, Illinois*

Image: [Wikimedia Commons](#), public domain

This is the Home Insurance Building in Chicago, which many people call the first skyscraper. It was taken down in 1931, so photographs like this are how we know it today.

### Look closely

- Count the floors. How many can you see?
- Look at the rows of windows. Why can a steel-frame building have so many big windows?
- Find the street and the cars. How do they look next to the building?
- Find the taller building beside it. Skyscrapers soon grew taller and taller.

### Talk about it

1. Would people have wanted to work on the top floor without an elevator?
2. Why do tall buildings need a strong frame?
3. What safety parts would you put in a skyscraper?

**Safety first.** An adult should cut any skewers and use a sharp tool to poke holes. Keep fingers out from under the elevator cup when testing the catch.

## BUILD

### A Skyscraper with an Elevator

You will build a tall tower frame and an elevator that you lift with a crank. Then you will invent a safety catch that stops the elevator if you let go.

#### You will need

- A tall cereal box or two shoeboxes stacked, for the tower
- A pencil or a wooden dowel for the crank axle
- String, about 3 feet
- A small paper cup for the elevator car, and a few pennies for riders
- A strip of corrugated cardboard, with its bumpy inside showing, as a toothed rail
- Paper clips, tape and scissors
- Engineer's notebook

#### Steps

1. Have an adult cut a window down the front of the box so you can see inside. This is your elevator shaft.
2. Have an adult poke two holes near the top of the box, one on each side. Push the pencil through. This is the crank.
3. Punch two holes near the rim of the cup and tie on a string handle. Tie the long string to the handle and wind its other end around the pencil.
4. Turn the pencil to lift the cup. Count how many turns it takes to lift the cup to the top. Put 10 pennies in the cup and try again.
5. **Ask.** What happens if you let go of the crank? Try it. The cup falls!
6. **Invent a safety catch.** Tape the bumpy cardboard strip up the inside back wall of the shaft. Bend a paper clip into a hook and tape it to the back of the cup so it drags on the bumps. Can you make it slide up easily but catch when the cup starts to fall?
7. Test your catch five times with 10 pennies inside. Write how many times it caught.
8. **Improve.** Change the hook's shape or angle and test five more times.

### Tips

- A hook that points down and leans against the bumps works best, like Otis's hooks in the teeth.
- Tape the pencil so it turns but does not slide out.

### Check your work

- ☐ I can tell how Otis showed that his elevator was safe.
- ☐ I can tell what a safety brake does.
- ☐ I can tell why skyscrapers need a strong frame.

### ENGINEER'S NOTEBOOK

1. Draw your elevator and label the crank, string, car and safety catch.
2. Write how many times out of five your catch worked, before and after you improved it.
3. Draw a skyscraper frame with its beams and columns, before the walls go on.

**From history.** The first passenger elevator using Otis's safety brake went into a store in New York City in 1857. Otis's sons carried on his company, which still makes elevators and moving stairs all over the world.

### COMMON MISTAKES

- Thinking the rope is the only thing that keeps an elevator safe. The safety brake is a second protection.
- Making the hook so tight that the elevator cannot go up. It should slide up and catch on the way down.

**Make it a game • Otis Elevator Drop.** Be Elisha Otis at his show. Hold a toy on a string and say, all is safe, then tell your parent how he cut the rope and the safety brake held. Build a cardboard elevator and test your own brake with a clothespin. Say skyscraper, frame and elevator in a sentence.

## UNIT 3

# BUILDINGS

Jesus told a story about two builders. One built his house on the rock, and the other built on the sand. When the storm came, only the house on the rock stood. Every engineer who builds a building starts the same way: with the ground underneath. In this unit you will see what happened to a famous tower in Italy that was built on soft ground. You will learn how Inuit builders make strong snow domes with no wood at all, how castle builders lifted heavy stones with a giant wheel, and how a safe elevator made tall skyscrapers possible.

You will test towers on sand and on rock, load eggshell domes with books, compare paper columns of different shapes, and build a skyscraper frame with a working elevator. As always, guess first, test fairly, write it down, and make it better.

### PREREQUISITES

- Knows that triangles are strong and that arches push out at their feet (Unit 2)
- Knows what a wheel and axle and a lever are (Unit 1)
- Can count and record numbers in a simple table

### MASTERY CHECKLIST

- ☐ I can tell why a building needs a strong foundation, and tell what happened to the Leaning Tower of Pisa.
- ☐ I can tell how an igloo is built and why a dome is strong.
- ☐ I can tell how castle builders lifted heavy stones, and show which column shape is strongest.
- ☐ I can tell how Elisha Otis made elevators safe, and why that let people build skyscrapers.

### OPTIONAL KITS FOR THIS UNIT

- **KEVA Planks:** All ages. Plain wooden planks that stack without glue. Children can build towers, domes and castle walls and test how tall they can go. Fits Lessons 3.1–3.4.
- **LEGO Education:** Ages 6 and up for the early sets. Bricks, beams and simple gears for building towers, cranes and a crank-lifted elevator. Fits Lessons 3.3 and 3.4.

Not required. Every project in this unit can be built with household materials. School Launch has no ties to these companies.

## LESSONS IN THIS UNIT

**3.1 The Wise Builder: Foundations and the Leaning Tower** 2 sessions of 30–40 minutes

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**3.2 Domes and Igloos** 2 sessions of 30–40 minutes

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**3.3 Castles: Thick Walls, Round Towers and a Giant Wheel** 2 sessions of 30–40 minutes

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**3.4 Skyscrapers and Otis’s Safe Elevator** 2 sessions of 30–40 minutes

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## UNIT 3 REVIEW

A parent asks these questions aloud. Your child may answer by telling, pointing, drawing or showing with the builds from this unit. There are no points. Listen for understanding and praise careful answers.

1. Tell the story of the wise and foolish builders. Which house stood, and why?
2. Why does the Tower of Pisa lean? What did engineers do to help it?
3. Show me with a drawing how an igloo is built. Why is a dome strong?
4. How did castle builders lift heavy stones high up the wall?
5. Show me your three paper columns. Which held the most, and why?
6. What did Elisha Otis invent, and how did he show it was safe?

#### ANSWER KEY

1. The house on the rock stood, because its foundation was strong. The house on the sand fell.
2. The ground under one side is soft, and the foundation was not deep enough, so one side sank. Engineers took a little soil from under the high side so the tower leaned a bit less.
3. Snow blocks go around in a spiral, each leaning in more, until the last block closes the top. The weight spreads all around the dome and squeezes it, and snow is strong when squeezed.
4. With a treadwheel crane. People walked inside a giant wheel, which wound the rope around the axle and lifted the stone.
5. Usually the round one. It has no corners, so the weight spreads evenly.
6. A safety brake for elevators. He rode his lift high up and had the rope cut, and the brake caught and held it.

#### PORTFOLIO PIECE: A TOWER THAT STANDS

Build the tallest tower you can from paper, straws, tape and cardboard on a strong, wide foundation. Use round columns or triangles to make it strong. Test it three ways: put a book on top, blow on it with a fan or your breath, and tap the table. Improve it after each test, and show your family your tower and your notebook.

| LOOK FOR             | WHAT IT MEANS                                                       |
|----------------------|---------------------------------------------------------------------|
| <b>Foundation</b>    | Built a wide, firm base and could explain why it matters.           |
| <b>Strong shapes</b> | Used round columns, triangles or a dome, and could tell why.        |
| <b>Testing</b>       | Tested the tower three ways and wrote down what happened each time. |
| <b>Improving</b>     | Fixed the weak spot after a test and tried again.                   |

## UNIT 4

# ELECTRICITY

Electricity lights our homes, runs our refrigerators and charges our phones. But for most of history, people knew it only as the crackle when they stroked a cat's fur, or as lightning in the sky. In this unit you will meet the people who first learned to understand it and use it. William Gilbert studied the little sparks and pulls of static electricity. Alessandro Volta built the first battery. Samuel Morse used a switch to send messages along a wire. Joseph Henry wrapped wire around iron and made a magnet he could turn on and off.

You will rub balloons, build circuits with batteries, bulbs and clip leads, make your own switch and send a coded message, and build an electromagnet that picks up paper clips. In this course, electricity comes only from batteries. Never use the outlets in the wall.

### PREREQUISITES

- Knows how to make a fair test by changing one thing (Units 1–3)
- Can count to 50 and keep a tally
- Knows that magnets pull on iron things like paper clips

### MASTERY CHECKLIST

- ☐ I can show static electricity with a balloon and tell what William Gilbert discovered.
- ☐ I can build a circuit with a battery, wires and a bulb, and tell why it must be a closed loop.
- ☐ I can build a switch and tell how Samuel Morse used one to send messages.
- ☐ I can build an electromagnet and show that more turns of wire pick up more clips.
- ☐ I can tell the safety rules: batteries only, never the outlets in the wall.

## OPTIONAL KITS FOR THIS UNIT

- **Snap Circuits Jr. (Elenco):** Ages 8 and up, or younger with a parent. Parts snap onto a plastic grid with no soldering or loose wires, and it runs on AA batteries. Fits Lessons 4.2–4.4 and Unit 8.
- **KiwiCo Tinker Crate:** Ages 9 and up, but many crates suit a seven-year-old working with a parent. Some crates include simple battery circuits, switches and motors. Fits Lessons 4.2–4.4.

Not required. Every project in this unit can be built with household materials. School Launch has no ties to these companies.

## LESSONS IN THIS UNIT

|                                                              |                             |
|--------------------------------------------------------------|-----------------------------|
| <b>4.1 Static Electricity: William Gilbert and the Amber</b> | 2 sessions of 30–40 minutes |
| <b>4.2 Volta’s Battery and the Closed Circuit</b>            | 2 sessions of 30–40 minutes |
| <b>4.3 Switches and Samuel Morse’s Telegraph</b>             | 2 sessions of 30–40 minutes |
| <b>4.4 Joseph Henry’s Electromagnet</b>                      | 2 sessions of 30–40 minutes |

## UNIT 4 REVIEW

A parent asks these questions aloud. Your child may answer by telling, pointing, drawing or showing with the builds from this unit. There are no points. Listen for understanding and praise careful answers.

1. Show me static electricity with a balloon. What did William Gilbert find out?
2. Build a circuit that lights a bulb. Why must it be a closed loop?
3. What happened when you put two bulbs in series, and then took one out?
4. Show me your switch. What does a switch do?
5. What was the first message on Samuel Morse’s telegraph line?
6. Show me your electromagnet. How can you make it stronger? What is our big safety rule for electricity?

## ANSWER KEY

1. A rubbed balloon picks up paper bits or makes hair stand up. Gilbert found that many things, not only amber, can do this when rubbed.
2. Electricity must flow out of the battery, through the bulb and back. Any gap stops it.
3. Both glowed dimmer. Taking one out opened the loop, so the other went out too.
4. It opens and closes a gap in the circuit to turn the light off and on.
5. “What hath God wrought!”
6. Add more turns of wire (or more batteries). Use only batteries, never the outlets in the wall.

## PORTFOLIO PIECE: A SIGNAL BOX

Build a signal box in a shoebox: a battery circuit with a switch you can press on the lid and a bulb that shines through a hole. Send three messages in Morse code to a family member, and have them write down what they received. Show your box, your circuit drawing and your message results.

| LOOK FOR               | WHAT IT MEANS                                                                |
|------------------------|------------------------------------------------------------------------------|
| <b>Working circuit</b> | The bulb lights when the switch is pressed and goes out when it is let go.   |
| <b>Explaining</b>      | Could show the loop of the circuit and tell what the switch does.            |
| <b>Messages</b>        | Sent three messages and recorded how many were received correctly.           |
| <b>Safety</b>          | Used batteries only, unclipped them when finished, and told the safety rule. |

## 4.1 STATIC ELECTRICITY: WILLIAM GILBERT AND THE AMBER

### OBJECTIVES

- Show static electricity with a balloon, a comb and bits of paper.
- Tell what William Gilbert discovered about rubbing things.
- Test which rubbed objects pick up the most bits of paper.

**Warm-up.** Rub a balloon on your hair or on a wool sweater. Hold it near your hair. What happens? Now hold it near a wall and let go. What do you notice?

### WATCH

#### 5 Awesome Static Electricity Experiments for Kids

TheDadLab · 3:21

<https://www.youtube.com/watch?v=YZHJcQK4Nig>

### WHEN TO WATCH

Before the build. Pick one of the experiments to try after yours.

### KEY TERMS

#### **static electricity**

Electricity that builds up on the outside of things when they are rubbed together.

#### **attract**

To pull toward.

#### **repel**

To push away.

#### **amber**

A golden stone made from old tree sap. When rubbed, it picks up bits of straw.

### CORE IDEAS

**The story.** More than two thousand years ago, people in Greece noticed something strange. When they rubbed a piece of golden **amber** with wool, it could pick up bits of straw and feathers. The Greek word for amber was *elektron*. That is where our word electricity comes from.

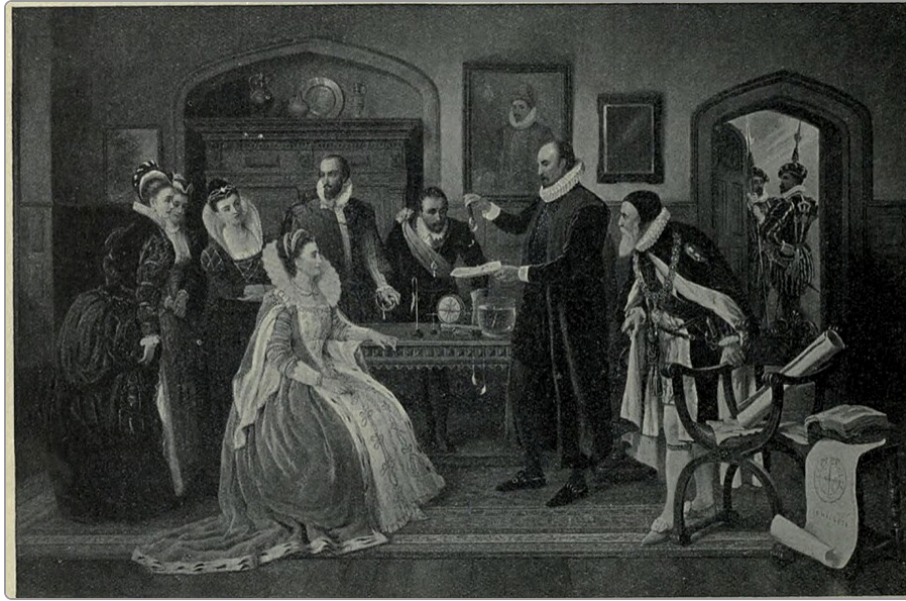
**How he figured it out.** About four hundred years ago in England lived a doctor named William Gilbert. He took care of Queen Elizabeth. He loved to test things.

People believed that only amber could do the straw trick. Gilbert did not just believe it. He rubbed glass, jewels, sulfur and wax, one after another. Many of them worked! To see the pull even when it was very weak, he made a little needle that could turn on a point, like a compass needle. When he brought a rubbed object near, the needle swung toward it. In the year 1600 he wrote a book about all his tests, and he gave a new name to things that act like amber: “electric.”

**The physics.** Everything is made of tiny bits too small to see, and some of them carry electric charge. When you rub two things together, some charge rubs off one and onto the other. Now they are charged. A charged balloon **attracts**, or pulls on, small bits of paper and your hair. Two balloons charged the same way **repel**, or push each other away. This is called **static electricity**, because the charge stays put instead of flowing.

**The engineering.** Static electricity can be a problem. It makes clothes cling and gives you a little shock from a doorknob. Engineers who build computers wear special straps so a tiny spark does not harm the parts. But engineers also put static to work. Copy machines and laser printers use static electricity to pull black powder onto paper in the shape of letters.

## PICTURE STUDY



*William Gilbert Shows His Experiments to Queen Elizabeth*, Arthur Ackland Hunt, Late 1800s · Painting (reproduced as a print) · Painted in England

Image: [Wikimedia Commons](#), public domain

Many years after Gilbert lived, an artist imagined what it looked like when the doctor showed the Queen his experiments. Look for the tools of an experimenter.

### Look closely

- Find William Gilbert. What is he holding up?
- Find the table. What tools or objects can you see on it?
- Find the Queen. Does she look interested?
- Look at the faces of the people watching. Who looks curious?

### Talk about it

1. Why do you think the Queen wanted to see Gilbert's experiments?
2. Gilbert tested many things instead of just believing what people said. Why is that a good habit for an engineer?

**Safety first.** Electricity for every build in this course comes from batteries only. Never put anything into the outlets in the wall, and never touch a power cord that is frayed or broken.

## BUILD

### Which Rubbed Thing Is Strongest?

You will rub different things with wool and see how many tiny bits of paper each one picks up. Then you will build Gilbert's turning needle.

#### You will need

- A balloon, a plastic comb, a plastic ruler and a wooden spoon or pencil
- A wool sock or sweater
- Tissue paper torn into about 50 tiny bits, smaller than your fingernail
- A strip of aluminum foil about 4 inches long, a pushpin and a small ball of clay
- Engineer's notebook

#### Steps

1. Spread the paper bits on the table.
2. **Predict.** Which thing will pick up the most bits? Write your guess.
3. Rub the balloon on the wool ten times. Hold it just above the paper bits for three seconds. Count how many bits stick to it. Write the number.
4. Clean off the bits. Rub the comb ten times and test it the same way. Then the ruler, then the wooden spoon.
5. Make a table: object, number of bits. Which one worked best? Which did not work at all?
6. **Gilbert's needle.** Stick the pushpin, point up, into the clay. Fold the foil strip in half the long way, then press a small dent in its middle and balance it on the pin point so it can spin.
7. Bring each rubbed object near one end of the foil without touching it. Does the needle turn? Which object makes it swing from farthest away?
8. **Improve.** Try rubbing 20 times instead of 10, or try a different cloth. Test one change at a time.

#### Tips

- Static works best on a dry day. On a damp day, it may be weak.

- Rub the same number of times for each object, so the test is fair.

#### Check your work

- ☐ I can show static electricity with a balloon.
- ☐ I can tell what William Gilbert discovered.
- ☐ I can tell which object picked up the most bits in my test.

#### ENGINEER'S NOTEBOOK

1. Draw the balloon picking up paper bits. Draw little arrows to show the pull.
2. Fill in your table of objects and bits picked up. Circle the winner.
3. Draw Gilbert's turning needle and label the pin, the foil and the rubbed object.

**From history.** Gilbert's book was called *De Magnete*, which is Latin for "On the Magnet." Most of it is about magnets and the earth, which he showed acts like one giant magnet. That is why a compass needle points north.

#### COMMON MISTAKES

- Touching the paper bits with the balloon. Hold it just above them.
- Rubbing some things more than others. Keep the rubbing the same.

**Make it a game • Static Strength Ranking.** Rub a balloon, a comb and a plastic spoon on wool. Hold each over tiny paper bits and count how many it lifts. Predict the ranking before the test, then write it down. Say attract and repel. Tell your parent what William Gilbert learned from amber, and what rubbing does.

## 4.2 VOLTA’S BATTERY AND THE CLOSED CIRCUIT

### OBJECTIVES

- Tell how Alessandro Volta made the first battery.
- Build a circuit with a battery, wires and a bulb, and explain why it must be a closed loop.
- Test what happens to the brightness when two bulbs are in a line.

**Warm-up.** Look at a flashlight with a grown-up. Find the batteries, the bulb and the button. Where do you think the electricity goes when you press the button?

### WATCH

#### The Power of Circuits! | Technology for Kids | SciShow Kids

SciShow Kids · 4:42

<https://www.youtube.com/watch?v=HOFp8bHTN30>

### WHEN TO WATCH

After the physics paragraph, before the build.

### BACKUP VIDEO

#### Simple Circuits | Science for Kids

Little School · 3:34

<https://www.youtube.com/watch?v=45E2NmoBj-8>

If your child wants to see the circuit loop again.

### KEY TERMS

#### **battery**

A container that stores energy and pushes electricity around a circuit.

#### **circuit**

A complete path, like a loop, that electricity flows around.

#### **closed circuit**

A loop with no gaps. Electricity flows and the bulb lights.

#### **open circuit**

A loop with a gap. Electricity stops and the bulb goes dark.

## **series**

Parts connected one after another in a single loop.

### **CORE IDEAS**

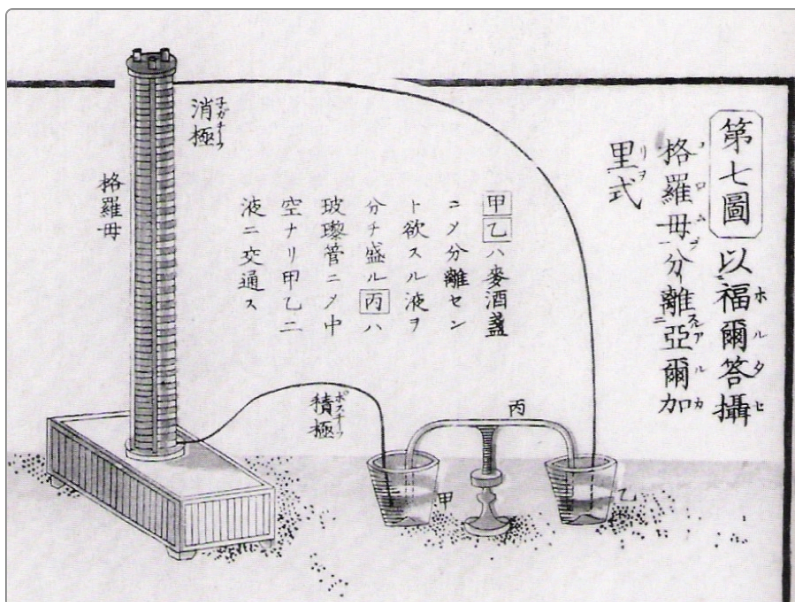
**The story.** About 225 years ago in Italy lived a teacher named Alessandro Volta. He was curious about electricity. Static electricity gave quick sparks, but nobody knew how to make electricity flow steadily, like water in a stream. Volta wanted to find a way.

**How he figured it out.** Volta tried putting two different metals together with something wet between them. He made a tall stack of little disks: a zinc disk, a copper disk, a piece of cloth soaked in salt water, and then zinc, copper and cloth again, over and over. When he touched a wire to the top and the bottom of the stack, electricity flowed through the wire, and it kept flowing. In the year 1800 he wrote about it. His stack was called a **pile**, and it was the first **battery**. Volta was a faithful Christian all his life.

**The physics.** A battery has two ends, marked plus (+) and minus (-). Electricity flows out one end, through the wires and the bulb, and back into the other end. The path must be a complete loop. That loop is called a **circuit**. If there is any gap, the electricity stops, and the bulb goes dark. That is an **open circuit**. When the loop is complete, it is a **closed circuit**.

**The engineering.** When two bulbs are put one after the other in a single loop, they are in **series**. The battery's push is shared, so both bulbs glow more dimly. And if one bulb goes out, it breaks the loop, so the other goes out too. Old strings of Christmas tree lights were made this way: when one bulb broke, the whole string went dark! Engineers learned to wire lights in other ways so that one bad bulb does not turn off the rest.

## PICTURE STUDY



A Voltaic Pile in a Japanese Science Book, Udagawa Yōan, 1837–1847 · Woodblock-printed book illustration · From *Seimi Kaisō*, the first chemistry book written in Japanese

Image: [Wikimedia Commons](#), public domain

News of Volta's battery traveled all around the world. A Japanese scientist drew this picture of a Volta pile in his science book. Follow the wires and you will find a complete circuit.

### Look closely

- Find the tall stack of disks. That is Volta's pile.
- Follow the wire from the top of the pile. Where does it go?
- Follow the other wire from the bottom of the pile. Does the path make a complete loop?
- Find the Japanese writing. What do you think the labels might say?

### Talk about it

1. What would happen if one wire were unhooked?
2. Why do you think scientists in Japan wanted to learn about Volta's pile?

**Safety first.** Use only AA, C or D batteries in holders. Never connect a bare wire straight from one end of a battery to the other with nothing else in the loop. It makes a short circuit, and the wire and battery get hot. Never use the outlets in the wall.

## BUILD

### Light the Bulb: Closed Loops and Bulbs in Series

You will build a circuit to light a small bulb. Then you will break the loop on purpose, and then add a second bulb to see what happens.

#### You will need

- One D-cell battery in a holder (or two AA batteries in a holder)
- Two small flashlight bulbs (about 1.5 to 3 volts) in bulb holders
- Three or four alligator clip leads
- Some things to test: a paper clip, a craft stick, a foil strip, a rubber band, a coin
- Engineer's notebook

#### Steps

1. Clip one lead from the + end of the battery holder to one side of the bulb holder.
2. Clip a second lead from the other side of the bulb holder back to the – end of the battery. Does the bulb light? You made a closed circuit!
3. Unclip one lead. What happens? You made an open circuit.
4. **Test materials.** Leave a gap in the loop and bridge it with each test object, one at a time. Write which ones light the bulb (conductors) and which do not (insulators).
5. **Predict.** If you add a second bulb in the same loop, will the bulbs be brighter or dimmer? Write your guess.
6. Add the second bulb in series: battery, bulb, bulb, back to the battery. Compare its brightness to one bulb alone.
7. Unscrew one of the two bulbs. What happens to the other one? Write what you see.
8. **Improve.** Add a second battery in its holder (+ of one to – of the other). What happens to the brightness of the two bulbs?

#### Tips

- If a bulb does not light, check that it is screwed in tightly and that each clip bites on bare metal.
- Take the batteries out when you finish.

#### Check your work

- ☐ I can build a closed circuit that lights a bulb.
- ☐ I can tell the difference between an open and a closed circuit.
- ☐ I can tell what happened when I put two bulbs in series.

#### ENGINEER'S NOTEBOOK

1. Draw your circuit as a loop. Draw arrows to show electricity going around it.
2. Make two lists: conductors and insulators.
3. Draw one bulb and two bulbs in series. Color how bright each one was.

**From history.** The unit we use to measure the push of a battery, the volt, is named after Alessandro Volta. A AA battery gives 1.5 volts.

#### COMMON MISTAKES

- Leaving a gap in the loop. Electricity needs a complete path.
- Clipping both wires to the same end of the battery. One must go to +, the other to -.

**Make it a game • Closed Loop Race.** Light a bulb with a battery and wire, then break the loop and say open circuit. Close it, and say closed circuit. Set a timer for one minute and see how many times you can break and fix the loop. Tell your parent how Volta made the first battery. Explain why the loop must be complete.

**Scripture.** “Ye are the light of the world. A city that is set on an hill cannot be hid. Neither do men light a candle, and put it under a bushel, but on a candlestick; and it giveth light unto all that are in the house.” (Matthew 5:14-15, KJV)

Jesus said a light is meant to shine where everyone can see it. Engineers who bring light to homes help people, and Jesus calls us to let our good works shine too.

## 4.3 SWITCHES AND SAMUEL MORSE'S TELEGRAPH

### OBJECTIVES

- Explain that a switch opens and closes a circuit.
- Tell how Samuel Morse sent messages along a wire with a switch and a code.
- Build a switch and send a short message in Morse code with a light.

**Warm-up.** Flip a light switch in your house on and off with a grown-up watching.

What do you think happens inside the switch? Now tap a short tap and a long tap on the table. Could you send a message with just those two taps?

### WATCH

#### Samuel Morse and The Telegraph | History For Kids

Bedtime History · 3:59

<https://www.youtube.com/watch?v=CjVxVd9rWYc>

### WHEN TO WATCH

After the story.

### BACKUP VIDEO

#### Morse Code Explained

Staten Island Children's Museum · 1:50

<https://www.youtube.com/watch?v=9kGvhjSX9h4>

Before the build, to hear what dots and dashes sound like.

### KEY TERMS

#### **switch**

A part that opens or closes a gap in a circuit, to turn something off or on.

#### **telegraph**

A machine that sends messages over a long wire using electricity.

#### **Morse code**

A code that uses short and long signals, called dots and dashes, to stand for letters.

#### **key**

The switch on a telegraph that the operator taps to send dots and dashes.

## CORE IDEAS

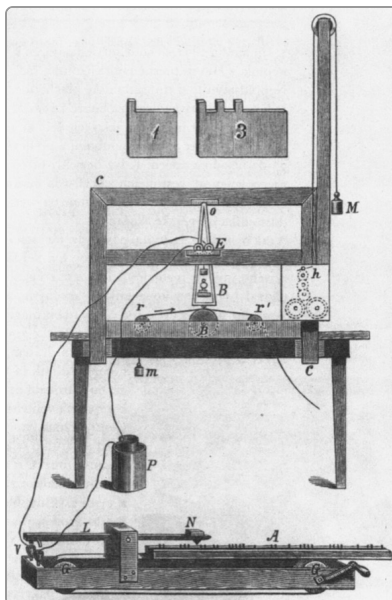
**The story.** Samuel Morse was a painter in America. In his day, letters traveled by horse and took many days. Once, while Morse was away painting in another city, sad news from home reached him too late for him to hurry back. Morse wished there were a faster way to send news. A few years later, on a ship coming home from Europe, he heard other passengers talking about electricity and magnets. He thought: if electricity can travel along a wire in an instant, it could carry a message.

**How he figured it out.** Morse worked on his idea for years with helpers, especially Alfred Vail. They needed two things. First, a way to turn the electricity on and off quickly. They used a **switch** called a **key**: press it down, and the circuit closes; let it up, and the circuit opens. Second, they needed a code. They made up **Morse code**, where each letter is a pattern of short signals (dots) and long signals (dashes). The letter E, used most often, got the shortest code: one dot. Congress paid for a test line of wire on poles from Washington to Baltimore, about 40 miles. On May 24, 1844, Morse tapped out the first message on it, a Bible verse chosen by a young friend: “What hath God wrought!”

**The physics.** A **switch** is a gap in a circuit that you can open or close. When the two metal parts of the switch touch, the loop is closed and electricity flows. When they move apart, the loop is open and electricity stops. A light switch, a doorbell button and a keyboard key are all switches.

**The engineering.** Within a few years, telegraph wires stretched across the country, and later under the ocean. News that had taken weeks now took minutes. Engineers had to solve many problems: how to hold up the wires on poles, how to keep rain from leaking the electricity away, and how to boost the signal over long distances. Every phone and computer today still uses the same simple idea: switches turning on and off very fast to send a message.

## PICTURE STUDY



*Morse's Telegraph*, Unknown engraver, 1800s · Engraving · From a nineteenth-century book

Image: [Wikimedia Commons](#), public domain

This old engraving shows Morse's early telegraph. At the bottom is the sender. At the top is the receiver, which marked the message on a moving strip of paper.

### Look closely

- Find the battery. Follow the wires from it.
- Find the long strip at the bottom with notches. Each notch opened or closed the circuit, like a switch.
- Find the frame at the top with a pencil that marks a strip of paper.
- Find the weight hanging down. What might it do?

### Talk about it

1. How does a switch help send a message?
2. Why was a telegraph so much faster than a letter?
3. How is this machine like a phone today?

**Safety first.** Use only batteries in holders. If any wire or battery feels hot, unclip it right away and tell a grown-up.

## BUILD

### A Paper-Clip Switch and a Light Telegraph

You will build your own switch from cardboard, brass paper fasteners and a paper clip. Then you will add it to your bulb circuit and flash a message in Morse code.

#### You will need

- Your battery, bulb and clip leads from Lesson 4.2
- A piece of cardboard about the size of your hand
- Two brass paper fasteners and one metal paper clip
- A Morse code chart (written below)
- A partner and engineer's notebook

#### Steps

1. Push two brass fasteners through the cardboard about 1 inch apart. Spread their legs flat on the back.
2. Hook the paper clip around one fastener so it can swing over and touch the other fastener. This is your switch.
3. Clip one lead from the battery to the first fastener, and one lead from the second fastener to the bulb. Finish the loop from the bulb back to the battery.
4. Swing the paper clip onto the second fastener. Does the bulb light? Swing it off. Does the bulb go out?
5. Practice short flashes (dots) and long flashes (dashes). Here are some letters:  
S = dot dot dot. O = dash dash dash. H = dot dot dot dot. I = dot dot. E = dot. T = dash.
6. Send HI to your partner. Then send SOS, the famous call for help. Your partner writes down the dots and dashes and figures out the message.
7. Count how many messages your partner got right out of five.
8. **Improve.** Make your switch better: bend the paper clip so it springs back up by itself, like a real telegraph key. Did it make sending easier and faster?

#### Tips

- Make dashes about three times as long as dots, and leave a little pause between letters.
- If the bulb flickers, press the fasteners flat so the clip touches them firmly.

#### Check your work

- ☐ I can show how my switch opens and closes the circuit.
- ☐ I can tell the story of Morse's first message.
- ☐ I can send HI and SOS in Morse code.

#### ENGINEER'S NOTEBOOK

1. Draw your circuit with the switch. Draw it once open and once closed.
2. Write your name in dots and dashes. (Ask a grown-up to help you find a full Morse code chart.)
3. Write how many messages your partner got right, before and after you improved your switch.

**From history.** The young friend who chose the first message was Annie Ellsworth, the daughter of the man in charge of the U.S. Patent Office. She took the words from the Bible, from the book of Numbers. Morse later wrote that the words gave the glory to God, where it belonged.

#### COMMON MISTAKES

- Thinking the switch makes the electricity. It only opens and closes the path.
- Rushing the code. Pauses between letters matter.

**Make it a game • Morse Message Switch.** Make a paper-clip switch to blink a light. Send your parent a short Morse message, such as dot dot dash, with long and short blinks, and let them write it down. Switch roles. Say the words switch, telegraph and key. Tell how Samuel Morse sent messages along a wire with a code.

**Scripture.** “according to this time it shall be said of Jacob and of Israel, What hath God wrought!” (Numbers 23:23, KJV)

Samuel Morse sent these words as the first message on his telegraph line. He wanted people to remember that the wonders of electricity come from God.

## 4.4 JOSEPH HENRY’S ELECTROMAGNET

### OBJECTIVES

- Tell how Joseph Henry made powerful electromagnets.
- Explain that electricity flowing in a coil of wire makes a magnet that can be turned on and off.
- Test how the number of turns of wire changes how many paper clips an electromagnet picks up.

**Warm-up.** Hold a magnet near a pile of paper clips. Count how many it picks up. Now try to make the magnet let go of the clips without pulling them off with your fingers. Can you? Wouldn’t it be handy if you could turn a magnet off?

### WATCH

#### How to make an Electromagnet!

Super Science with Simon · 4:31

<https://www.youtube.com/watch?v=v8mPY1Ee32s>

#### WHEN TO WATCH

Before the build.

**Note:** The presenter uses a soldering iron near the end. Only an adult should ever use one; your child’s build does not need it.

### BACKUP VIDEO

#### How to Make an Electromagnet for Kids | STEAM DIY | KiwiCo

KiwiCo · 1:38

[https://www.youtube.com/watch?v=\\_odHVX4mUAQ](https://www.youtube.com/watch?v=_odHVX4mUAQ)

A short step-by-step to watch just before you wind your nail.

### KEY TERMS

#### **electromagnet**

A magnet made by electricity flowing through a coil of wire. It turns off when the electricity stops.

#### **coil**

Wire wound around and around in loops.

**iron core**

The iron bar or nail inside the coil that makes the magnet much stronger.

**insulated wire**

Wire with a thin coating that keeps the electricity inside the wire.

**CORE IDEAS**

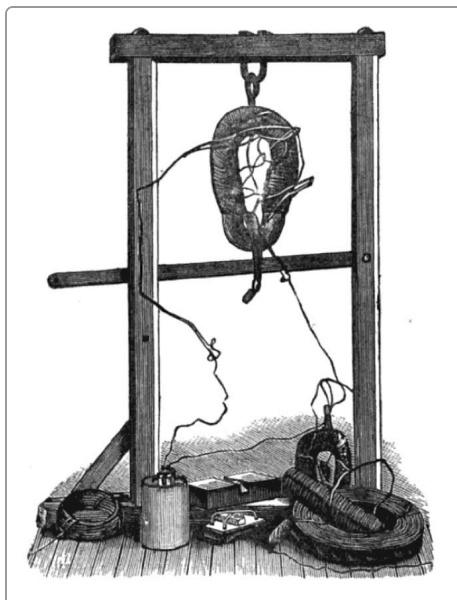
**The story.** In 1820, a teacher in Denmark named Hans Christian Ørsted noticed that a wire carrying electricity made a compass needle swing. Electricity could make magnetism! Soon after, a schoolteacher in Albany, New York, named Joseph Henry began to experiment with this idea. Henry was a careful, humble man and a devout Christian, and he loved to teach.

**How he figured it out.** Other people had wrapped a few loops of bare wire around an iron bar, but their magnets were weak. Henry found out why. Bare wires touching each other let the electricity take a shortcut. So Henry wrapped his wire in silk thread, to **insulate** it. Now he could wind many, many turns close together without the wires leaking into each other. Each new turn made the magnet stronger. In 1831 he built an electromagnet for Yale College that could lift more than 2,000 pounds, as heavy as a small car! And when he turned off the electricity, it let go at once.

**The physics.** When electricity flows through a wire, it makes a weak magnetic pull around the wire. Wind the wire into a **coil**, and all the loops add up. Put an **iron core** inside, and the iron becomes a strong magnet too. More turns of wire make a stronger magnet. More electricity makes a stronger magnet. Stop the electricity, and the magnet turns off.

**The engineering.** Electromagnets are everywhere. They are in doorbells, speakers, electric motors and the telegraph you learned about in Lesson 4.3. In scrapyards, giant electromagnets on cranes lift whole cars and drop them where they belong. Joseph Henry later became the first leader of the Smithsonian Institution, where he helped many other scientists with their work.

## PICTURE STUDY



*Joseph Henry's Electromagnet*, Unknown engraver, About 1880 · Wood engraving · From a nineteenth-century book

Image: [Wikimedia Commons](#), public domain

This old engraving shows one of Joseph Henry's great electromagnets hanging in a wooden frame. Look for the parts you will build yourself today.

### Look closely

- Find the horseshoe-shaped iron core. What is wrapped around it?
- Follow the wires down. What do they connect to?
- Find the heavy frame. Why does it need to be so strong?
- Find the bar under the magnet. What do you think it held up?

### Talk about it

1. Why did Henry cover his wire with silk?
2. What happens to an electromagnet when the electricity is turned off?
3. Where might you find an electromagnet in your house?

**Safety first.** Connect the battery only for a few seconds at a time. The wire and battery can get warm. If they feel hot, unclip them. An adult should sand the ends of the wire. Use batteries only.

## BUILD

### The Paper Clip Electromagnet Test

You will wrap wire around a nail to make an electromagnet. Then you will find out whether more turns of wire pick up more paper clips.

#### You will need

- A large iron nail, about 3 inches long (not stainless steel)
- About 6 feet of thin insulated wire, such as magnet wire or thin hookup wire, with the ends stripped or sanded by an adult
- A D-cell battery in a holder and two clip leads
- A small box of steel paper clips
- Masking tape and engineer's notebook

#### Steps

1. Leave about 8 inches of wire loose at one end. Wind the wire neatly around the nail 10 times, all in the same direction. Tape it so it does not unwind.
2. Clip the two wire ends to the battery holder. Touch the tip of the nail to the paper clips and lift. Count the clips. Unclip the battery. Do the clips fall?
3. **Predict.** How many clips will you lift with 20 turns? With 30? Write your guesses.
4. Wind 10 more turns on top (20 in all). Test and count. Then wind 10 more (30 in all). Test and count.
5. Test each one three times and write all the numbers in a table.
6. Look at your table. Did more turns lift more clips?
7. **Improve.** Try something new, such as adding a second battery in its holder or using a thicker nail. Change only one thing and test again.

#### Tips

- Always wind in the same direction around the nail.
- Use clips from the same box, so they all weigh the same.

#### Check your work

- ☐ I can build an electromagnet and turn it on and off.

- ☐ I can tell what my test showed about more turns of wire.
- ☐ I can tell how Joseph Henry made his magnets so strong.

#### ENGINEER'S NOTEBOOK

1. Draw your electromagnet and label the nail, the coil, the battery and the clips.
2. Make a bar graph: 10 turns, 20 turns, 30 turns, and how many clips each lifted.
3. Draw something in your house that might have an electromagnet inside.

**From history.** In 1831 Joseph Henry also used an electromagnet to ring a bell at the far end of a long wire strung around his classroom. That was a big step toward the telegraph. Later, Henry gave Samuel Morse helpful advice about how to send signals over long wires.

#### COMMON MISTAKES

- Leaving the battery connected for a long time. It gets warm and runs down fast.
- Using a stainless steel nail or an aluminum one. It must be iron or plain steel.

**Make it a game • Magnet On or Off.** Wrap insulated wire around an iron nail and touch it to a battery with a grown-up. Count how many paper clips it briefly picks up. Take the wire off to turn it off and watch them drop. Say electromagnet, coil and iron core. Tell your parent how Joseph Henry made powerful electromagnets. Beat your clip count.

## UNIT 4

# ELECTRICITY

Electricity lights our homes, runs our refrigerators and charges our phones. But for most of history, people knew it only as the crackle when they stroked a cat's fur, or as lightning in the sky. In this unit you will meet the people who first learned to understand it and use it. William Gilbert studied the little sparks and pulls of static electricity. Alessandro Volta built the first battery. Samuel Morse used a switch to send messages along a wire. Joseph Henry wrapped wire around iron and made a magnet he could turn on and off.

You will rub balloons, build circuits with batteries, bulbs and clip leads, make your own switch and send a coded message, and build an electromagnet that picks up paper clips. In this course, electricity comes only from batteries. Never use the outlets in the wall.

### PREREQUISITES

- Knows how to make a fair test by changing one thing (Units 1–3)
- Can count to 50 and keep a tally
- Knows that magnets pull on iron things like paper clips

### MASTERY CHECKLIST

- ☐ I can show static electricity with a balloon and tell what William Gilbert discovered.
- ☐ I can build a circuit with a battery, wires and a bulb, and tell why it must be a closed loop.
- ☐ I can build a switch and tell how Samuel Morse used one to send messages.
- ☐ I can build an electromagnet and show that more turns of wire pick up more clips.
- ☐ I can tell the safety rules: batteries only, never the outlets in the wall.

## OPTIONAL KITS FOR THIS UNIT

- **Snap Circuits Jr. (Elenco):** Ages 8 and up, or younger with a parent. Parts snap onto a plastic grid with no soldering or loose wires, and it runs on AA batteries. Fits Lessons 4.2–4.4 and Unit 8.
- **KiwiCo Tinker Crate:** Ages 9 and up, but many crates suit a seven-year-old working with a parent. Some crates include simple battery circuits, switches and motors. Fits Lessons 4.2–4.4.

Not required. Every project in this unit can be built with household materials. School Launch has no ties to these companies.

## LESSONS IN THIS UNIT

|                                                              |                             |
|--------------------------------------------------------------|-----------------------------|
| <b>4.1 Static Electricity: William Gilbert and the Amber</b> | 2 sessions of 30–40 minutes |
| <b>4.2 Volta’s Battery and the Closed Circuit</b>            | 2 sessions of 30–40 minutes |
| <b>4.3 Switches and Samuel Morse’s Telegraph</b>             | 2 sessions of 30–40 minutes |
| <b>4.4 Joseph Henry’s Electromagnet</b>                      | 2 sessions of 30–40 minutes |

## UNIT 4 REVIEW

A parent asks these questions aloud. Your child may answer by telling, pointing, drawing or showing with the builds from this unit. There are no points. Listen for understanding and praise careful answers.

1. Show me static electricity with a balloon. What did William Gilbert find out?
2. Build a circuit that lights a bulb. Why must it be a closed loop?
3. What happened when you put two bulbs in series, and then took one out?
4. Show me your switch. What does a switch do?
5. What was the first message on Samuel Morse’s telegraph line?
6. Show me your electromagnet. How can you make it stronger? What is our big safety rule for electricity?

## ANSWER KEY

1. A rubbed balloon picks up paper bits or makes hair stand up. Gilbert found that many things, not only amber, can do this when rubbed.
2. Electricity must flow out of the battery, through the bulb and back. Any gap stops it.
3. Both glowed dimmer. Taking one out opened the loop, so the other went out too.
4. It opens and closes a gap in the circuit to turn the light off and on.
5. “What hath God wrought!”
6. Add more turns of wire (or more batteries). Use only batteries, never the outlets in the wall.

## PORTFOLIO PIECE: A SIGNAL BOX

Build a signal box in a shoebox: a battery circuit with a switch you can press on the lid and a bulb that shines through a hole. Send three messages in Morse code to a family member, and have them write down what they received. Show your box, your circuit drawing and your message results.

| LOOK FOR               | WHAT IT MEANS                                                                |
|------------------------|------------------------------------------------------------------------------|
| <b>Working circuit</b> | The bulb lights when the switch is pressed and goes out when it is let go.   |
| <b>Explaining</b>      | Could show the loop of the circuit and tell what the switch does.            |
| <b>Messages</b>        | Sent three messages and recorded how many were received correctly.           |
| <b>Safety</b>          | Used batteries only, unclipped them when finished, and told the safety rule. |

## UNIT 5

# WATER, POWER AND ROADS

When you turn on a faucet, clean water comes out. When you flip a switch, a light comes on. When you ride in the car, a smooth road carries you to church or the store. These are called public utilities and public works, and engineers designed every one. In this unit you will follow the water that New York City brought down from the hills in 1842, see how wells and pumps lift water out of the ground, learn how mills and dams turn falling water into power, and find out how a Scottish road builder made roads that stay dry.

You will build a bottle water tower, a pump, a waterwheel and a model road, and test each one. Many people work every day, often out of sight, to keep water, power and roads safe for us. Loving our neighbor includes thanking them, and someday perhaps being one of them.

### PREREQUISITES

- Knows that gravity pulls things down (Unit 1)
- Knows what a wheel and axle is (Unit 1)
- Can measure with a ruler or tape measure and record numbers

### MASTERY CHECKLIST

- ☐ I can tell how water travels from the rain to my faucet, and why water towers are tall.
- ☐ I can tell how a well and a hand pump bring up water from under the ground.
- ☐ I can tell how a waterwheel and a dam turn falling water into power.
- ☐ I can tell how John McAdam made roads that stay dry, and what traffic lights are for.
- ☐ I can name people who keep our water, power and roads working, and the safety rules for them.

## OPTIONAL KITS FOR THIS UNIT

- **Thames & Kosmos science kits:** Ages vary by kit. Some of their kits build working waterwheels and water-powered machines. Fits Lessons 5.1–5.3.
- **Snap Circuits Jr. (Elenco):** Ages 8 and up, or younger with a parent. Can be used to build a battery-powered light that blinks like a signal. Fits Lesson 5.4 and Unit 4.

Not required. Every project in this unit can be built with household materials. School Launch has no ties to these companies.

## LESSONS IN THIS UNIT

|                                                          |                             |
|----------------------------------------------------------|-----------------------------|
| <b>5.1 From the Rain to the Tap: The Croton Aqueduct</b> | 2 sessions of 30–40 minutes |
| <b>5.2 Wells and Pumps</b>                               | 2 sessions of 30–40 minutes |
| <b>5.3 Waterwheels and Dams Make Power</b>               | 2 sessions of 30–40 minutes |
| <b>5.4 Roads, Signs and Traffic Lights</b>               | 2 sessions of 30–40 minutes |

## UNIT 5 REVIEW

A parent asks these questions aloud. Your child may answer by telling, pointing, drawing or showing with the builds from this unit. There are no points. Listen for understanding and praise careful answers.

1. Draw the trip a drop of water takes from the rain to your faucet.
2. Show me with the bottle: why are water towers tall?
3. Where does well water come from, and how does a hand pump bring it up?
4. How can falling water make electricity?
5. Show me your McAdam road. Why is the middle higher?
6. Name two people who keep our water, power or roads working, and one safety rule we learned.

#### ANSWER KEY

1. Rain falls into a river, lake or the ground; it is collected (a reservoir), cleaned at a treatment plant, pumped up to a water tower, and flows through pipes to the faucet.
2. Water up high pushes harder (more pressure), so it can flow through the pipes into houses.
3. From groundwater in the spaces between sand and rocks. The pump's plunger lifts the water, and a valve keeps it from falling back.
4. A dam holds water up high. The water falls and spins a turbine, which turns a generator that makes electricity.
5. So rain runs off to the sides and the ditches, and the road stays firm and dry.
6. Any two, such as water workers, lineworkers, road crews or engineers. A safety rule such as: stay away from storm drains, manholes and downed power lines; cross at a crosswalk.

#### PORTFOLIO PIECE: A THANK-YOU MAP OF OUR TOWN

Draw a big map of your house and neighborhood that shows where your water comes from, where the power lines run and which roads you travel. Add your bottle water tower and model road (or photographs of them) with your test results. Then write or tell a thank-you note to one group of workers who keep these things running, and deliver it if you can.

| LOOK FOR                | WHAT IT MEANS                                                             |
|-------------------------|---------------------------------------------------------------------------|
| <b>Water</b>            | Showed the path of water to the house and told why water towers are tall. |
| <b>Power and roads</b>  | Showed where power comes from and told why roads have a crown.            |
| <b>Builds and tests</b> | Included the water tower and road test results.                           |
| <b>Thankfulness</b>     | Wrote or told a thank-you to workers who keep the town running.           |

## 5.1 FROM THE RAIN TO THE TAP: THE CROTON AQUEDUCT

### OBJECTIVES

- Tell how New York City brought clean water from far away in 1842.
- Explain that water flows downhill, and that water from higher up pushes harder.
- Build a bottle water tower and test how the height of the water changes the squirt.

**Warm-up.** Turn on a faucet and watch the water. Where do you think it was yesterday? Where was it last month? Draw a quick picture of your guess.

### WATCH

#### How Does Water Get to Your House?

SciShow Kids · 3:36

<https://www.youtube.com/watch?v=cGi4PugN4qY>

### WHEN TO WATCH

After the warm-up, before the story.

### BACKUP VIDEO

#### How it Works: Water Tower

City of Bloomington, Minnesota · 2:20

<https://www.youtube.com/watch?v=ZI8WOzqHl7w>

With the engineering paragraph, to see inside a real water tower.

### KEY TERMS

#### **aqueduct**

A long channel or pipe that carries water from far away.

#### **reservoir**

A big lake or tank where water is stored.

#### **water tower**

A tall tank that holds water up high so it pushes hard through the pipes.

#### **pressure**

How hard water pushes. Deeper or higher water pushes harder.

## CORE IDEAS

**The story.** About 180 years ago, New York City was growing fast, but it had no good water. People used wells and cisterns, and the water was often dirty. In the cold winter of 1835, a great fire burned many blocks of the city, and the firemen could not get enough water to put it out. The city leaders knew they needed a big supply of clean water.

**How they figured it out.** An engineer named John Jervis led the work. He chose the Croton River, about 40 miles north of the city, in the hills. Workers built a dam to make a lake, called a **reservoir**. Then they built a long brick tunnel, the Croton **Aqueduct**, all the way to the city. There were no pumps. The water flowed by gravity alone, so Jervis had to make the tunnel slope down very gently, only about one foot for every mile. Where the aqueduct crossed valleys, workers built bridges for it. In 1842 the water reached the city. People held a great celebration with parades and tall fountains.

**The physics.** Water always flows downhill, pulled by gravity. Water that is stored up high also pushes hard on the water below it. That push is called **pressure**. The higher the water, the harder it pushes, and the farther it can squirt out of a hole near the bottom.

**The engineering.** Today, rain and snow fall into rivers, lakes and the ground. Engineers collect the water, clean it at a treatment plant, and pump it up into tall **water towers** or tanks on hills. From there, gravity pushes it through pipes under the streets and up into your faucet. That is why water towers are so tall. Water workers test the water every day to make sure it is safe to drink.

## PICTURE STUDY



*Croton Water Celebration, 1842*, Unknown artist, published in New York, 1842 · Lithograph · Library of Congress

Image: [Wikimedia Commons](#), public domain

This print was made in 1842, the year the Croton water first reached New York City. The whole city came out to celebrate.

### Look closely

- Find the tall fountain. How high does the water shoot?
- Find the people marching in the parade. What are they carrying?
- Find the flags. Why do you think people were so happy?
- Look for the church steeple. How tall is the fountain compared to the buildings?

### Talk about it

1. What pushed the water so high in the fountain?
2. Why was clean water worth a parade?
3. Who do you think should be thanked for the water in your house?

## BUILD

### A Bottle Water Tower

You will poke holes at different heights in a bottle, fill it with water, and measure how far each stream squirts. Then you will raise the bottle up high, like a water tower, and test again.

#### You will need

- A large empty plastic bottle (2 liters is best)
- A pushpin or nail (an adult pokes the holes)
- Masking tape and a ruler or tape measure
- A pitcher of water and a tray, sink or outdoor spot
- A box or step stool to raise the bottle
- Engineer's notebook

#### Steps

1. Have an adult poke three small holes in a straight line up the side of the bottle: one near the bottom, one in the middle and one near the top. Cover them with a strip of tape.
2. Set the bottle on the edge of a tray or outside. Fill it to the top with water.
3. **Predict.** Which hole will squirt the farthest? Write your guess.
4. Pull off the tape. Watch the three streams. Measure how far out each one lands. Write the numbers.
5. Refill the bottle. This time keep it filled to the top while it squirts, so the water stays deep.
6. **Water tower test.** Put the bottle on a box or step, so it is higher. Test the bottom hole again. Measure how far it lands from the box.
7. **Improve.** Use the bottle as a “water tower” and tape a straw or tube into the bottom hole as a “pipe.” Can you make water come out the far end of the pipe? What happens if you lift the bottle higher?

#### Tips

- Do this outside or in a bathtub. It will spill.

- Keep the holes small and the same size, so the test is fair.

#### Check your work

- ☐ I can tell how the Croton water got to New York City.
- ☐ I can tell which hole squirted farthest and why.
- ☐ I can tell why water towers are tall.

#### ENGINEER'S NOTEBOOK

1. Draw the path of water from the rain to a reservoir, to a treatment plant, to a water tower, to your faucet.
2. Draw your bottle with its three streams. Write how far each one went.
3. Write one thank-you sentence to the people who keep your water clean.

**From history.** The Croton Aqueduct crossed the Harlem River on the High Bridge, a long stone arch bridge finished in 1848. It is the oldest bridge still standing in New York City, and today people walk and bike across it.

#### COMMON MISTAKES

- Thinking water towers are just for storing water. Their height gives the water its push.
- Letting the water level drop between tests. Keep the bottle full for a fair test.

**Make it a game • Water Tower Height Duel.** Fill a bottle with a hole near the bottom and hold it low, then high. Compare how far the stream shoots, and point to where you think it will land before each try. Say pressure, reservoir and water tower. Then tell your parent how New York City got clean water through the Croton Aqueduct in 1842.

**Scripture.** “All the rivers run into the sea; yet the sea is not full; unto the place from whence the rivers come, thither they return again.” (Ecclesiastes 1:7, KJV)

God made the water cycle. Rivers run to the sea, and the water returns as rain. Engineers catch a little of that water on its way and bring it to our homes.

## 5.2 WELLS AND PUMPS

### OBJECTIVES

- Explain that a lot of water is stored under the ground, and that a well reaches down to it.
- Tell how a hand pump and a farm windmill lift water up.
- Build a model well with a soap-pump and test how much water it lifts.

**Warm-up.** Push a clear straw into a glass of water. Put your finger over the top and lift the straw out. What happens to the water in the straw? Lift your finger. What happens now?

### WATCH

#### Make Your Own Well! | Science Project for Kids

SciShow Kids · 3:10

[https://www.youtube.com/watch?v=dkk\\_YbB139E](https://www.youtube.com/watch?v=dkk_YbB139E)

### WHEN TO WATCH

Before the build. This is the well you will make.

### BACKUP VIDEO

#### How do Water Wells Work?

Concerning Reality · 7:00

<https://www.youtube.com/watch?v=JSM4FIpys8w>

Optional, for parents or older brothers and sisters who want more detail.

### KEY TERMS

#### **well**

A deep hole dug or drilled down to water under the ground.

#### **groundwater**

Water stored in the spaces between sand, gravel and rock under the ground.

#### **pump**

A machine that pushes or lifts water from one place to another.

#### **valve**

A little flap or door that lets water go one way but not back.

## CORE IDEAS

**The story.** Long ago, people dug wells by hand. The Bible tells how Abraham and his son Isaac dug wells in the dry land for their families and their flocks. Women came to the well every day with jars and pulled up water in a bucket on a rope. Many farms and towns still get their water from wells today.

**How they figured it out.** Pulling up a bucket is hard work. So people invented the hand **pump**. You push the handle down, and inside the pipe a plunger moves up and lifts the water. Each push brings up a little more. Later, American farmers on the wide, windy prairies needed water for their cattle, far from any river. In 1854 a mechanic named Daniel Halladay built a windmill that could turn itself to face the wind and slow down in a storm so it would not break. Windmills like his pumped water from wells on farms all across the West. You can still see them standing in fields today.

**The physics.** Rain soaks down into the ground and fills the tiny spaces between grains of sand, gravel and rock. That is **groundwater**. A well is a hole that reaches down to it. A hand pump has a plunger inside a pipe and two little flaps called **valves**. When the plunger rises, the bottom valve opens and water comes up. When the plunger goes down, that valve closes, so the water cannot fall back. Up and down, up and down, the water climbs higher with each stroke.

**The engineering.** Well drillers today use big machines to drill deep and line the hole with pipe to keep it clean. Electric pumps lift the water into the house. Engineers make sure wells are far from anything that could make the water dirty, and they test the water to make sure it is safe. A water pump in your kitchen soap bottle works the same way as an old hand pump.

## PICTURE STUDY



*Myers Force Pumps Trade Card*, F. E. Myers & Bro., Ashland, Ohio, About 1900 · Printed color trade card · Ashland, Ohio

Image: [Wikimedia Commons](#), public domain

Long ago, companies gave out little picture cards to advertise. This one is from a company in Ohio that made pumps for farms and homes. The pump in the picture is a hand pump like the ones that stood in many farmyards.

### Look closely

- Find the pump's long handle. Which way would you push it?
- Find the spout where the water comes out.
- Find the small drawing at the bottom of the card. What part of the pump might it show?
- What is the little girl drinking?

### Talk about it

1. Where does the water in this pump come from?
2. Why does the pump need a long handle? (Think of levers in Unit 1!)
3. Why would a farm family be glad to have this pump?

**Safety first.** Never lean over or climb on a real well or a well cover. Never drink water from a model or from any well that has not been tested.

## BUILD

### A Model Well with a Soap Pump

You will make a model of the ground with water hidden in it, then pump the water up with a soap pump, just like a real well.

#### You will need

- A clear jar or plastic cup
- Small gravel or aquarium rocks, and some sand
- A clean soap or lotion pump top with its tube (from an empty bottle, well rinsed)
- Water with a drop of food coloring
- A small cup, a measuring spoon and a stopwatch or phone timer
- Engineer's notebook

#### Steps

1. Stand the pump tube in the middle of the jar. Pour gravel around it to fill the jar about two-thirds. Add a layer of sand on top.
2. Slowly pour colored water over the sand, like rain. Watch it soak down into the gravel. That is your groundwater.
3. **Predict.** How many pumps will it take to fill a tablespoon? Write your guess.
4. Pump the water into the small cup. Count the pumps until you fill one tablespoon. Do it three times.
5. **Fair test.** Pump fast for 20 seconds, then slow for 20 seconds. Which way brought up more water? Measure each with the spoon.
6. **Improve.** Let the well run low. What happens when the water level drops below the bottom of the tube? Add more "rain" and test again.

#### Tips

- Push the pump top all the way down each time, so every pump is the same.
- Rinse the pump very well before you start so no soap is left.

#### Check your work

- ☐ I can tell where groundwater comes from.

- ☐ I can tell how a hand pump lifts water.
- ☐ I can tell what happened when my well ran low.

#### ENGINEER'S NOTEBOOK

1. Draw your jar from the side. Show the sand, the gravel, the water and the pump tube.
2. Make a table: fast pumping and slow pumping, and how much water came up.
3. Draw a farm windmill pumping water into a tank for cows.

**From history.** Many farm windmills in America were made by a company called Aermotor, which started in Chicago in 1888 and still makes windmills today. A good windmill can pump water for many years with only a little oil and care.

#### COMMON MISTAKES

- Thinking groundwater is an underground lake. Most of it fills tiny spaces between sand and rocks.
- Changing the number of pumps between tests.

**Make it a game • Well and Pump Story.** Use a soap pump and a bowl to act as a hand pump lifting water from a model well. Pump ten times and count how many cups you fill. Say groundwater, valve and well. Tell your parent where water is stored underground and how a farm windmill pumps it up. Then try to beat your count.

**Scripture.** “Therefore with joy shall ye draw water out of the wells of salvation.” (Isaiah 12:3, KJV)

People in Bible times knew how precious a well was. Isaiah used drawing water from a well as a picture of the joy of God’s salvation.

## 5.3 WATERWHEELS AND DAMS MAKE POWER

### OBJECTIVES

- Tell how waterwheels powered mills long ago.
- Explain how a dam and a turbine turn falling water into electricity.
- Build a waterwheel and test how the height of the falling water changes how fast it lifts a load.

**Warm-up.** Hold a pinwheel or a paper plate on a pencil under a slow stream from the faucet. What makes it turn? What happens if you turn the water up a little?

### WATCH

#### What is Hydropower | Science for Kids

Little School • 4:25

[https://www.youtube.com/watch?v=-Zwe\\_2f\\_PyY](https://www.youtube.com/watch?v=-Zwe_2f_PyY)

### WHEN TO WATCH

After the physics paragraph.

### BACKUP VIDEO

#### An 18th Century Saw Mill Powered by Water

NEWS CENTER Maine • 1:57

<https://www.youtube.com/watch?v=wtZ4Q9l9p7o>

With the story, to see a real waterwheel turning a mill.

### KEY TERMS

#### **waterwheel**

A big wheel with paddles or buckets that falling or flowing water turns.

#### **dam**

A wall built across a river to hold back water.

#### **mill**

A building with machines for grinding grain, sawing wood or making cloth.

#### **turbine**

A modern waterwheel that spins very fast to turn a generator.

## **generator**

A machine that makes electricity when it is turned.

### **CORE IDEAS**

**The story.** For hundreds of years, almost every village had a **mill** beside a stream. A big **waterwheel** turned in the water. Its axle turned millstones that ground wheat into flour, or saws that cut logs into boards. The miller built a little dam to make a pond above the mill, so there was always water to turn the wheel.

**How they figured it out.** Millers learned that water falling from higher up turns a wheel with more power. So they built wheels where the water poured onto the top, filling buckets that pulled the wheel around. Then, in 1882, in the town of Appleton, Wisconsin, some businessmen and engineers tried something new. They hooked a waterwheel on the Fox River to a **generator**, a machine that makes electricity when it spins. On a fall evening that year, its electricity lit the lamps in a nearby house and in a paper mill. It was one of the first places in the world where falling water made electricity for people to use.

**The physics.** Water held up high behind a **dam** has stored energy, because gravity is pulling on it. When the water falls, it speeds up and can push hard. The push turns a wheel. The higher the water falls, the more energy it has. That is the same thing you saw with the water tower in Lesson 5.1.

**The engineering.** Today, huge dams hold back great lakes of water. Water rushes down big pipes inside the dam and spins **turbines**, which are fast, modern waterwheels. The turbines turn generators that make electricity for whole cities. Engineers design dams to be very strong, and inspectors check them often. Falling water is one of several ways engineers make electricity, along with coal, natural gas, nuclear power, wind and sunshine. Each one has good points and hard problems.

## PICTURE STUDY



*The Watermill with the Great Red Roof*, Meindert Hobbema, About 1663 · Oil on canvas · Art Institute of Chicago

Image: [Wikimedia Commons](#), public domain

Meindert Hobbema was a Dutch painter who loved to paint watermills in the woods. Look closely to find the machine that powers the mill.

### Look closely

- Find the red roof of the mill.
- Find the waterwheel. Can you see the water pouring onto it?
- Find the wooden channel that brings water to the wheel.
- Find the pond. Why do you think the miller kept a pond above the mill?

### Talk about it

1. What might this mill have been used for?
2. What would happen to the mill in a dry summer when the stream got low?
3. How is a waterwheel like the wheel and axle you built in Unit 1?

## BUILD

### A Paper-Plate Waterwheel

You will build a waterwheel that lifts a little load on a string. You will pour water from different heights and time how fast it lifts the load.

#### You will need

- Two sturdy paper plates and six small paper cups (or plastic spoons)
- A pencil or wooden dowel for the axle
- Tape, string about 2 feet long, and a paper clip with 2 pennies taped to it as the load
- A pitcher of water, a large tub or the bathtub
- A ruler and a stopwatch or phone timer
- Engineer's notebook

#### Steps

1. Have an adult poke a hole in the center of both plates. Tape the plates together back to back with the cups between them around the edge, all facing the same way, like buckets.
2. Push the pencil through the center holes. Tape the plates to the pencil so they turn together.
3. Tape one end of the string to the pencil. Tie the paper-clip load to the other end, so it hangs down.
4. Have a helper hold the ends of the pencil over the tub, so the wheel can spin freely.
5. **Predict.** Will water poured from high up lift the load faster than water poured from low down? Write your guess.
6. Pour the water onto the cups from 2 inches above the wheel. Time how many seconds it takes the string to wind up and lift the load 6 inches. Do it three times.
7. Now pour the same amount of water the same way from 8 inches above the wheel. Time it three times. Write all the numbers.

8. **Improve.** Try bigger cups, more cups or a different pouring spot. Change one thing and test again.

**Tips**

- Pour at the same speed each time. Only the height should change.
- If the wheel slips on the pencil, add more tape.

**Check your work**

- ☐ I can tell how a waterwheel powered a mill.
- ☐ I can tell what my test showed about the height of falling water.
- ☐ I can tell how a dam makes electricity.

**ENGINEER'S NOTEBOOK**

1. Draw your waterwheel and label the buckets, the axle, the string and the load.
2. Make a table of your times for low pouring and high pouring.
3. Draw a dam with water falling through a turbine and a wire going to a house.

**From history.** The Appleton power plant was called the Vulcan Street Plant. It used ideas from Thomas Edison's company. A copy of the little plant now stands in Appleton for visitors to see.

**COMMON MISTAKES**

- Pouring faster for one test than another. Keep everything the same except the height.
- Thinking electricity is stored in the dam. The dam holds water; the generator makes electricity when the water spins it.

**Make it a game • Waterwheel Turn Count.** Pour water over a paper-plate waterwheel from low and from high, over a sink, and count how many turns you get. Say dam, turbine and generator. Tell your parent how waterwheels powered mills and how a dam turns falling water into electricity. Then spin it with a slow stream and a fast stream, and say which gives more turns.

## 5.4 ROADS, SIGNS AND TRAFFIC LIGHTS

### OBJECTIVES

- Tell how John McAdam built roads that stayed dry and smooth.
- Explain why roads are higher in the middle and built in layers.
- Build two model roads and test which one stays dry after a rainstorm.

**Warm-up.** Take a short walk with a grown-up and look at the street. Is the middle higher or lower than the sides? Where does the rainwater go? Find a storm drain, but never reach into it or go near it.

### WATCH

#### How are roads built? (Are We There Yet: Guide to Roads)

Fun Kids Learn · 4:01

<https://www.youtube.com/watch?v=K3Y3JSEYrHs>

#### WHEN TO WATCH

After the story.

**Note:** Made by a British children’s radio station with the Royal Academy of Engineering, so it says “tarmac” for blacktop.

### BACKUP VIDEO

#### How do traffic lights work? (Are We There Yet: Guide to Roads)

Fun Kids Learn · 3:51

<https://www.youtube.com/watch?v=nWY7ZcOjGXc>

With the engineering paragraph about traffic lights.

### KEY TERMS

#### macadam

A road made of layers of small, broken stones packed tightly together, named after John McAdam.

#### crown

The high middle of a road, so rain runs off to the sides.

**drain**

A ditch or pipe that carries water away.

**traffic signal**

A light that tells drivers when to stop and when to go.

**CORE IDEAS**

**The story.** About two hundred years ago, most roads were just dirt. When it rained, they turned into deep mud. Wagons sank up to their axles, and travel took a long, long time. In Scotland, a man named John McAdam was put in charge of some roads. He walked and rode over them for years, studying why they broke down.

**How he figured it out.** McAdam saw that the real enemy of a road was water. When water soaked into the dirt underneath, the ground got soft, and wheels pushed it into ruts. So he built roads in a new way. He made the dirt underneath firm and dry. He put on layers of small, broken stones, all about the same size, and let the wagon wheels pack them down tight. Most important, he made the road higher in the middle, with ditches along the sides, so rain ran right off. His roads stayed hard and smooth. People called them **macadam** roads. In 1823 the first one in America was built in Maryland.

**The physics.** Water runs downhill. A road with a high middle, called a **crown**, sends rain to the edges, where **drains** carry it away. Small stones packed together lock into each other and spread the weight of each wheel over a wide area, the way a wide foundation spreads the weight of a building.

**The engineering.** Today's roads still use McAdam's ideas: a firm base, layers of stone, a crown and drains. On top, engineers add a layer of blacktop (stones glued together with tar) or concrete. Busy roads also need rules and signals to keep people safe. In 1914 the city of Cleveland, Ohio, put up one of the first electric **traffic signals**, with red and green lights. Later inventors, such as William Potts in Detroit and Garrett Morgan in Cleveland, added a warning signal between stop and go, which became our yellow light. Road engineers plan signs, lines, lights and crosswalks so that drivers and walkers can share the road safely.

## PICTURE STUDY



*The First American Macadam Road*, Carl Rakeman, 1920s (painting of the year 1823) · Oil painting · U.S. Federal Highway Administration

Image: [Wikimedia Commons](#), public domain

Carl Rakeman painted many pictures of the history of American roads for the government. This one shows workers building the first macadam road in America, in Maryland in 1823.

### Look closely

- Find the workers breaking big stones into small ones with hammers.
- Find the workers spreading and raking the stones.
- Find the finished part of the road. Is it flat, or higher in the middle?
- Find the man in the tall hat. Who do you think he is?

### Talk about it

1. Why did McAdam want the stones to be small and all the same size?
2. What would happen to this road in the rain if it had no crown?
3. Why are roads important to a town?

**Safety first.** Never play near a street, a storm drain or a manhole. Stay far away from road crews and their machines, and always cross at a crosswalk with a grown-up.

## BUILD

### The Rainstorm Road Test

You will build two model roads in a pan: a plain dirt road and a McAdam road with a stone layer, a crown and ditches. Then you will make it rain and see which road stays firm.

#### You will need

- Two foil baking pans or shallow plastic tubs
- Garden soil or sand
- Small gravel or aquarium rocks
- A toy car or a small wheel
- A watering can or a cup with holes poked in the bottom for “rain”
- A ruler and engineer’s notebook

#### Steps

1. **Dirt road.** Fill one pan with soil and press it flat. Make a road down the middle with your hand.
2. **McAdam road.** Fill the other pan with soil and press it firm. Shape the road so the middle is higher than the edges, and scoop a little ditch along each side. Spread a layer of gravel on the road and press it down hard.
3. **Predict.** Which road will stay firmer after the rain? Write your guess.
4. Pour the same amount of “rain” on each road, slowly and evenly.
5. Roll the toy car down each road five times, pressing gently. Measure how deep the ruts are with a ruler. Look for puddles.
6. Write your results in a table: road, puddles (yes or no), rut depth.
7. **Improve.** Make your McAdam road even better: a higher crown, deeper ditches or a thicker stone layer. Test it again.

#### Tips

- Do this outside or on a tray. It gets muddy.
- Use the same amount of water and the same car for both roads.

#### Check your work

- ☐ I can tell how McAdam made roads that stay dry.
- ☐ I can show the crown and the ditches on my model road.
- ☐ I can tell what traffic lights are for and one road safety rule.

#### ENGINEER'S NOTEBOOK

1. Draw a slice of a McAdam road: the firm ground, the stone layer, the crown and the ditches. Draw arrows showing where the rain goes.
2. Write your table of ruts and puddles.
3. Draw a traffic light and write what each color means.

**From history.** The road in the painting was part of the Boonsborough Turnpike in Maryland. Travelers paid a small toll to use it, and the money helped keep it in good repair.

#### COMMON MISTAKES

- Making the road flat. Without a crown, water sits on top and soaks in.
- Pouring more rain on one road than the other.

**Make it a game • Rainstorm Road Detective.** Pour water on a flat road model and on a model with a high middle and layers, over a tray. Watch where the water goes. Say crown and drain. Tell your parent how John McAdam built dry, smooth roads. Then draw a road from the side, and label the crown and the layers.

**Scripture.** “Every valley shall be exalted, and every mountain and hill shall be made low: and the crooked shall be made straight, and the rough places plain:” (Isaiah 40:4, KJV)

Isaiah describes building a highway for the Lord, with the valleys filled and the rough places made smooth. Road builders do just that, and the verse reminds us to make our hearts ready for God.

## UNIT 5

# WATER, POWER AND ROADS

When you turn on a faucet, clean water comes out. When you flip a switch, a light comes on. When you ride in the car, a smooth road carries you to church or the store. These are called public utilities and public works, and engineers designed every one. In this unit you will follow the water that New York City brought down from the hills in 1842, see how wells and pumps lift water out of the ground, learn how mills and dams turn falling water into power, and find out how a Scottish road builder made roads that stay dry.

You will build a bottle water tower, a pump, a waterwheel and a model road, and test each one. Many people work every day, often out of sight, to keep water, power and roads safe for us. Loving our neighbor includes thanking them, and someday perhaps being one of them.

### PREREQUISITES

- Knows that gravity pulls things down (Unit 1)
- Knows what a wheel and axle is (Unit 1)
- Can measure with a ruler or tape measure and record numbers

### MASTERY CHECKLIST

- ☐ I can tell how water travels from the rain to my faucet, and why water towers are tall.
- ☐ I can tell how a well and a hand pump bring up water from under the ground.
- ☐ I can tell how a waterwheel and a dam turn falling water into power.
- ☐ I can tell how John McAdam made roads that stay dry, and what traffic lights are for.
- ☐ I can name people who keep our water, power and roads working, and the safety rules for them.

## OPTIONAL KITS FOR THIS UNIT

- **Thames & Kosmos science kits:** Ages vary by kit. Some of their kits build working waterwheels and water-powered machines. Fits Lessons 5.1–5.3.
- **Snap Circuits Jr. (Elenco):** Ages 8 and up, or younger with a parent. Can be used to build a battery-powered light that blinks like a signal. Fits Lesson 5.4 and Unit 4.

Not required. Every project in this unit can be built with household materials. School Launch has no ties to these companies.

## LESSONS IN THIS UNIT

|                                                          |                             |
|----------------------------------------------------------|-----------------------------|
| <b>5.1 From the Rain to the Tap: The Croton Aqueduct</b> | 2 sessions of 30–40 minutes |
| <b>5.2 Wells and Pumps</b>                               | 2 sessions of 30–40 minutes |
| <b>5.3 Waterwheels and Dams Make Power</b>               | 2 sessions of 30–40 minutes |
| <b>5.4 Roads, Signs and Traffic Lights</b>               | 2 sessions of 30–40 minutes |

## UNIT 5 REVIEW

A parent asks these questions aloud. Your child may answer by telling, pointing, drawing or showing with the builds from this unit. There are no points. Listen for understanding and praise careful answers.

1. Draw the trip a drop of water takes from the rain to your faucet.
2. Show me with the bottle: why are water towers tall?
3. Where does well water come from, and how does a hand pump bring it up?
4. How can falling water make electricity?
5. Show me your McAdam road. Why is the middle higher?
6. Name two people who keep our water, power or roads working, and one safety rule we learned.

#### ANSWER KEY

1. Rain falls into a river, lake or the ground; it is collected (a reservoir), cleaned at a treatment plant, pumped up to a water tower, and flows through pipes to the faucet.
2. Water up high pushes harder (more pressure), so it can flow through the pipes into houses.
3. From groundwater in the spaces between sand and rocks. The pump's plunger lifts the water, and a valve keeps it from falling back.
4. A dam holds water up high. The water falls and spins a turbine, which turns a generator that makes electricity.
5. So rain runs off to the sides and the ditches, and the road stays firm and dry.
6. Any two, such as water workers, lineworkers, road crews or engineers. A safety rule such as: stay away from storm drains, manholes and downed power lines; cross at a crosswalk.

#### PORTFOLIO PIECE: A THANK-YOU MAP OF OUR TOWN

Draw a big map of your house and neighborhood that shows where your water comes from, where the power lines run and which roads you travel. Add your bottle water tower and model road (or photographs of them) with your test results. Then write or tell a thank-you note to one group of workers who keep these things running, and deliver it if you can.

| LOOK FOR                | WHAT IT MEANS                                                             |
|-------------------------|---------------------------------------------------------------------------|
| <b>Water</b>            | Showed the path of water to the house and told why water towers are tall. |
| <b>Power and roads</b>  | Showed where power comes from and told why roads have a crown.            |
| <b>Builds and tests</b> | Included the water tower and road test results.                           |
| <b>Thankfulness</b>     | Wrote or told a thank-you to workers who keep the town running.           |

## UNIT 6

# BOATS

“They that go down to the sea in ships, that do business in great waters; these see the works of the LORD, and his wonders in the deep.” People have built boats for as long as there have been people. In this unit you will learn why a heavy boat floats, from the story of Archimedes and the king’s crown. You will see why the shape of a hull matters, and you will look at the shape God gave Noah for the ark. You will sail with the Vikings in their long, fast ships, and ride up the Hudson River on Robert Fulton’s steamboat.

You will measure how much water things push aside, build foil boats and count how many pennies they carry, add a keel to keep a boat sailing straight, and power a paddle boat with a rubber band. Always have a grown-up nearby when you work with a tub or sink of water.

### PREREQUISITES

- Knows how to make a fair test by changing only one thing
- Can count pennies and measure with a ruler
- Knows that gravity pulls things down (Unit 1)

### MASTERY CHECKLIST

- ☐ I can tell the story of Archimedes and the crown, and show that a floating thing pushes water aside.
- ☐ I can show that the shape of a boat changes how much it can carry.
- ☐ I can tell how Viking ships were built and why a keel helps a boat go straight.
- ☐ I can tell how Robert Fulton’s steamboat worked and how a paddle wheel pushes a boat.

## OPTIONAL KITS FOR THIS UNIT

- **Thames & Kosmos science kits:** Ages vary by kit. Their range includes boat-building kits with sail, paddle and propeller boats to test in the tub. Fits Lessons 6.2–6.4.
- **LEGO Education:** Ages 6 and up for the early sets. Bricks can be built into floating hulls and paddle wheels for tub tests. Fits Lessons 6.2 and 6.4.

Not required. Every project in this unit can be built with household materials. School Launch has no ties to these companies.

## LESSONS IN THIS UNIT

|     |                                                |                             |
|-----|------------------------------------------------|-----------------------------|
| 6.1 | Archimedes and the King's Crown                | 2 sessions of 30–40 minutes |
| 6.2 | Hull Shape and Load: The Ark and the Foil Boat | 2 sessions of 30–40 minutes |
| 6.3 | Viking Longships                               | 2 sessions of 30–40 minutes |
| 6.4 | Robert Fulton's Steamboat                      | 2 sessions of 30–40 minutes |

## UNIT 6 REVIEW

A parent asks these questions aloud. Your child may answer by telling, pointing, drawing or showing with the builds from this unit. There are no points. Listen for understanding and praise careful answers.

1. Tell the story of Archimedes and the king's crown. How did he catch the goldsmith?
2. Show me with clay: why does a ball of clay sink, but a clay bowl float?
3. Which of your foil boats carried the most pennies? Why?
4. How big did God tell Noah to make the ark?
5. Show me a keel on your boat. What does it do?
6. How did Robert Fulton's steamboat move up the river against the current?

#### ANSWER KEY

1. He put the crown and the same weight of pure gold in water. The crown pushed aside more water, so it was not pure gold.
2. The bowl shape pushes aside more water, enough to equal its own weight, so the water holds it up.
3. Usually the long, wide boat with medium sides. It pushed aside the most water without tipping or letting water in.
4. Three hundred cubits long, fifty cubits wide and thirty cubits high.
5. It sticks down into the water and keeps the boat from sliding sideways, so it goes straight.
6. A steam engine turned paddle wheels that pushed the water backward, so the boat moved forward.

#### PORTFOLIO PIECE: MY BEST BOAT

Design and build one boat that combines what you learned: a hull shape that carries a big load, a keel to go straight, and a sail or paddle wheel to make it go. Test how many pennies it can carry and how far it travels across the tub. Improve it once, and show your family the boat and your notebook pages.

| LOOK FOR                  | WHAT IT MEANS                                                     |
|---------------------------|-------------------------------------------------------------------|
| <b>Floats and carries</b> | Counted how many pennies the boat carried before sinking.         |
| <b>Goes straight</b>      | Used a keel or rudder and showed that it helped.                  |
| <b>Moves</b>              | Used a sail or a paddle wheel and measured how far the boat went. |
| <b>Improving</b>          | Changed one thing after the first test and tried again.           |

## 6.1 ARCHIMEDES AND THE KING'S CROWN

### OBJECTIVES

- Tell the story of Archimedes and the king's gold crown.
- Show that anything put in water pushes some water aside.
- Test a lump of clay that sinks and the same clay shaped into a boat that floats.

**Warm-up.** Fill a glass of water almost to the top and mark the water level with tape. Gently put in three spoons, one at a time. Watch the water. What happens to the level? Why?

### WATCH

#### Sink or Float?

[SciShow Kids](https://www.youtube.com/watch?v=eQuW8G2QV_Q) · 5:50

[https://www.youtube.com/watch?v=eQuW8G2QV\\_Q](https://www.youtube.com/watch?v=eQuW8G2QV_Q)

### WHEN TO WATCH

After the story, before the physics. Make your own guesses as the friends test each object.

### KEY TERMS

#### **float**

To stay up on top of the water.

#### **sink**

To go down to the bottom of the water.

#### **displace**

To push aside. A boat pushes water out of the way to make room for itself.

#### **buoyancy**

The push of water up on a thing in it. It is what holds up a boat.

### CORE IDEAS

**The story.** More than two thousand years ago, on the island of Sicily, King Hiero gave a goldsmith a lump of pure gold to make a crown. The crown came back beautiful, and it weighed just as much as the gold. But the king wondered: had the goldsmith kept some of the gold for himself and mixed in cheaper silver? He asked Archimedes, the wisest thinker in the city, to find out without harming the crown.

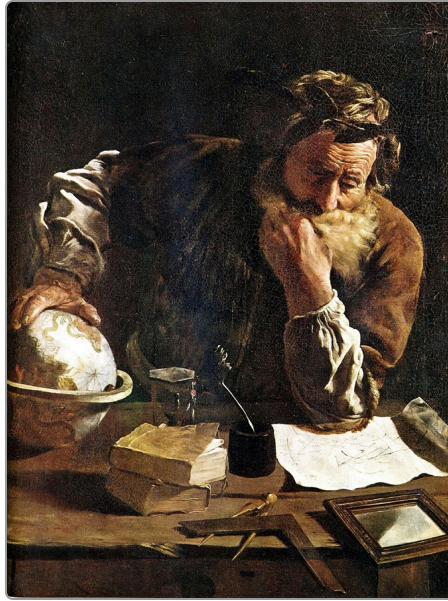
**How he figured it out.** Archimedes thought and thought. The old story says that one day he stepped into a full bathtub and saw the water spill over the side. His body had

pushed the water out of the way! He was so excited that he jumped out shouting, “Eureka!” which means “I have found it!” He knew that silver takes up more space than the same weight of gold. A crown with silver mixed in would be bigger, so it would push aside more water than a lump of pure gold. Archimedes put the crown in water, and then the same weight of pure gold. The crown pushed aside more water. The goldsmith had cheated.

**The physics.** Anything you put in water pushes some water aside, or **displaces** it. The water pushes back up. That upward push is called **buoyancy**. Archimedes found the rule: the push up is as strong as the weight of the water that was pushed aside. If a thing can push aside its own weight in water before it is all the way under, it **floats**. If it cannot, it **sinks**.

**The engineering.** That is why a huge steel ship can float. Its hull is shaped like a big bowl, full of air. It pushes aside a great deal of water, enough to weigh as much as the whole ship and everything in it. A lump of clay sinks, but the same clay shaped into a bowl can float. Shipbuilders use Archimedes’ rule every time they design a ship. They work out exactly how much a ship can carry before it sits too low in the water.

## PICTURE STUDY



*Archimedes Thoughtful*, Domenico Fetti, 1620 · Oil on canvas · Old Masters Picture Gallery, Dresden, Germany

Image: [Wikimedia Commons](#), public domain

An Italian painter imagined Archimedes deep in thought at his desk. Archimedes solved the king's problem by thinking hard and then testing his idea.

### Look closely

- Find Archimedes' face. What do you think he is thinking about?
- Find the tools on the table. Can you find the measuring compasses?
- Find the globe under his hand.
- Find the papers. What might he have written or drawn?

### Talk about it

1. How did Archimedes find out about the crown without breaking it?
2. Why is careful measuring important, even for a king's crown?
3. What would you have used to test the crown?

**Safety first.** A grown-up should be nearby whenever you work with a tub or sink of water. Wipe up spills so no one slips.

## BUILD

### Sinking Clay and Floating Clay

You will measure how much water rises when you put things in a container. Then you will see how the same lump of clay can sink or float, depending on its shape.

#### You will need

- A clear plastic container or large glass, about half full of water
- Masking tape and a marker
- A lump of modeling clay about the size of a golf ball
- Small objects to test: a marble, a cork, a coin, a crayon
- A kitchen scale (optional) and a ruler
- Engineer's notebook

#### Steps

1. Put a strip of tape up the side of the container. Mark the water level.
2. **Predict.** For each object, guess: sink or float? Write your guesses.
3. Put in one object at a time. Mark the new water level on the tape, and write sink or float. Take it out before testing the next one.
4. Roll the clay into a ball. Drop it in. Does it sink? Mark the water level.
5. Take it out and dry it. Now press the same clay into a thin, wide bowl. Set it gently on the water. Does it float? Mark the water level.
6. Compare your two marks. Which shape pushed aside more water?
7. **Improve.** Make your clay boat carry as many pennies as you can. Count them. Then change the shape (wider, deeper or thinner walls) and test again.

#### Tips

- Keep the clay in one piece, so you are testing the same amount every time.
- Set the clay boat down gently. Water sloshing in will sink it.

#### Check your work

- ☐ I can tell the story of Archimedes and the crown.
- ☐ I can show that things push water aside.

- ☐ I can tell why the clay bowl floats but the clay ball sinks.

#### ENGINEER'S NOTEBOOK

1. Draw your container with tape marks for each object. Label each mark.
2. Make a table: object, my guess, sink or float.
3. Draw the clay ball and the clay boat, and show which way the water pushes.

**From history.** We know the crown story from a Roman engineer named Vitruvius, who wrote it down about two hundred years after Archimedes lived. Archimedes himself wrote a book called *On Floating Bodies*, where he explained the rule of buoyancy carefully.

#### COMMON MISTAKES

- Thinking heavy things always sink. A heavy ship floats because of its shape.
- Thinking light things always float. A tiny pebble sinks.

**Make it a game • Crown Displacement Guess.** Mark the water level in a glass. Drop in a ball of clay and mark the new level. Then shape it into a boat and see what changes. Say displace and buoyancy. Tell your parent the story of Archimedes and the king's crown. Guess how much each object will raise the water before you test it.

## 6.2 HULL SHAPE AND LOAD: THE ARK AND THE FOIL BOAT

### OBJECTIVES

- Tell the shape and size God gave Noah for the ark.
- Explain how the shape of a hull changes how much a boat can carry.
- Build foil boats of different shapes and count how many pennies each holds.

**Warm-up.** Float a plastic cup and a plastic plate in the sink. Push down gently on each. Which is easier to tip over? Which do you think could carry more toys?

### WATCH

#### How to make a TIN FOIL BOAT!

KSU iTeach • 6:31

<https://www.youtube.com/watch?v=SMbO00zWQnM>

#### WHEN TO WATCH

Before the build.

**Note:** Made by a university teacher-education program. It shows one way to fold a foil boat; your child should also try his or her own shapes.

### BACKUP VIDEO

#### Science Max | BUILD IT YOURSELF | Tin Foil Boat | EXPERIMENT

Science Max - Scholastic • 1:58

<https://www.youtube.com/watch?v=mt5Mjti89TQ>

After the build, to compare your results.

### KEY TERMS

#### **hull**

The body of a boat, the part that sits in the water.

#### **load**

Everything a boat carries: people, animals and cargo.

**cubit**

An old measure of length, from a man's elbow to the tip of his middle finger, about a foot and a half.

**stable**

Steady and hard to tip over.

**CORE IDEAS**

**The story.** In the book of Genesis, God told Noah to build an ark. God gave him the size: three hundred cubits long, fifty cubits wide and thirty cubits high. A **cubit** is about a foot and a half, so the ark was about as long as one and a half football fields. It was made of wood and covered with pitch inside and out to keep the water out. It did not need to sail anywhere. It needed to float safely and carry a great **load**: Noah's family and all the animals.

**How builders think about it.** Look at those numbers. The ark was six times as long as it was wide, and not very tall. Shipbuilders today know that a long, wide, box-like **hull** can hold a lot and is very **stable**, which means it is hard to tip over in the waves. A tall, narrow boat would tip easily. A short, round tub would spin and wobble. Engineers in Korea once tested a model of the ark's shape in a wave tank and found that it was very steady.

**The physics.** Remember Archimedes: a boat floats when it pushes aside its own weight in water. The more water a hull can push aside before water spills over its sides, the more load it can carry. A wide, flat-bottomed hull with tall enough sides pushes aside a lot of water. If the sides are too low, water pours in. If the boat is too narrow, it tips. Good hull design balances all of these.

**The engineering.** Boat designers choose a hull shape for each job. Cargo ships and barges are long and wide, like boxes, to carry heavy loads. Racing boats are long and narrow to slip through the water fast. Canoes are light and pointed at both ends. Every big ship has marks painted on its side to show how low it may safely sit in the water when it is loaded. Overloading a boat is dangerous, so captains must follow those marks.

## PICTURE STUDY



*Noah's Ark*, Edward Hicks, 1846 · Oil on canvas · Philadelphia Museum of Art

Image: [Wikimedia Commons](#), public domain

Edward Hicks was an American painter and a Christian preacher. He painted the animals walking into the ark before the rain began.

### Look closely

- Find the long hull of the ark. Is it tall and narrow, or long and wide?
- Find the ramp. How do the animals get on board?
- Find the windows along the top. What might they be for?
- Look at the sky. What is about to happen?

### Talk about it

1. Why would a long, wide shape be good for carrying so many animals?
2. The painter did not see the real ark. What did he get right from the Bible's description? What might be different?
3. Where would you put the heaviest animals so the ark would not tip?

**Safety first.** Have a grown-up nearby when you work with a tub of water.

## BUILD

### The Foil Boat Penny Test

You will build three boats from the same size piece of foil, each with a different hull shape. You will count how many pennies each can carry before it sinks.

#### You will need

- Aluminum foil, cut into three squares, each 12 by 12 inches
- About 150 pennies
- A tub or sink of water
- A ruler
- A towel
- Engineer's notebook

#### Steps

1. **Boat 1, the raft.** Fold up the edges of one foil square only about half an inch. It will be wide and flat.
2. **Boat 2, the tall tub.** Fold the second square into a small, deep box, about 4 inches across with tall sides.
3. **Boat 3, the ark.** Fold the third square into a long box about 6 times as long as it is wide, with sides about 1 inch tall.
4. **Predict.** Which boat will carry the most pennies? Write your guess.
5. Float each boat. Add pennies one at a time, spreading them out evenly. Count until water comes in and the boat sinks. Write the number.
6. Make a table: boat, length, width, height of sides, pennies held.
7. **Improve.** Use a new 12-inch square to design your own best boat. Try changing one thing, such as making the sides a little taller or the bottom a little wider. Test it and beat your best number.

#### Tips

- Spread the pennies out. If they all pile on one side, the boat tips.
- Use the same size foil every time so the test is fair.

#### Check your work

- ☐ I can tell the size of the ark in cubits.
- ☐ I can tell which hull shape carried the most pennies.
- ☐ I can tell why a boat that is too narrow tips over.

#### ENGINEER'S NOTEBOOK

1. Draw your three boats and write how many pennies each held.
2. Draw a bar graph of the penny counts.
3. Draw the ark's shape: 300 cubits long, 50 wide, 30 high. Use one square on your graph paper for every 10 cubits.

**From history.** Long after Noah, big wooden barges on rivers and canals were built in the same long, box-like shape, because it carries the most cargo. A single horse walking on the bank could pull a loaded canal barge that carried many times what it could pull in a wagon.

#### COMMON MISTAKES

- Piling all the pennies in one spot.
- Using different sizes of foil for different boats.

**Make it a game • Noah's Hull Load Test.** Make two foil boats, one deep and wide and one narrow. Guess which holds more pennies, then load each and count. Say hull, load and stable. Tell your parent the shape God gave Noah for the ark and what a cubit is. Take turns being the engineer and the judge, and beat your best count.

**Scripture.** “And this is the fashion which thou shalt make it of: The length of the ark shall be three hundred cubits, the breadth of it fifty cubits, and the height of it thirty cubits.” (Genesis 6:15, KJV)

God gave Noah exact measurements for the ark. Good builders follow careful plans and measure honestly.

## 6.3 VIKING LONGSHIPS

### OBJECTIVES

- Tell how the Vikings built their long, fast ships.
- Explain how a keel helps a boat sail straight.
- Test a model boat with and without a keel in front of a fan.

**Warm-up.** Float a flat plastic lid in the tub and blow on one side of it. Which way does it go? Now hold a craft stick straight down under the middle of it and blow again. What changed?

### WATCH

#### Every Genius Detail That Made Viking Longships Remarkable

Smithsonian Channel • 3:57

<https://www.youtube.com/watch?v=M2v0CsoFctA>

### WHEN TO WATCH

After the story.

**Note:** This clip is from a series about historic warships, but it shows only the ship itself and how boatbuilders make one today with old tools.

### KEY TERMS

#### **keel**

The strong backbone that runs along the bottom of a boat from front to back.

#### **clinker-built**

Built with planks that overlap each other, like shingles on a roof.

#### **oar**

A long pole with a flat end, used to row a boat.

#### **sail**

A big piece of cloth that catches the wind to push a boat.

### CORE IDEAS

**The story.** About a thousand years ago, the Vikings lived in the cold, rocky lands of Norway, Denmark and Sweden. They were farmers, traders and bold explorers. Their ships carried them across stormy seas to Iceland and Greenland, and Leif Erikson even reached North America, about five hundred years before Columbus. In

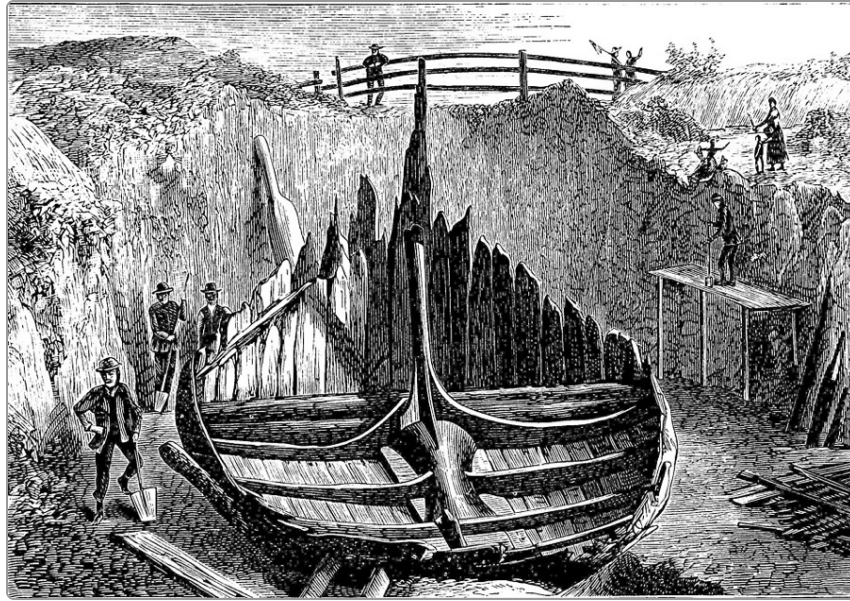
1880, farmers in Norway dug into a big mound of earth and found an old Viking ship buried in blue clay. The clay had kept the oak wood from rotting. We call it the Gokstad ship.

**How they figured it out.** Viking builders split oak logs into long, thin planks with axes and wedges. They laid each plank so it overlapped the one below it, like shingles on a roof, and fastened them with iron rivets. This is called **clinker-built**. It made a hull that was light, strong and a little bendy, so it could flex in the waves instead of cracking. Down the middle of the bottom ran a strong **keel**, cut from one long tree. In 1893, a Norwegian captain named Magnus Andersen built a copy of the Gokstad ship and sailed it across the Atlantic Ocean in about four weeks, and then on to Chicago. That proved how good the old design was.

**The physics.** Wind pushing on a sail does not always blow the way you want to go. Without a keel, a boat slides sideways across the water. A **keel** sticks down into the water like a fin. The water pushes against its flat sides and stops the boat from sliding, so the boat goes forward instead. The keel also makes the boat steadier.

**The engineering.** Viking ships could use a big square **sail** in the wind, or **oars** when the wind died. They sat so shallow in the water that they could sail up rivers and land right on a beach. Boat builders in Norway and Denmark still build boats the Viking way, and many small wooden boats today are still clinker-built.

## PICTURE STUDY



*The Gokstad Ship Uncovered*, Unknown engraver, from *Popular Science Monthly*, 1880–1881 · Wood engraving · *Popular Science Monthly*, Volume 19  
Image: [Wikimedia Commons](#), public domain

When the Gokstad ship was found, magazines around the world printed pictures of it. This engraving shows the ship still in the pit where it was dug up.

### Look closely

- Find the tall, curved front of the ship. That is the bow.
- Find the long keel along the bottom.
- Look at the side of the hull. Can you see the planks overlapping?
- Find the people. How big is the ship compared to them?

### Talk about it

1. Why did the wood last so long in the clay?
2. Why would overlapping planks make a strong but bendy hull?
3. How did the Viking sailors move when there was no wind?

**Safety first.** Keep fingers, hair and loose paper away from the fan, and keep the fan away from the water. A grown-up should set it up.

## BUILD

### The Keel Test

You will build a little sailboat and blow it across a tub with a fan, first without a keel and then with one. You will measure how far it drifts off course.

#### You will need

- A foam tray, a clean plastic food container or half of a milk carton cut the long way, for the hull
- A straw or wooden skewer for the mast, and a piece of paper for the sail
- A craft stick or a strip of plastic for the keel
- Modeling clay and tape
- A long tub or bathtub with a few inches of water
- A small fan (or blow through a straw) and a ruler
- Engineer's notebook

#### Steps

1. Stick the mast in a ball of clay in the middle of the hull. Tape a paper sail to it.
2. Put a piece of tape on the edge of the tub at one end as the “start,” and one straight across at the other end as the “harbor.”
3. Set the fan so it blows a little from the side, not straight down the tub.
4. **Predict.** Will the boat reach the harbor? Write your guess.
5. Let the boat go at the start. Measure how far from the harbor mark it lands. Do it three times.
6. Tape the craft stick straight down under the middle of the hull, from front to back, like a keel. Test it three times the same way.
7. Write both sets of numbers. Did the keel help the boat go straighter?
8. **Improve.** Try a longer keel, a deeper keel, or moving the sail. Change one thing at a time.

#### Tips

- Keep the fan in the same spot for every test.

- A small ball of clay on the keel can help keep the boat upright.

#### Check your work

- ☐ I can tell how the Vikings built their ships.
- ☐ I can tell what a keel does.
- ☐ I can show my test results with and without a keel.

#### ENGINEER'S NOTEBOOK

1. Draw a Viking longship and label the keel, the sail, the oars and the overlapping planks.
2. Draw your boat from below with and without its keel. Write how far off course each went.
3. Draw arrows showing the wind on the sail and the water pushing on the keel.

**From history.** The real Gokstad ship is about 76 feet long and had places for 32 oars. You can still see it today in a museum in Oslo, Norway.

#### COMMON MISTAKES

- Thinking the keel makes the boat go. The wind or oars make it go; the keel keeps it going straight.
- Moving the fan between tests.

**Make it a game • Keel Straight Race.** Push two clay-and-foil boats across a tub, one with a keel and one without. Watch which goes straight and which wanders. Say keel and oar. Tell your parent how the Vikings built long, fast ships. Then draw a longship from the side and label the keel, the oar and the sail.

**Scripture.** “Behold also the ships, which though they be so great, and are driven of fierce winds, yet are they turned about with a very small helm, whithersoever the governor listeth.” (James 3:4, KJV)

A small rudder steers a big ship. James says our small tongue steers our whole life, so we should guide our words well.

## 6.4 ROBERT FULTON'S STEAMBOAT

### OBJECTIVES

- Tell the story of Robert Fulton's first steamboat trip up the Hudson River.
- Explain how a paddle wheel pushes a boat forward.
- Build a rubber-band paddle boat and test how the number of twists changes how far it goes.

**Warm-up.** Sit in the bathtub or by a tub of water and paddle the water backward with your hand. Which way does the water go? Which way would a boat go?

### WATCH

#### Robert Fulton and the Steamboat for Kids | Little Patriots Course 18

Little Patriots • 6:15

<https://www.youtube.com/watch?v=w3Toqajxl88>

### WHEN TO WATCH

After the story.

### BACKUP VIDEO

#### Invention of the Steamboat

NBC News Learn • 2:01

<https://www.youtube.com/watch?v=2QXq5D37YEw>

With the engineering paragraph, to see drawings of Fulton's boat.

### KEY TERMS

#### **steam engine**

A machine that uses the push of hot steam to make things move.

#### **paddle wheel**

A wheel with flat boards that dip into the water and push it backward, so the boat moves forward.

#### **current**

Water in a river moving in one direction.

#### **push back, go forward**

When something pushes water backward, the water pushes it forward.

## CORE IDEAS

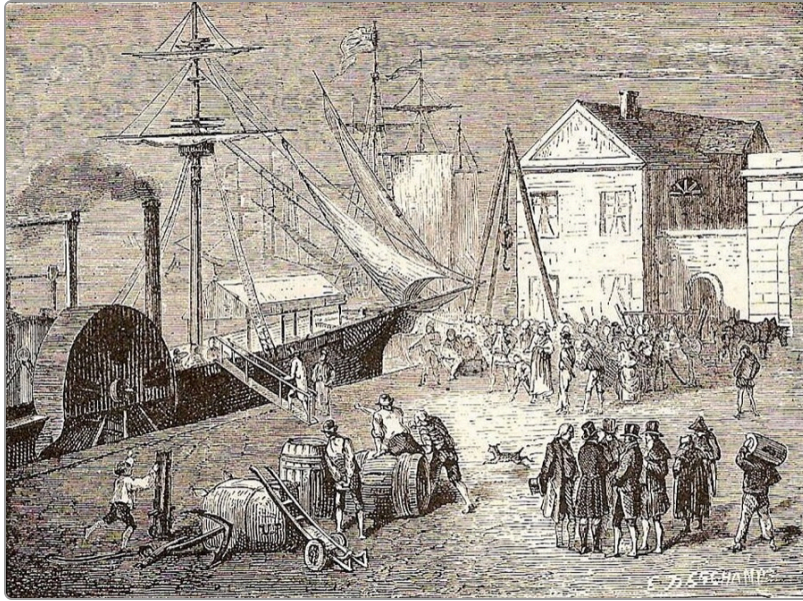
**The story.** Long ago, boats on rivers moved by sails, oars or the river's **current**. Going downstream was easy. Going upstream against the current was slow and hard, and when the wind stopped, sailboats stopped too. Robert Fulton, an American painter who became an engineer, wanted to build a boat that could go anywhere, any time, by steam.

**How he figured it out.** Fulton studied other people's steamboats, many of which had failed. He tested models in water to find the best shape and the best paddle wheels. He bought a strong **steam engine** from England and built a long, narrow boat. People laughed and called it "Fulton's Folly." On August 17, 1807, it left New York City and steamed up the Hudson River. It reached Albany, about 150 miles away, in 32 hours. A sailboat often took four days. People along the river ran to the shore to watch it chug past, puffing smoke. The boat later became known as the *Clermont*. It began the first regular steamboat service in America.

**The physics.** The steam engine turned two big **paddle wheels**, one on each side of the boat. As each wheel turned, its flat paddles dipped into the water and pushed it backward. When you push water back, the water pushes you forward. It is the same thing that happens when you swim or row a canoe.

**The engineering.** Steamboats soon carried people and goods up and down the great rivers of America, like the Mississippi. Engineers kept making them better: stronger and safer boilers, bigger wheels, and later, propellers under the water instead of paddle wheels on the sides. Most big ships today use propellers, but they still work by pushing water backward.

## PICTURE STUDY



*Robert Fulton Boards His Steamboat, the Clermont, 1807*, Unknown engraver, 1867 (showing the year 1807) · Wood engraving · From a nineteenth-century book

Image: [Wikimedia Commons](#), public domain

Many years after the first trip, an artist imagined the busy dock in New York City as Robert Fulton's steamboat got ready to leave. Look for the parts that make it go.

### Look closely

- Find the tall smokestack. What does it tell you about the engine?
- Find the big round cover on the side of the boat. What is hidden inside it?
- Find the sailing ship next to it. How was it pushed?
- Find the crowd. What do you think the people are saying?

### Talk about it

1. Why was going upriver so hard before steamboats?
2. How does a paddle wheel push a boat forward?
3. Why did people call it "Fulton's Folly" at first? Were they right?

**Safety first.** Have a grown-up nearby when you work with a tub of water. Wear safety glasses while winding the rubber band, in case it snaps. An adult should cut the cardboard and plastic.

## BUILD

### A Rubber-Band Paddle Boat

You will build a small boat with a paddle wheel turned by a twisted rubber band. You will test how far it goes with different numbers of twists.

#### You will need

- A clean half-gallon juice or milk carton, or a block of foam, for the hull
- Two pencils or wooden craft sticks for the arms that hold the paddle
- A strong rubber band
- A piece of plastic lid or thick card, cut into two rectangles that fit together in an X, for the paddle
- Tape and a tub or bathtub of water
- A ruler or tape measure
- Engineer's notebook

#### Steps

1. Have an adult cut the carton in half the long way to make a flat boat. Tape the two pencils to the sides so they stick out past the back end, like two arms.
2. Stretch the rubber band between the ends of the two arms.
3. Slide the two plastic rectangles together into an X. Push them into the middle of the rubber band, between its two strands. This is your paddle wheel.
4. Wind the paddle backward 10 turns, holding it so it cannot unwind.
5. **Predict.** How far will the boat go? Write your guess.
6. Set the boat in the water and let go. Measure how far it goes. Do it three times with 10 turns.
7. Test again with 20 turns, then 30 turns. Write all the numbers in a table.
8. **Improve.** Try a bigger paddle, a different hull or winding the other way. Does it go backward? Change one thing and test again.

#### Tips

- The paddle must turn freely and not hit the boat.
- Count the turns carefully. That is the one thing you are changing.

### Check your work

- ☐ I can tell the story of Fulton's steamboat.
- ☐ I can tell how a paddle wheel pushes a boat.
- ☐ I can tell what my test showed about the number of twists.

### ENGINEER'S NOTEBOOK

1. Draw your paddle boat and label the hull, the arms, the rubber band and the paddle.
2. Make a table and bar graph: 10, 20 and 30 turns, and how far the boat went.
3. Draw arrows showing the paddle pushing water back and the boat going forward.

**From history.** Fulton's partner in the steamboat business was Robert Livingston, who had helped write the Declaration of Independence. Fulton also designed one of the first working submarines and drew up plans for canals.

### COMMON MISTAKES

- Winding the paddle the wrong way. Then the boat goes backward!
- Changing the number of turns and the paddle size at the same time.

**Make it a game • Fulton's Paddle Boat.** Wind a rubber-band paddle boat and release it in a tub. Time how far it travels in seconds, counting out loud. Then try with a bigger paddle. Say paddle wheel, push back and go forward. Tell the story of Robert Fulton's first trip up the Hudson River, then try to beat your time.

## UNIT 6

# BOATS

“They that go down to the sea in ships, that do business in great waters; these see the works of the LORD, and his wonders in the deep.” People have built boats for as long as there have been people. In this unit you will learn why a heavy boat floats, from the story of Archimedes and the king’s crown. You will see why the shape of a hull matters, and you will look at the shape God gave Noah for the ark. You will sail with the Vikings in their long, fast ships, and ride up the Hudson River on Robert Fulton’s steamboat.

You will measure how much water things push aside, build foil boats and count how many pennies they carry, add a keel to keep a boat sailing straight, and power a paddle boat with a rubber band. Always have a grown-up nearby when you work with a tub or sink of water.

### PREREQUISITES

- Knows how to make a fair test by changing only one thing
- Can count pennies and measure with a ruler
- Knows that gravity pulls things down (Unit 1)

### MASTERY CHECKLIST

- ☐ I can tell the story of Archimedes and the crown, and show that a floating thing pushes water aside.
- ☐ I can show that the shape of a boat changes how much it can carry.
- ☐ I can tell how Viking ships were built and why a keel helps a boat go straight.
- ☐ I can tell how Robert Fulton’s steamboat worked and how a paddle wheel pushes a boat.

## OPTIONAL KITS FOR THIS UNIT

- **Thames & Kosmos science kits:** Ages vary by kit. Their range includes boat-building kits with sail, paddle and propeller boats to test in the tub. Fits Lessons 6.2–6.4.
- **LEGO Education:** Ages 6 and up for the early sets. Bricks can be built into floating hulls and paddle wheels for tub tests. Fits Lessons 6.2 and 6.4.

Not required. Every project in this unit can be built with household materials. School Launch has no ties to these companies.

## LESSONS IN THIS UNIT

|     |                                                |                             |
|-----|------------------------------------------------|-----------------------------|
| 6.1 | Archimedes and the King's Crown                | 2 sessions of 30–40 minutes |
| 6.2 | Hull Shape and Load: The Ark and the Foil Boat | 2 sessions of 30–40 minutes |
| 6.3 | Viking Longships                               | 2 sessions of 30–40 minutes |
| 6.4 | Robert Fulton's Steamboat                      | 2 sessions of 30–40 minutes |

## UNIT 6 REVIEW

A parent asks these questions aloud. Your child may answer by telling, pointing, drawing or showing with the builds from this unit. There are no points. Listen for understanding and praise careful answers.

1. Tell the story of Archimedes and the king's crown. How did he catch the goldsmith?
2. Show me with clay: why does a ball of clay sink, but a clay bowl float?
3. Which of your foil boats carried the most pennies? Why?
4. How big did God tell Noah to make the ark?
5. Show me a keel on your boat. What does it do?
6. How did Robert Fulton's steamboat move up the river against the current?

#### ANSWER KEY

1. He put the crown and the same weight of pure gold in water. The crown pushed aside more water, so it was not pure gold.
2. The bowl shape pushes aside more water, enough to equal its own weight, so the water holds it up.
3. Usually the long, wide boat with medium sides. It pushed aside the most water without tipping or letting water in.
4. Three hundred cubits long, fifty cubits wide and thirty cubits high.
5. It sticks down into the water and keeps the boat from sliding sideways, so it goes straight.
6. A steam engine turned paddle wheels that pushed the water backward, so the boat moved forward.

#### PORTFOLIO PIECE: MY BEST BOAT

Design and build one boat that combines what you learned: a hull shape that carries a big load, a keel to go straight, and a sail or paddle wheel to make it go. Test how many pennies it can carry and how far it travels across the tub. Improve it once, and show your family the boat and your notebook pages.

| LOOK FOR                  | WHAT IT MEANS                                                     |
|---------------------------|-------------------------------------------------------------------|
| <b>Floats and carries</b> | Counted how many pennies the boat carried before sinking.         |
| <b>Goes straight</b>      | Used a keel or rudder and showed that it helped.                  |
| <b>Moves</b>              | Used a sail or a paddle wheel and measured how far the boat went. |
| <b>Improving</b>          | Changed one thing after the first test and tried again.           |

## UNIT 7

# FLIGHT

People have always watched the birds and wished they could fly. “They shall mount up with wings as eagles,” wrote the prophet Isaiah. In this unit you will meet the people who learned how. Sir George Cayley figured out the four forces that act on anything that flies. Alexander Graham Bell, the inventor of the telephone, built giant kites out of triangles. Wilbur and Orville Wright made the first airplane flight in 1903. And Igor Sikorsky built a helicopter that spins its wings like a maple seed.

You will fly paper airplanes and test them fairly, build and fly a kite, add steering flaps to a glider, and drop paper helicopters to see which falls most slowly. Measure every flight and write it down, just as the Wright brothers did.

### PREREQUISITES

- Knows that gravity pulls things down (Unit 1)
- Knows that triangles are strong (Unit 2)
- Can measure distances with a tape measure and time with a stopwatch, with help

### MASTERY CHECKLIST

- ☐ I can name the four forces of flight: lift, weight, thrust and drag.
- ☐ I can tell how a kite flies and the kite safety rules.
- ☐ I can tell the story of the Wright brothers’ first flight.
- ☐ I can tell how a maple seed and a helicopter use spinning wings.
- ☐ I can run a fair test on something that flies and record the results.

### OPTIONAL KITS FOR THIS UNIT

- **KiwiCo Kiwi Crate**: Ages 5–8. A monthly box with one hands-on build. Some crates are flying projects, such as gliders, launchers and spinners, which fit Lessons 7.1–7.4.
- **KiwiCo Tinker Crate**: Ages 9 and up, but a seven-year-old can build many with a parent. Some crates are flight projects with notes on the science. Fits Lessons 7.3 and 7.4.

Not required. Every project in this unit can be built with household materials. School Launch has no ties to these companies.

## LESSONS IN THIS UNIT

|                                                 |                             |
|-------------------------------------------------|-----------------------------|
| <b>7.1 The Four Forces of Flight</b>            | 2 sessions of 30–40 minutes |
| <b>7.2 Kites and Alexander Graham Bell</b>      | 2 sessions of 30–40 minutes |
| <b>7.3 The Wright Brothers Fly</b>              | 2 sessions of 30–40 minutes |
| <b>7.4 Helicopters and Spinning Maple Seeds</b> | 2 sessions of 30–40 minutes |

## UNIT 7 REVIEW

A parent asks these questions aloud. Your child may answer by telling, pointing, drawing or showing with the builds from this unit. There are no points. Listen for understanding and praise careful answers.

1. Point to the four forces on your paper airplane and name them.
2. How does a wing or a kite make lift?
3. Tell me three kite safety rules.
4. Tell the story of the first flight. Who flew, when, and how far?
5. Show me with your glider: how do you make it turn?
6. How is a helicopter like a maple seed? What does the tail rotor do?

### ANSWER KEY

1. Lift (up), weight (down), thrust (forward), drag (back).
2. It is tilted so it turns the air downward. The air pushes back up on it. The air on top also pushes less than the air below.
3. Fly only in open places away from power lines, trees, roads and airports; never in rain or thunder; if the kite catches in a power line, let go and tell a grown-up.
4. Orville Wright, on December 17, 1903, at Kitty Hawk, North Carolina. He flew 12 seconds, about 120 feet.
5. Bend one flap up and the other down, like the Wrights' wing warping.
6. Both have spinning wings that push on the air. The tail rotor keeps the helicopter's body from spinning around.

### PORTFOLIO PIECE: MY FLIGHT TEST REPORT

Choose your best flying build from this unit: the paper airplane, the kite, the glider or the paper helicopter. Make it better one more time, then test it five times and write down every result. Make a report like the Wrights did: a drawing with labels, a table of your measurements, and one sentence about what you changed and what happened. Show it to your family and fly it for them.

| LOOK FOR           | WHAT IT MEANS                                                                 |
|--------------------|-------------------------------------------------------------------------------|
| <b>Four forces</b> | Labeled lift, weight, thrust and drag on the drawing, or told where they act. |
| <b>Fair test</b>   | Launched the same way from the same spot every time.                          |
| <b>Records</b>     | Wrote down all five results in a table with a date.                           |
| <b>Improving</b>   | Made one change and told what happened.                                       |

## 7.1 THE FOUR FORCES OF FLIGHT

### OBJECTIVES

- Name the four forces of flight: lift, weight, thrust and drag.
- Tell how Sir George Cayley worked out what a flying machine needs.
- Test how adding weight to a paper airplane changes how far it flies.

**Warm-up.** Hold a sheet of paper flat by its two short edges, just under your lower lip, so it droops down. Blow hard straight out across the top of it. What does the paper do? Now drop a flat sheet and a crumpled sheet at the same time. Which falls slower, and why?

### WATCH

#### How Airplanes Fly! | Airplane Science | SciShow Kids

SciShow Kids · 4:30

<https://www.youtube.com/watch?v=VLpSxHwfU04>

### WHEN TO WATCH

After the story, before the physics.

### KEY TERMS

#### **lift**

The upward push of the air on a wing.

#### **weight**

The pull of gravity down on the airplane.

#### **thrust**

The forward push from a throw, a propeller or an engine.

#### **drag**

The backward push of the air that slows a flying thing down.

#### **glider**

An aircraft with wings but no engine.

### CORE IDEAS

**The story.** More than two hundred years ago in England lived Sir George Cayley. As a boy he loved to watch birds and wondered how they stayed up. Most people who tried to fly built machines with flapping wings, like a bird's, and none of them worked. Cayley wanted to understand flight first.

**How he figured it out.** Cayley studied birds and tested model wings, measuring how much they lifted. He saw that flying could be split into separate jobs. Fixed wings could hold a machine up. Something else could push it forward. A tail could keep it steady. In 1804 he flew a small model **glider** with a kite-shaped wing and a tail. Years later, in 1853, he built a glider big enough to carry a man. His coachman rode it across a little valley on Cayley's land. The story says the coachman was so scared that he said he was hired to drive, not to fly!

**The physics.** Cayley found the four forces that act on anything that flies. **Weight** pulls it down. **Lift** pushes it up. **Thrust** pushes it forward. **Drag** pulls it back. A wing makes lift by turning the air that flows past it downward. When the wing pushes air down, the air pushes the wing up. The air pressing on top of the wing also pushes less than the air underneath, which helps hold the wing up too.

**The engineering.** To fly, a plane needs enough lift to beat its weight, and enough thrust to beat its drag. Engineers make airplanes as light as they can, with smooth, pointed shapes to cut drag, and with wings shaped and tilted just right for lift. A glider has no engine, so it has no thrust of its own. It slowly trades height for speed as it glides down, the way the space shuttle glided all the way to its landing.

## PICTURE STUDY



*The Space Shuttle Enterprise in Free Flight*, NASA, September 26, 1977 · Photograph · NASA Dryden Flight Research Center, California

Image: [Wikimedia Commons](#), public domain

Before any shuttle went to space, NASA tested whether it could glide safely back to the ground. A big jet carried the *Enterprise* high in the sky and let it go. It had no engines running, so it glided down like a giant paper airplane.

### Look closely

- Find the wings. Which force do they make?
- Find the tall tail fin. What do you think it helps with?
- Find the pointed cone on the back. Engineers added it to make the drag smaller.
- Look for any engine flames. Are there any?

### Talk about it

1. Which of the four forces was missing during this flight?
2. How could the shuttle keep flying without an engine?
3. Why would engineers test a spacecraft as a glider first?

**Safety first.** Throw paper airplanes away from faces and people's eyes, and only in an open room or yard.

## BUILD

### The Paper Airplane Weight Test

You will fold a paper airplane, throw it the same way several times, and measure how far it flies. Then you will add paper clips to change its weight and see what happens.

#### You will need

- Several sheets of printer paper, all the same
- Paper clips
- A tape measure and masking tape
- A long hallway or open room
- Engineer's notebook

#### Steps

1. Fold a simple dart paper airplane. (A grown-up can help with the folds.)
2. Put a strip of tape on the floor for a starting line. Always throw from the line, with the same gentle push.
3. Throw the airplane three times. Measure each flight from the line to where it first touches the floor. Write the numbers.
4. **Predict.** What will happen if you add a paper clip to the nose? Write your guess.
5. Clip one paper clip to the nose. Throw three times and measure. Then try two paper clips, then three.
6. Make a table: number of clips, three distances, and the best distance.
7. **Improve.** Move one clip to the back of the plane instead. What happens? Find the best spot for the clip and test it.

#### Tips

- Throw the same way every time. Your throw is the thrust, so keep it the same.
- Use the same plane for all tests. Only the weight should change.

#### Check your work

- ☐ I can name the four forces of flight.
- ☐ I can point to where each force acts on my paper airplane.
- ☐ I can tell what adding weight did to my plane's flights.

#### ENGINEER'S NOTEBOOK

1. Draw your paper airplane. Draw four arrows and label them lift, weight, thrust and drag.
2. Fill in your table of paper clips and distances.
3. Draw Cayley's glider with its wing and tail, and the coachman riding in it.

**From history.** Cayley was also an engineer of many other things. He invented a new kind of lightweight wheel with thin wire spokes pulled tight, the same idea used in bicycle wheels today.

#### COMMON MISTAKES

- Throwing harder on some tries than others. That changes the thrust.
- Thinking more weight always means a worse flight. A little weight in the nose can make a plane fly steadier.

**Make it a game • Four Forces Acting.** Act out the four forces with your body. Lift your arms for lift, drop them for weight, push forward for thrust and lean back for drag. Your parent calls a force and you act it out within three seconds. Then test a paper airplane with and without a paperclip. Tell how Sir George Cayley studied flying machines.

## 7.2 KITES AND ALEXANDER GRAHAM BELL

### OBJECTIVES

- Tell how Alexander Graham Bell built giant kites out of triangle-shaped cells.
- Explain how the wind lifts a kite and why a kite needs a string and a tail.
- Build a kite and test how the length of its tail changes how steadily it flies.

**Warm-up.** Hold a sheet of card stock flat in front of a fan or out a car window (with a grown-up). Tilt the front edge up a little. What does the card do? Tilt it more. What happens?

### WATCH

#### Let's Make a Kite! | Science Project for Kids

SciShow Kids · 4:30

[https://www.youtube.com/watch?v=mc3AUuuj9\\_I](https://www.youtube.com/watch?v=mc3AUuuj9_I)

### WHEN TO WATCH

Before the build.

### BACKUP VIDEO

#### Alexander Graham Bell Thought the Future of Flight was Giant Kites

Concerning Reality · 4:16

<https://www.youtube.com/watch?v=HjZBpT0BVX8>

With the story, to see old films and photographs of Bell's kites.

### KEY TERMS

#### **kite**

A light frame covered with paper or cloth that the wind holds up while a string holds it down.

#### **angle**

How much something is tilted.

#### **tetrahedron**

A shape made of four triangles, like a pyramid with a triangle for its bottom.

#### **tail**

A long strip at the bottom of a kite that keeps it pointing into the wind.

## CORE IDEAS

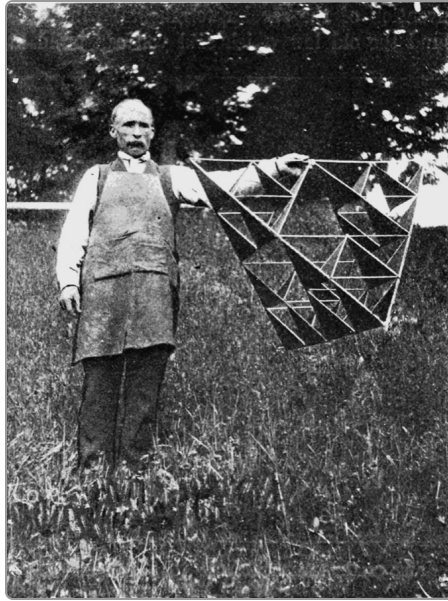
**The story.** Alexander Graham Bell is famous for inventing the telephone. But for many summers at his home in Nova Scotia, Canada, Bell worked on something else: kites. He wanted to build a kite big and strong enough to carry a person into the air. He wanted it to be safe and steady, so that if anything went wrong it would float gently down.

**How he figured it out.** Bell needed a kite that was strong but very light. He remembered that triangles are strong. So he built little kite cells shaped like a **tetrahedron**, a shape made of four triangles. Each cell was made of thin sticks and covered with red silk on two sides. Then he joined many cells together, like building blocks. The more cells he added, the bigger the kite got, but it stayed just as strong for its size. His wife, Mabel, helped plan and pay for the work. In 1907 his giant kite, made of more than three thousand cells, lifted a man about 168 feet up over the water.

**The physics.** A kite flies tilted at an **angle** to the wind. The wind hits the tilted kite and is turned downward, so the air pushes the kite up. That is lift, just like a wing. The string pulls the kite down and back, holding it in place so the wind can keep pushing on it. The **tail** adds a little weight and drag at the bottom, so the kite keeps its nose pointed into the wind and does not spin around.

**The engineering.** Kites were among the first flying machines that people tested. The Wright brothers flew a big kite to test their ideas before they built their gliders. Weather scientists once flew kites with instruments to measure the wind and the air up high. Engineers still use Bell's idea of building big, light frames out of many small triangles, in towers, bridges and roofs.

## PICTURE STUDY



*A Sixteen-Celled Tetrahedral Kite*, Photograph published in *Popular Science Monthly*, 1903–1904 ·

Photograph · *Popular Science Monthly*, Volume 64

Image: [Wikimedia Commons](#), public domain

Bell wrote about his kites in a magazine and included this photograph. One of his workers holds up a kite made of sixteen tetrahedral cells.

### Look closely

- Count the triangles you can find in the kite.
- Find where some of the cells are covered and some are open.
- Look at the size of the kite next to the man. Is it heavy or light?
- Find the long sticks that join the cells together.

### Talk about it

1. Why did Bell build his kite from triangles?
2. What would happen if he added more cells?
3. How is this kite like a truss bridge?

**Safety first.** Fly kites only in a wide open field or beach, far from power lines, trees, roads and airports. Never fly a kite in rain or when there is thunder or lightning. If a kite gets caught in a power line, let go of the string and tell a grown-up; never try to pull it down.

## BUILD

### A Paper Kite and the Tail Test

You will build a simple paper kite, fly it in a steady breeze, and test how the length of its tail changes how steadily it flies.

#### You will need

- A large sheet of paper or a thin plastic bag, about 16 by 20 inches
- Two thin wooden dowels or long straws, one about 16 inches and one about 12 inches
- Strong tape and string (kite string or thread, about 50 feet, wound on a stick)
- Crepe paper streamers or strips of plastic bag for tails
- A ruler, a marker and a timer
- Engineer's notebook

#### Steps

1. Lay the long stick down the middle of the paper and the short stick across it, about a third of the way down, to make a cross. Tape them on.
2. Draw lines from the tip of each stick to the next and cut out a diamond shape. Fold the edges over and tape them.
3. Poke a small hole where the sticks cross, reinforced with tape. Tie the string there.
4. Tape a tail 2 feet long to the bottom point.
5. **Predict.** Will a short tail or a long tail make the kite fly more steadily? Write your guess.
6. In an open field with a steady breeze, let out the string slowly. Count how many times the kite loops or dives in one minute. Write the number.
7. Try the same kite with a tail 4 feet long, then 6 feet long. Count the loops and dives each time.
8. **Improve.** Try moving where the string is tied, a little higher or lower. Which spot makes the kite fly best?

### Tips

- A steady breeze is best. If the wind is too strong, the kite will dive no matter what.
- Let out string slowly and keep it tight.

### Check your work

- ☐ I can tell how Bell built his kites from triangles.
- ☐ I can tell how the wind lifts a kite.
- ☐ I can tell the kite safety rules.

### ENGINEER'S NOTEBOOK

1. Draw your kite in the sky. Draw arrows for the wind, the lift, the weight and the pull of the string.
2. Make a table: tail length and number of loops and dives in one minute.
3. Draw one tetrahedral cell. Count its triangles.

**From history.** Bell named one of his giant kites the *Cygnet*, which means a young swan. It was towed by a boat across a lake to get it into the air. Bell and his friends later went on to build early airplanes too.

### COMMON MISTAKES

- Flying in gusty, changing wind. It makes a fair test impossible.
- Making the tail too heavy. It should be long but light.

**Make it a game • Kite Tail Test.** Fly your paper kite on a string or run with it, first with no tail, then with a short tail, then with a long tail. Score how steady it stays out of five. Say tetrahedron, angle and tail. Tell your parent how Alexander Graham Bell built giant kites out of triangle cells.

**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)

An eagle rises on the wind with hardly a flap of its wings. Isaiah says God lifts up those who trust Him, the way the wind lifts the eagle.

## 7.3 THE WRIGHT BROTHERS FLY

### OBJECTIVES

- Tell the story of the Wright brothers' first flight on December 17, 1903.
- Explain how the Wrights steered their airplane by changing the shape of the wings.
- Build a paper glider with flaps and test how bending the flaps changes the way it flies.

**Warm-up.** Hold your arms out like wings and pretend to fly. How would you turn left? How would you go up? Try tipping your arms. A bird does something like this with its wing tips.

### WATCH

#### Biography of the Wright Brothers for Children: Orville and Wilbur Wright for Kids - FreeSchool

Free School · 7:28

<https://www.youtube.com/watch?v=Qt3pry6cWJM>

### WHEN TO WATCH

After the story.

### BACKUP VIDEO

#### The Wright Brothers, First Successful Airplane (1903)

Simple History · 2:29

[https://www.youtube.com/watch?v=YDlk4Ky\\_ahs](https://www.youtube.com/watch?v=YDlk4Ky_ahs)

A short cartoon retelling of the first flight, good for telling the story back.

### KEY TERMS

#### **pilot**

The person who flies and steers an aircraft.

#### **elevator**

A small wing that tips the nose of an airplane up or down.

#### **wing warping**

The Wrights' way of steering by twisting the ends of the wings.

#### **propeller**

Spinning blades that push air backward to pull an airplane forward.

## CORE IDEAS

**The story.** Wilbur and Orville Wright grew up in Dayton, Ohio. Their father, Milton Wright, was a bishop in his church, and their home was full of books. When they were boys, their father brought home a little toy helicopter powered by a rubber band, and they played with it until it broke. They never stopped wondering about flight. When they grew up, they ran a bicycle shop, where they built and fixed bicycles.

**How they figured it out.** The Wrights read everything they could about flying. They decided the hardest problem was steering and balance. Watching birds, Wilbur saw that they twist the tips of their wings to turn. So the brothers built wings that the **pilot** could twist, called **wing warping**. They tested it first on a kite, then on gliders, on the windy sand hills of Kitty Hawk, North Carolina. Their first gliders did not lift as much as they expected, so they built a wind tunnel in their shop and tested about two hundred little wing shapes. They wrote down every result. Then they built an engine and two **propellers**. On December 17, 1903, Orville lay on the lower wing of the *Flyer*. It lifted off the ground and flew for 12 seconds, about 120 feet. It was the first time a person flew in a powered airplane that he could control. That day they flew three more times, and the longest flight, by Wilbur, lasted 59 seconds.

**The physics.** The Flyer had all four forces. The engine turned the propellers, which pushed air back and made thrust. The long wings made lift. The **elevator** in front tipped the nose up or down. Wing warping tipped one wing up and the other down, to roll into a turn. A rudder at the back helped the nose swing around smoothly.

**The engineering.** The Wrights were careful engineers. They solved one problem at a time, tested in the cheapest and safest way first, and trusted their measurements. They built almost everything themselves. Today, airplanes use flaps on the wings called ailerons instead of wing warping, but they still roll, pitch and turn just as the Wrights learned to do.

## PICTURE STUDY



*The First Flight*, John T. Daniels, December 17, 1903 · Glass-plate photograph · Library of Congress

Image: [Wikimedia Commons](#), public domain

The Wrights set up their camera before the flight and asked a man from the nearby lifesaving station, John T. Daniels, to squeeze the button. He had never taken a picture before. He caught the airplane just as it lifted off.

### Look closely

- Find Orville. He is lying on the lower wing, flying the airplane.
- Find Wilbur on the right. He had been running beside the wing to steady it.
- Find the long wooden rail on the sand. That was the runway.
- Find the elevator out in front of the wings.

### Talk about it

1. Why do you think Wilbur ran beside the wing?
2. Why did the Wrights fly at Kitty Hawk, where there was strong wind and soft sand?
3. Why is this photograph so important?

**Safety first.** Throw gliders away from faces, in an open room or yard.

## BUILD

### A Paper Glider with Steering Flaps

You will fold a paper glider and cut small flaps at the back of its wings. By bending the flaps, you will make the glider climb, dive and turn, like the Wrights steering the Flyer.

#### You will need

- Printer paper
- Scissors (with a grown-up)
- A paper clip
- A tape measure and masking tape
- Engineer's notebook

#### Steps

1. Fold a paper glider with wide wings. Clip a paper clip on the nose.
2. With a grown-up, cut two small slits about half an inch long in the back edge of each wing, about an inch apart, to make four little flaps.
3. Leave all the flaps flat. Throw the glider gently from a starting line three times. Measure how far it goes and watch which way it turns.
4. **Predict.** What will happen if you bend both back flaps up a little? Write your guess.
5. Bend both flaps up. Throw three times. Does the nose go up or down? Write what you see.
6. Now bend the left flap up and the right flap down. Throw three times. Which way does it turn? Then try the other way.
7. **Improve.** Use the flaps to make your glider fly as straight and as far as it can. Measure your best flight.

#### Tips

- Bend the flaps only a little at first. Small changes make a big difference.
- Throw gently and the same way every time.

#### Check your work

- ☐ I can tell the story of December 17, 1903.
- ☐ I can tell how the Wrights steered the Flyer.
- ☐ I can make my glider turn left or right by bending its flaps.

#### ENGINEER'S NOTEBOOK

1. Draw your glider from behind. Show the flaps up, down or flat, and draw an arrow for which way it turned.
2. Make a table: flap setting, distance, and what the glider did.
3. Draw the Wright Flyer and label the wings, the elevator, the propellers and the pilot.

**From history.** The real 1903 Flyer hangs today in the Smithsonian's National Air and Space Museum in Washington, D.C. In 1969, the astronaut Neil Armstrong carried a small piece of its wing fabric with him to the moon.

#### COMMON MISTAKES

- Bending the flaps too far. Then the glider flips or dives.
- Changing two things at once. Change one flap setting at a time.

**Make it a game • Wing Warp Steering.** Build a paper glider with flaps that bend. Before each throw, call your steering, such as left or right. Bend a flap and toss it. Did it turn the way you called? Count your correct turns out of five. Say wing warping and pilot. Tell how the Wright brothers first flew in 1903.

**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 the secrets of flight in His creation for people to search out. The Wrights searched patiently, one test at a time.

## 7.4 HELICOPTERS AND SPINNING MAPLE SEEDS

### OBJECTIVES

- Explain how a maple seed spins and floats slowly down.
- Tell how Igor Sikorsky built a working helicopter.
- Build paper helicopters and test how the length of the blades changes how slowly they fall.

**Warm-up.** If you can find maple seeds outside, toss a few into the air and watch them fall. (If not, drop a flat paper square and a paper square with two flaps folded down.) What do you see? Why do you think the seeds spin?

### WATCH

#### Maple tree DIY helicopter seed

American Museum of Science and Energy · 2:26

<https://www.youtube.com/watch?v=5-sd9gjH6PQ>

### WHEN TO WATCH

Before the build.

### BACKUP VIDEO

#### How do helicopters fly? | Discovery Space

Airbus Helicopters · 1:39

<https://www.youtube.com/watch?v=by4bT9y09zc>

After the engineering paragraph, to see how a pilot controls the spinning blades.

### KEY TERMS

#### **helicopter**

An aircraft that flies with spinning wings on top, so it can go straight up, hover and land almost anywhere.

#### **rotor**

The set of spinning blades on a helicopter.

#### **blade**

One of the long, thin wings on a rotor.

#### **hover**

To stay still in the air.

## CORE IDEAS

**The story.** God gave the maple tree a clever way to spread its seeds. Each seed has a thin wing. When it falls, it spins around and around and drifts slowly down, so the wind can carry it far from the tree. More than five hundred years ago, Leonardo da Vinci drew a flying machine with a spinning screw on top. It could never have flown, but it showed he was thinking about spinning wings. Many inventors tried to build a **helicopter**, but their machines shook, spun around or would not lift.

**How he figured it out.** Igor Sikorsky grew up in Russia and loved flying machines. As a young man he built two helicopters, and neither one could lift him. So he built airplanes instead and became a famous airplane builder in America. But he never forgot his dream. Thirty years later, he tried again. He built a small helicopter called the VS-300 with one big **rotor** on top and one little rotor on the tail. He tested it, changed it and tested it again, again and again. In 1939 it lifted off and **hovered**, and by 1941 it could fly for more than an hour. Sikorsky was a man of strong Christian faith who also wrote books about prayer.

**The physics.** A helicopter's **blades** are long, thin wings. When the rotor spins, each blade cuts through the air and pushes air down, so the air pushes the helicopter up. A maple seed works the other way around: as it falls, the air pushes on its tilted wing and makes it spin, and the spinning slows its fall. When a big rotor spins one way, it tries to spin the helicopter's body the other way. The little tail rotor pushes sideways to stop that.

**The engineering.** A helicopter can do things an airplane cannot. It can go straight up and down, hover in one spot and land on a rooftop or a mountain. Helicopters rescue people from floods and mountains, carry sick people to hospitals, fight fires and lift heavy loads to building tops. In 2021 a tiny helicopter named *Ingenuity* even flew on the planet Mars.

## PICTURE STUDY



*Igor Sikorsky Flies the VS-300*, Unknown photographer, About 1940 · Photograph · U.S. National Archives

Image: [Wikimedia Commons](#), public domain

This is Igor Sikorsky flying his VS-300 helicopter. He liked to wear a hat when he flew. Look for the parts that make it fly and keep it steady.

### Look closely

- Find the big rotor on top. Why does it look blurry?
- Find Igor Sikorsky. What is he wearing?
- Find the long tail with its open frame of triangles. What is at the end of it?
- Find the floats on the bottom. Where could this helicopter land?

### Talk about it

1. Why does a helicopter need a tail rotor?
2. How is a helicopter blade like a maple seed's wing?
3. Sikorsky's first two helicopters did not fly. What did he do?

## BUILD

### The Paper Helicopter Drop Test

You will make paper helicopters that spin like maple seeds. You will drop them from the same height and time how long each one takes to fall.

#### You will need

- Printer paper or card stock
- Scissors and a ruler
- Paper clips
- A stopwatch or phone timer
- A safe high spot, such as the top of a staircase with a grown-up, or standing on the floor and dropping from as high as you can reach
- Engineer's notebook

#### Steps

1. Cut a strip of paper 2 inches wide and 8 inches long. Cut down the middle from one end about 3 inches to make two blades. Fold one blade forward and one back.
2. Fold in the bottom sides a little and clip on a paper clip to make the body.
3. Drop it from the same spot every time. Time how long it takes to reach the floor. Do it three times. Write the times.
4. **Predict.** Will longer blades make it fall more slowly? Write your guess.
5. Make two more helicopters the same way, but with blades 2 inches long and 5 inches long. Time each one three times.
6. Make a table: blade length and three fall times.
7. **Improve.** Design a helicopter that falls as slowly as possible. Try changing one thing: the paper, the blade width, or the number of paper clips.

#### Tips

- Hold the helicopter by the clip and let it go without pushing.
- Drop it in a room with no fan or open window, so the air is still.

#### Check your work

- ☐ I can tell how a maple seed spins and why.
- ☐ I can tell how Igor Sikorsky built his helicopter.
- ☐ I can tell what my test showed about blade length.

#### ENGINEER'S NOTEBOOK

1. Draw a maple seed and your paper helicopter side by side. How are they alike?
2. Make a bar graph of blade length and fall time.
3. Draw a helicopter and label the main rotor, the tail rotor and the pilot.

**From history.** Leonardo da Vinci's drawing of the "aerial screw" is in one of his notebooks in Paris. The VS-300 is now in the Henry Ford Museum in Dearborn, Michigan.

#### COMMON MISTAKES

- Dropping from different heights. Always use the same spot.
- Folding both blades the same way. One goes forward and one goes back, or it will not spin.

**Make it a game • Maple Seed Spin Drop.** Make a paper helicopter and drop it from a chair. Time its fall in seconds, counting aloud. Fold the blades a different way and drop again. Say rotor, blade and hover. Tell your parent how a maple seed spins down slowly and how Igor Sikorsky built a working helicopter. Beat your time.

## UNIT 7

# FLIGHT

People have always watched the birds and wished they could fly. “They shall mount up with wings as eagles,” wrote the prophet Isaiah. In this unit you will meet the people who learned how. Sir George Cayley figured out the four forces that act on anything that flies. Alexander Graham Bell, the inventor of the telephone, built giant kites out of triangles. Wilbur and Orville Wright made the first airplane flight in 1903. And Igor Sikorsky built a helicopter that spins its wings like a maple seed.

You will fly paper airplanes and test them fairly, build and fly a kite, add steering flaps to a glider, and drop paper helicopters to see which falls most slowly. Measure every flight and write it down, just as the Wright brothers did.

### PREREQUISITES

- Knows that gravity pulls things down (Unit 1)
- Knows that triangles are strong (Unit 2)
- Can measure distances with a tape measure and time with a stopwatch, with help

### MASTERY CHECKLIST

- ☐ I can name the four forces of flight: lift, weight, thrust and drag.
- ☐ I can tell how a kite flies and the kite safety rules.
- ☐ I can tell the story of the Wright brothers’ first flight.
- ☐ I can tell how a maple seed and a helicopter use spinning wings.
- ☐ I can run a fair test on something that flies and record the results.

### OPTIONAL KITS FOR THIS UNIT

- **KiwiCo Kiwi Crate**: Ages 5–8. A monthly box with one hands-on build. Some crates are flying projects, such as gliders, launchers and spinners, which fit Lessons 7.1–7.4.
- **KiwiCo Tinker Crate**: Ages 9 and up, but a seven-year-old can build many with a parent. Some crates are flight projects with notes on the science. Fits Lessons 7.3 and 7.4.

Not required. Every project in this unit can be built with household materials. School Launch has no ties to these companies.

## LESSONS IN THIS UNIT

|                                                 |                             |
|-------------------------------------------------|-----------------------------|
| <b>7.1 The Four Forces of Flight</b>            | 2 sessions of 30–40 minutes |
| <b>7.2 Kites and Alexander Graham Bell</b>      | 2 sessions of 30–40 minutes |
| <b>7.3 The Wright Brothers Fly</b>              | 2 sessions of 30–40 minutes |
| <b>7.4 Helicopters and Spinning Maple Seeds</b> | 2 sessions of 30–40 minutes |

## UNIT 7 REVIEW

A parent asks these questions aloud. Your child may answer by telling, pointing, drawing or showing with the builds from this unit. There are no points. Listen for understanding and praise careful answers.

1. Point to the four forces on your paper airplane and name them.
2. How does a wing or a kite make lift?
3. Tell me three kite safety rules.
4. Tell the story of the first flight. Who flew, when, and how far?
5. Show me with your glider: how do you make it turn?
6. How is a helicopter like a maple seed? What does the tail rotor do?

#### ANSWER KEY

1. Lift (up), weight (down), thrust (forward), drag (back).
2. It is tilted so it turns the air downward. The air pushes back up on it. The air on top also pushes less than the air below.
3. Fly only in open places away from power lines, trees, roads and airports; never in rain or thunder; if the kite catches in a power line, let go and tell a grown-up.
4. Orville Wright, on December 17, 1903, at Kitty Hawk, North Carolina. He flew 12 seconds, about 120 feet.
5. Bend one flap up and the other down, like the Wrights' wing warping.
6. Both have spinning wings that push on the air. The tail rotor keeps the helicopter's body from spinning around.

#### PORTFOLIO PIECE: MY FLIGHT TEST REPORT

Choose your best flying build from this unit: the paper airplane, the kite, the glider or the paper helicopter. Make it better one more time, then test it five times and write down every result. Make a report like the Wrights did: a drawing with labels, a table of your measurements, and one sentence about what you changed and what happened. Show it to your family and fly it for them.

| LOOK FOR           | WHAT IT MEANS                                                                 |
|--------------------|-------------------------------------------------------------------------------|
| <b>Four forces</b> | Labeled lift, weight, thrust and drag on the drawing, or told where they act. |
| <b>Fair test</b>   | Launched the same way from the same spot every time.                          |
| <b>Records</b>     | Wrote down all five results in a table with a date.                           |
| <b>Improving</b>   | Made one change and told what happened.                                       |

## UNIT 8

# ROBOTS AND INVENTIONS

A robot is a machine that can sense the world around it, follow a plan, and move to do a job. Inside every robot are the same simple machines you met this year: wheels, levers, gears and motors. In this unit you will see a clock with moving figures built more than eight hundred years ago, help drive a rover on Mars by writing step-by-step instructions, meet two little robot tortoises that followed a light, and learn how drones and the Mars helicopter fly and help people.

You will build a cam machine that makes a figure bob up and down, “program” a grown-up robot across the floor, wire a bump sensor that lights a bulb, and design a delivery drone. The year ends with a family engineering fair, where you show your best builds and explain how they work. *Fabricando fit faber*: by making, one becomes a maker.

### PREREQUISITES

- Knows wheels, levers and ramps (Unit 1)
- Can build a battery circuit with a switch (Unit 4)
- Knows the four forces of flight and how a helicopter rotor works (Unit 7)

### MASTERY CHECKLIST

- ☐ I can tell what makes a machine a robot: it senses, follows a plan and moves.
- ☐ I can build a cam and show how it changes turning into up-and-down motion.
- ☐ I can write step-by-step instructions to move a robot along a path, and fix a mistake in them.
- ☐ I can build a touch sensor that turns on a light.
- ☐ I can tell how drones help people and the safety rules for flying them.
- ☐ I can explain my best builds of the year at our family engineering fair.

## OPTIONAL KITS FOR THIS UNIT

- **Sphero indi:** Ages 4 and up. A small robot car that drives over colored cards and follows the instruction each color stands for, so children can program a path with no screen. Fits Lessons 8.2 and 8.3.
- **LEGO Education:** Ages 6 and up for the early robotics sets, which add a motor, a sensor and simple picture-block coding. Fits Lessons 8.1–8.3.
- **Snap Circuits Jr. (Elenco):** Ages 8 and up, or younger with a parent. Includes a press switch and a motor for building simple sensor and robot circuits. Fits Lesson 8.3.

Not required. Every project in this unit can be built with household materials. School Launch has no ties to these companies.

## LESSONS IN THIS UNIT

|                                                                 |                                                               |
|-----------------------------------------------------------------|---------------------------------------------------------------|
| <b>8.1 Machines Inside Robots: Al-Jazari’s Elephant Clock</b>   | 2 sessions of 30–40 minutes                                   |
| <b>8.2 Programming a Path: Driving a Rover on Mars</b>          | 2 sessions of 30–40 minutes                                   |
| <b>8.3 Robot Sensors: Grey Walter’s Tortoises</b>               | 2 sessions of 30–40 minutes                                   |
| <b>8.4 Drones, the Mars Helicopter and Our Engineering Fair</b> | 2 sessions of 30–40 minutes, plus the family engineering fair |

## UNIT 8 REVIEW

A parent asks these questions aloud. Your child may answer by telling, pointing, drawing or showing with the builds from this unit. There are no points. Listen for understanding and praise careful answers.

1. What three things can a robot do that a plain machine cannot?
2. Turn the crank on your cam machine. How does the cam make the figure move?
3. Give me a program to walk from the couch to the door. What do you do if I go the wrong way?

4. Show me your bump sensor. What sense is it like, and what did Grey Walter's tortoises use?
5. Why don't quadcopter drones twirl around? Name one way drones help people.
6. Tell me two drone safety rules.

**ANSWER KEY**

1. Sense the world, follow a plan (think), and move to do a job.
2. The cam's odd shape pushes the follower up and lets it drop as the cam turns around.
3. Any clear list of steps in order. If the robot goes wrong, find the bug in the steps and fix it (debug).
4. It is like touch. The tortoises used a touch sensor (the shell switch) and a light sensor.
5. Two rotors spin one way and two spin the other way. They check bridges and power lines, help farmers, search for lost people or carry medicine.
6. Any two: fly only with a grown-up; keep it in sight; stay under 400 feet; never fly over people, near airports or near power lines.

**PORTFOLIO PIECE: OUR FAMILY ENGINEERING FAIR**

Hold a family engineering fair with one build from each unit of the year, set out with its notebook pages. Practice telling the story of each build: the person from history who inspired it, what you tested, what went wrong and how you made it better. Invite family or friends, let them try your builds, and answer their questions.

| LOOK FOR                       | WHAT IT MEANS                                                          |
|--------------------------------|------------------------------------------------------------------------|
| <b>A build from every unit</b> | Showed at least one build or photograph from each of the eight units.  |
| <b>Telling the story</b>       | Told the history behind each build in his or her own words.            |
| <b>Testing and improving</b>   | Explained what was tested, what failed and what was changed.           |
| <b>Speaking to guests</b>      | Spoke clearly, let guests try the builds and answered their questions. |

## 8.1 MACHINES INSIDE ROBOTS: AL-JAZARI'S ELEPHANT CLOCK

### OBJECTIVES

- Tell what makes a machine a robot.
- Tell how al-Jazari's elephant clock moved its figures with water, strings and simple machines.
- Build a cam machine and test how the shape of the cam changes the motion.

**Warm-up.** Look around your house for machines that move by themselves: a washing machine, a fan, a toy car. Do any of them sense anything? Do any of them follow a plan? Make a list together.

### WATCH

#### Real-Life Robots

SciShow Kids · 4:08

<https://www.youtube.com/watch?v=8wHjLMnikU>

### WHEN TO WATCH

After the warm-up, before the story.

### BACKUP VIDEO

#### Jaquet Droz The Writer Automaton From 1774 In Action: Inspired Hugo Movie

aBlogtoWatch · 4:19

<https://www.youtube.com/watch?v=ux2KW20nqHU>

With the history note, to watch a 250-year-old machine boy write with a feather pen.

### KEY TERMS

#### **robot**

A machine that can sense things, follow a plan and move to do a job.

#### **automaton**

An old machine built to move by itself, often shaped like a person or animal.

#### **cam**

A wheel with an odd shape that pushes something up and down as it turns.

#### **gear**

A wheel with teeth that turns another wheel with teeth.

## CORE IDEAS

**The story.** More than eight hundred years ago, in a city in what is now Turkey, lived an engineer named al-Jazari. He worked for a king and built clever machines for him. In the year 1206 he finished a book that showed how to build fifty of them, with careful drawings. The most famous is the elephant clock. A model elephant carries a tall tower on its back, with little figures of people and birds. Every half hour, the figures move, a ball drops, and a cymbal rings.

**How he figured it out.** Al-Jazari needed something that would move slowly and steadily all by itself. He hid a tank of water inside the elephant. In the water floated a bowl with a tiny hole in the bottom. Water leaked into the bowl, and it sank slowly. It took exactly half an hour to sink. As it sank, it pulled on strings. The strings tipped a lever that let a ball roll out. The ball dropped and made the figures move. Then the bowl popped back up, ready to start again. Al-Jazari tested and adjusted his machines until they kept good time.

**The physics.** Machines that move by themselves change one kind of motion into another. A **cam** is a wheel with an odd shape. When it turns around and around, it pushes a rod up and down. **Gears** pass turning from one wheel to another, faster or slower. Levers tip, and wheels roll. These are the same simple machines you met in Unit 1.

**The engineering.** Old moving machines like al-Jazari's are called **automatons**. They could not sense anything or change their plans; they did the same thing every time. A **robot** today also has a computer brain, sensors and motors, so it can notice what is around it and decide what to do. But inside, robots still use cams, gears, levers and wheels. Robots weld car frames in factories, pack boxes, help doctors and explore other planets.

## PICTURE STUDY



*The Elephant Clock*, Illustration from al-Jazari's *Book of the Knowledge of Ingenious Mechanical Devices*, Copy dated 1315 · Ink, color and gold on paper · The Metropolitan Museum of Art, New York

Image: [Wikimedia Commons](#), public domain

This page comes from a copy of al-Jazari's book, painted about a hundred years after he wrote it. It shows the outside of the elephant clock. The clever parts were hidden inside.

### Look closely

- Find the elephant and the driver on its neck.
- Find the little figures on the tower. Which of them might move?
- Find the curving shapes on the sides. The balls rolled down through them.
- Find the bird at the very top.

### Talk about it

1. What do you think is hidden inside the elephant to make the clock work?
2. Is the elephant clock a robot? Why or why not?
3. What simple machines might be inside it?

**Safety first.** An adult should poke holes in the box and cut the cardboard.

## BUILD

### A Cam Machine

You will build a machine with a crank, a cam and a little figure that bobs up and down. Then you will test cams of different shapes and measure how high each one lifts the figure.

#### You will need

- A small cardboard box, such as a tissue box or shoebox
- A pencil or wooden dowel for the axle
- Thick cardboard for cams
- A drinking straw and a smaller straw or wooden skewer (blunt end) for the follower
- A paper figure you draw and cut out
- Tape, glue and a ruler
- Engineer's notebook

#### Steps

1. Have an adult poke a hole in each side of the box, across from each other. Push the pencil through. Tape a cardboard handle on one end to make a crank.
2. **Cam 1.** Cut a cardboard circle about 2 inches across. Poke the pencil through its exact center and tape it, inside the box.
3. Have an adult poke a hole in the top of the box, right over the cam. Tape a straw upright in the hole as a guide. Drop the skewer through the straw so its bottom rests on the cam. Tape your paper figure to its top.
4. Turn the crank. Does the figure move? Measure how far up and down it goes with a ruler.
5. **Predict.** What will happen with a circle whose hole is off center? With an egg shape? Write your guesses.
6. Make an off-center circle cam and an egg-shaped cam. Test each one the same way. Measure how high the figure rises.
7. Make a table: cam shape and how high the figure rose.

8. **Improve.** Design a cam that makes your figure jump up quickly and drop down, like a jack-in-the-box. (Hint: try a snail shape.) Test it.

**Tips**

- The follower must slide freely in the straw. Wiggle the straw a little if it sticks.
- Turn the crank slowly to watch exactly what the cam does.

**Check your work**

- ☐ I can tell what makes a machine a robot.
- ☐ I can tell how the elephant clock kept time.
- ☐ I can show how a cam turns turning into up-and-down motion.

**ENGINEER'S NOTEBOOK**

1. Draw your cam machine from the side. Label the crank, the axle, the cam, the follower and the figure.
2. Draw each cam shape and write how high it lifted the figure.
3. Draw a robot you would like to invent. Label its motors, wheels or levers.

**From history.** About 550 years after al-Jazari, a Swiss watchmaker named Pierre Jaquet-Droz and his son built a machine boy called the Writer. Thousands of parts, including a stack of cams, guide its hand to dip a feather pen in ink and write a message. It still works today in a museum in Switzerland.

**COMMON MISTAKES**

- Putting the hole in the center of a round cam. Then the figure does not move at all!
- Thinking every machine that moves is a robot. A robot also senses and follows a plan.

**Make it a game • Cam Machine Show.** Show your parent your cam machine and turn the crank. Point out each part that moves, and say gear, cam and automaton. Then tell the story of al-Jazari's elephant clock, and how water, strings and simple machines moved its figures. Quiz each other: what makes a machine a robot?

## 8.2 PROGRAMMING A PATH: DRIVING A ROVER ON MARS

### OBJECTIVES

- Explain that a program is a list of steps in order.
- Tell how engineers on Earth drove the Sojourner rover on Mars.
- Write a program to move a “robot” along a path, test it and fix any mistakes.

**Warm-up.** Ask a grown-up to be your robot. Tell them, step by step, how to make a peanut butter sandwich, and they must do exactly what you say and nothing more. What happened when you skipped a step?

### WATCH

#### ScratchJr Coding Lesson 1 | How to Make Character Move | Free Programming Lesson1

STEMinGames - Beginner Programming · 7:04

<https://www.youtube.com/watch?v=o5XiZpzWcNc>

### WHEN TO WATCH

In the second session, before you try ScratchJr on a tablet.

### BACKUP VIDEO

#### Introduction to Scratch Jr

Joel Aarons · 5:12

<https://www.youtube.com/watch?v=s6XvwEH0xpg>

A teacher shows a first- and second-grade class how to begin in ScratchJr.

### KEY TERMS

#### **program**

A list of instructions, in order, that tells a computer or robot what to do.

#### **algorithm**

A careful, step-by-step plan for doing a job.

#### **bug**

A mistake in a program.

#### **debug**

To find and fix the mistakes in a program.

## **rover**

A robot car that explores a planet or moon.

### **CORE IDEAS**

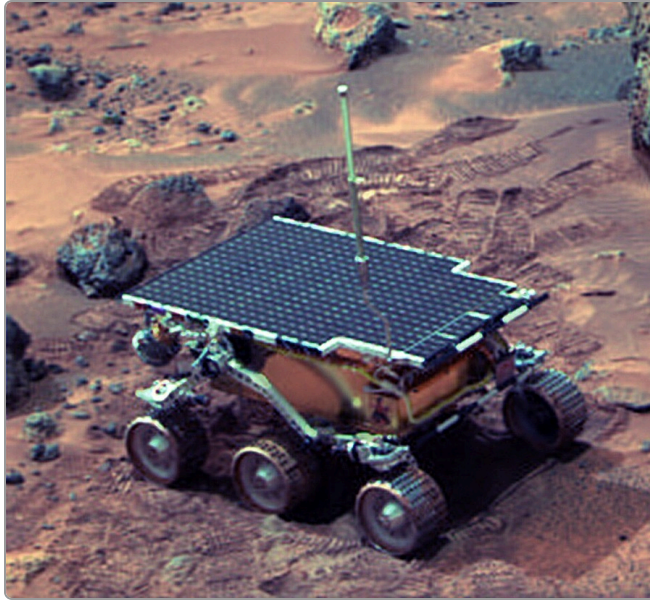
**The story.** On July 4, 1997, a spacecraft called Mars Pathfinder bounced down onto Mars inside giant airbags. When the airbags were pulled in, a tiny **rover** named Sojourner rolled down a ramp onto the red dirt. It was about the size of a wagon, with six wheels and a solar panel on top. It was the first rover ever to drive on another planet.

**How they figured it out.** Mars is so far away that a radio message takes many minutes to get there. No one could steer Sojourner with a joystick, the way you steer a toy car. If the drivers saw a rock in a picture and pressed “stop,” the rover would already have bumped into it! So the engineers on Earth studied pictures of the ground very carefully. They planned each drive and wrote a **program**, a list of steps in exact order: drive forward this far, turn this much, stop, take a picture. They sent the whole program to Mars, and Sojourner followed it step by step. If something went wrong, they found the mistake and fixed it the next day.

**The physics.** A robot only does exactly what it is told. It cannot guess what you meant. A good **algorithm** gives every step, in the right order, with nothing left out. A mistake in a program is called a **bug**. Finding and fixing it is called **debugging**. Every programmer, even at NASA, has to debug.

**The engineering.** Today, rovers like Curiosity and Perseverance can also drive themselves for short distances, using their cameras to steer around rocks. But engineers still write careful programs for them every day. You can learn to write programs too, with free tools like ScratchJr, where you snap picture blocks together to make a character move.

## PICTURE STUDY



*Sojourner on Mars*, NASA / Jet Propulsion Laboratory, 1997 · Photograph taken on Mars by the Pathfinder lander · Ares Vallis, Mars

Image: [Wikimedia Commons](#), public domain

This picture was taken on Mars by the lander that carried Sojourner. The little rover has driven up to a rock to study it.

### Look closely

- Count the wheels. How many are there?
- Find the flat solar panel on top. What do you think it does?
- Find the thin antenna. What is it for?
- Look at the rocks around the rover. Why did the drivers have to plan very carefully?

### Talk about it

1. Why couldn't the engineers steer Sojourner like a remote-control car?
2. What steps would you write to move Sojourner to the rock and stop?
3. What could happen if one step were missing?

## BUILD

### Program the Robot

You will make a grid on the floor and write a program with arrow cards to move a grown-up “robot” from a start square to a goal. Then you will try the same idea in ScratchJr.

#### You will need

- Masking tape to make a grid of 5 by 5 squares on the floor (each square about a foot wide)
- Index cards with arrows drawn on them: forward, turn left, turn right, and a “pick up” card
- A small toy or ball as the “sample” to pick up, and a few pillows as “rocks”
- Optional: a tablet with the free ScratchJr app
- Engineer’s notebook

#### Steps

1. Tape a 5-by-5 grid on the floor. Mark a start square and put the “sample” on a goal square. Put pillow “rocks” in two squares.
2. **Plan.** Lay your arrow cards in a row to make a program that moves the robot from the start to the sample without hitting a rock. Count how many cards you used.
3. **Run.** Your grown-up robot follows the cards exactly, one step per square. No guessing allowed!
4. Did the robot reach the sample? If not, find the bug. Fix the cards and run it again.
5. Write down how many times you had to debug.
6. Move the rocks and the sample. Write a new program. Can you do it with fewer cards?
7. **ScratchJr.** In ScratchJr, snap together blocks to move the cat across the screen to a goal. Then add a turn. Then add a jump.

#### Tips

- Robots turn in place. A turn card does not move the robot to a new square.

- Say each card out loud as the robot runs it.

#### Check your work

- ☐ I can tell what a program is.
- ☐ I can tell how engineers drove Sojourner on Mars.
- ☐ I can find and fix a bug in my program.

#### ENGINEER'S NOTEBOOK

1. Draw your grid with the start, the rocks and the sample. Draw arrows for your program's path.
2. Write your program as a list of arrows. Circle the step that had a bug and write the fix.
3. Write how many cards each program used.

**From history.** Sojourner was planned to work for just one week, but it kept going for nearly three months. Its drivers named the rocks it visited with friendly names like Barnacle Bill and Yogi.

#### COMMON MISTAKES

- Forgetting that left and right switch when the robot faces you. Stand behind the robot to check.
- Feeling bad about bugs. Every programmer has them; finding them is part of the job.

**Make it a game • Rover Program Bugs.** Drive your parent like a Mars rover around a path of shoes, using a written list of steps. Your parent follows exactly, even into a chair. If it fails, find the bug and fix the list. Say program, algorithm and debug. Tell how engineers on Earth drove Sojourner. Fix three bugs in a row.

**Scripture.** “Let all things be done decently and in order.” (1 Corinthians 14:40, KJV)

Paul wrote this about worship, but it is good advice for programmers too. A program works only when every step is in the right order.

## 8.3 ROBOT SENSORS: GREY WALTER’S TORTOISES

### OBJECTIVES

- Explain that sensors let a robot notice the world, like our senses.
- Tell how Grey Walter’s robot tortoises used a light sensor and a touch sensor.
- Build a touch sensor that lights a bulb when it bumps into something.

**Warm-up.** Close your eyes and have a grown-up hand you three objects one at a time. Can you tell what they are by touch alone? Then listen with your eyes closed: what sounds can you hear? Which senses did you use?

### WATCH

#### Watch This 1940s Robotic Tortoise Navigate A Room By Itself | Impossible Engineering

Science Channel • 2:07

<https://www.youtube.com/watch?v=TZJfsD3Ksu4>

### WHEN TO WATCH

After the story.

### BACKUP VIDEO

#### How iRobot Roomba® Vacuum Cleaning Robot Works | Roomba® | iRobot®

iRobot • 2:47

<https://www.youtube.com/watch?v=VPNQxulK4mE>

With the engineering paragraph, to see bump and cliff sensors in a robot vacuum.

### KEY TERMS

#### **sensor**

A part that lets a machine notice something, such as light, touch, sound or distance.

#### **light sensor**

A sensor that notices how bright it is.

#### **touch sensor**

A sensor that notices when something presses on it, like a bumper switch.

#### **sense, think, act**

What a robot does: notice the world, decide what to do, then move.

## CORE IDEAS

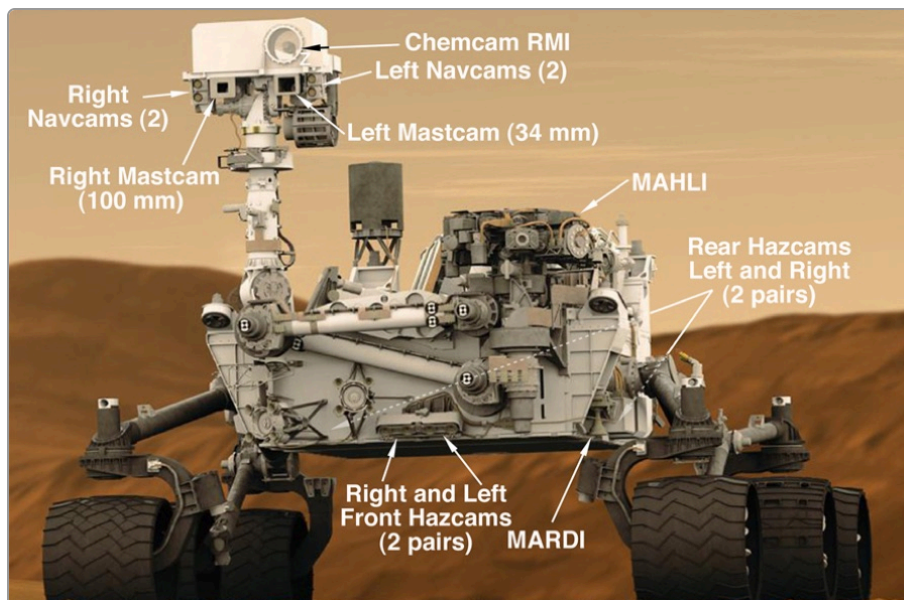
**The story.** About seventy-five years ago in England, a scientist named William Grey Walter wondered how simple a robot could be and still act as if it were alive. In 1948 and 1949 he built two little robots that he called tortoises, because of their round shells. He named them Elmer and Elsie.

**How he figured it out.** Grey Walter gave each tortoise just two **sensors**. On top was a **light sensor**, like a single eye, that slowly turned around and around looking for light. The shell was a **touch sensor**: when it bumped into something, it pressed a switch. With only these two sensors, a few parts and two motors, the tortoises wandered around a room. They steered toward a lamp, backed away from chairs when they bumped them, and in a later model, when the batteries got low, the tortoise found its way back into a lit “hutch” to recharge. People who watched them were amazed.

**The physics.** A touch sensor is a switch, just like the one you built in Unit 4. When it is pressed, the two metal parts touch, the circuit closes and electricity flows. A light sensor lets more electricity through when more light shines on it. The robot’s brain uses those signals to decide what its motors should do. Robots **sense, think and act**.

**The engineering.** God gave us eyes, ears, skin, a nose and a tongue to notice His world. Engineers give robots sensors that work a little like them: cameras for eyes, microphones for ears, and bump switches for touch. A robot vacuum has a bump sensor and “cliff” sensors that stop it from falling down the stairs. The Mars rovers have special cameras near their wheels to spot rocks and holes, so they can stop before they get stuck.

## PICTURE STUDY



*The Cameras on the Curiosity Rover*, NASA / Jet Propulsion Laboratory, 2011 · Labeled photograph ·  
NASA Jet Propulsion Laboratory, California  
Image: [Wikimedia Commons](#), public domain

The Curiosity rover has been exploring Mars since 2012. Its engineers gave it many cameras. Each label on this picture points to a camera that helps the rover see.

### Look closely

- Count the cameras that are labeled.
- Find the cameras on top of the tall mast, like a head with eyes.
- Find the “hazcams” near the wheels. Hazard means danger. What dangers might they look for?
- Find the wheels. Why do you think there are six?

### Talk about it

1. Why does the rover need cameras low down near its wheels?
2. Which of your senses is like a camera? Which is like a touch sensor?
3. What sensor would you add to Curiosity if you could?

**Safety first.** Use only batteries. If a wire or battery feels hot, unclip it and tell a grown-up.

## BUILD

### A Bump Sensor That Lights a Bulb

You will build a cardboard bumper with a touch sensor inside. When the bumper hits something, it closes a circuit and lights a bulb, just like the shell switch on Grey Walter's tortoise.

#### You will need

- Your battery, bulb and clip leads from Unit 4
- Two strips of cardboard about 2 by 6 inches
- Aluminum foil and tape
- A small piece of sponge or folded paper as a spring
- A shoebox or toy truck to be the "robot"
- Engineer's notebook

#### Steps

1. Cover one side of each cardboard strip with a strip of foil. Tape it on.
2. Lay the strips foil sides facing each other. Put a small piece of sponge between them at each end, so the foils do not touch unless you press.
3. Clip one lead from the battery to one foil strip. Clip a second lead from the other foil strip to the bulb. Finish the loop from the bulb back to the battery.
4. Press the strips together. Does the bulb light? You built a touch sensor!
5. Tape the sensor to the front of your shoebox robot. Push the robot slowly into a wall or chair leg. Does the bulb light when it bumps?
6. **Fair test.** Try it 10 times. Count how many times the light came on. Write it down.
7. **Improve.** Make the bumper wider, or the sponge springier, so it lights every time but does not stay on by itself. Test 10 more times.

#### Tips

- The foil strips must not touch until the bumper is pressed.
- Unclip the battery when you are finished.

#### Check your work

- ☐ I can tell what a sensor does.
- ☐ I can tell how Grey Walter's tortoises found the light and backed away from bumps.
- ☐ I can show my bump sensor working.

#### ENGINEER'S NOTEBOOK

1. Draw your bump sensor. Show the two foil strips, the sponge, the wires, the battery and the bulb.
2. Make two lists: our senses, and the robot sensors that are like them.
3. Write how many times out of 10 your sensor worked, before and after you improved it.

**From history.** Grey Walter gave his tortoises a Latin name, *Machina speculatrix*, which means a machine that explores. One of the tortoises he built is kept in the Science Museum in London.

#### COMMON MISTAKES

- Letting the foil strips touch all the time. Then the light stays on and the sensor cannot tell a bump.
- Thinking a robot knows things by itself. It only knows what its sensors tell it.

**Make it a game • Sense Think Act.** Play the Grey Walter tortoise. Walk slowly toward a lamp, which is your light sensor, and turn away when you bump something, which is your touch sensor. Your parent calls out sense, think or act. Switch roles. Then tell your parent how Grey Walter's tortoises used their sensors.

**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)

Engineers work very hard to give robots even a few simple sensors. God gave each of us eyes, ears and hands far more wonderful than any machine.

## 8.4 DRONES, THE MARS HELICOPTER AND OUR ENGINEERING FAIR

### OBJECTIVES

- Explain how a drone flies with four spinning rotors.
- Tell how NASA’s Ingenuity helicopter flew on Mars, and name ways drones help people.
- Design and test a zip-line delivery “drone,” and explain the year’s best builds at a family engineering fair.

**Warm-up.** Spin a paper helicopter from Lesson 7.4. Now imagine a flying machine with four of them. Which way would each one have to spin so the machine would not twirl around?

### WATCH

#### HOW DO DRONES FLY?

The Travelling Scientist (Jesse Crowe) • 3:20

<https://www.youtube.com/watch?v=6Bc2nuOuRjM>

#### WHEN TO WATCH

After the physics paragraph.

### BACKUP VIDEO

#### NASA’s Ingenuity Helicopter & The Role It Plays On Mars

Museum of Science • 2:06

[https://www.youtube.com/watch?v=YfhZof\\_ekBg](https://www.youtube.com/watch?v=YfhZof_ekBg)

With the story. A real Ingenuity pilot explains his job.

### KEY TERMS

#### **drone**

A flying robot with no pilot on board. It is flown by remote control or by a program.

#### **quadcopter**

A drone with four rotors.

**hover**

To stay still in the air.

**engineering fair**

A show where engineers display what they built and explain how it works.

**CORE IDEAS**

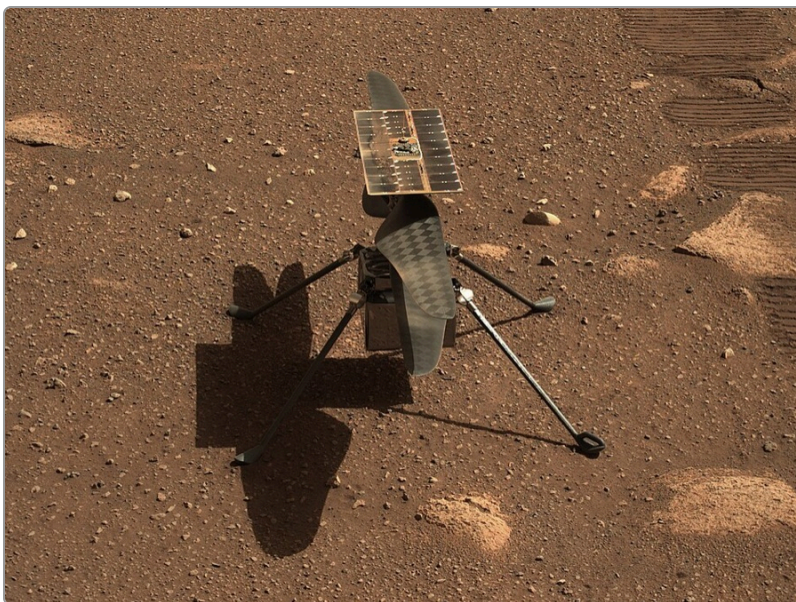
**The story.** On April 19, 2021, a tiny helicopter named *Ingenuity* lifted off the ground on Mars. It rose about 10 feet, hovered for about 30 seconds, and landed again. It was the first time any machine had made a powered, controlled flight on another planet. Under its solar panel, the engineers had tucked a little piece of cloth from the wing of the Wright brothers' 1903 Flyer.

**How they figured it out.** Flying on Mars is very hard, because the air there is about one hundred times thinner than on Earth. Thin air means the blades have very little air to push down. So the engineers made *Ingenuity* very light, about 4 pounds, as heavy as a bag of flour, and gave it long blades that spin very, very fast. They tested it on Earth in a big chamber where they pumped out most of the air to make it like Mars. Because radio messages take minutes to reach Mars, *Ingenuity* had to fly itself, using its program and its sensors. It was planned to fly five times. It flew 72 times!

**The physics.** Most drones are **quadcopters**, with four rotors. Each rotor pushes air down, so the air pushes the drone up. Two rotors spin one way and two spin the other way, so the drone does not twirl around. To move, the drone's computer spins some rotors a little faster than others, which tips the drone and sends it that way. Sensors inside it keep it level many times every second.

**The engineering.** Drones help people in many ways. They check bridges and power lines for damage, so workers do not have to climb up. They help farmers see which parts of a field need water. They help search for lost hikers and carry medicine to faraway places. Anyone who flies a drone must follow safety rules: fly only with a grown-up, keep it where you can see it, stay low (under 400 feet), and never fly over people, near airports or near power lines. In the United States, grown-ups must also pass a free safety test before flying for fun, and register any drone that weighs 250 grams or more.

## PICTURE STUDY



*Ingenuity on Mars, NASA / JPL-Caltech / ASU, taken by the Perseverance rover, April 5, 2021 ·*

Photograph taken on Mars · Jezero Crater, Mars

Image: [Wikimedia Commons](#), public domain

The Perseverance rover took this close-up picture of Ingenuity on Mars, just before its first flight. Look for the parts that let it fly in very thin air.

### Look closely

- Find the two long blades on top. They spin in opposite directions.
- Find the solar panel at the very top. What is it for?
- Find the four thin legs. Why might they be so thin?
- Find the shadow. Can you see the shape of the blades in it?

### Talk about it

1. Why did Ingenuity need such long, fast blades?
2. Why did it have to fly itself instead of being flown with a joystick?
3. How is Ingenuity like Sikorsky's helicopter and like a maple seed?

**Safety first.** Never fly a real drone without a grown-up, and never near people, roads, airports or power lines. Keep fingers and hair away from spinning propellers. For the zip line, an adult should tie the string and keep it away from faces.

## BUILD

### A Zip-Line Delivery Drone and Our Engineering Fair

First, you will design a “delivery drone” that slides down a string to bring a package across the room, and test how the slope of the string changes its speed. Then you will hold a family engineering fair to show the best builds of your whole year.

#### You will need

- A long piece of string or fishing line, about 12 feet
- A paper cup, a paper clip bent into a hook, and a straw
- Pennies for the package
- Tape, paper and markers for propellers and decoration
- A stopwatch or phone timer and a tape measure
- Your best builds and notebook pages from Units 1–8
- Engineer’s notebook

#### Steps

1. Thread the straw onto the string. Tie one end of the string high (to a chair back or door knob) and the other end low across the room. An adult should make it tight.
2. Tape the cup under the straw with the paper clip hook. Decorate it with four paper propellers so it looks like a quadcopter. Put 10 pennies in the cup as the package.
3. **Predict.** Will the drone get there faster on a steep string or a gentle one? Write your guess.
4. Let the drone go from the top. Time how long it takes to reach the bottom. Do it three times.
5. Make the slope gentler by lowering the high end. Time it three more times. Write both sets of times.
6. **Improve.** Make your drone deliver the package without spilling a single penny. Try a lid, a bigger cup or a different hook.

7. **Plan the fair.** Choose your best build from each unit. Set them out on a table with your notebook pages.

8. **Hold the fair.** Invite family or friends. For each build, tell what it does, what you tested, what went wrong, and what you changed to make it better.

#### **Tips**

- Pull the straw back to the top gently by the string, not by the cup.
- At the fair, let your guests try your builds and ask you questions.

#### **Check your work**

- ☐ I can tell how a quadcopter flies.
- ☐ I can tell the story of Ingenuity on Mars and two ways drones help people.
- ☐ I can explain my builds at our engineering fair.

#### **ENGINEER'S NOTEBOOK**

1. Draw your delivery drone on its zip line and label the straw, the hook, the cup and the package.
2. Make a table of your times for the steep and the gentle string.
3. Make a page for the fair: list your eight best builds and one thing you learned from each.

**From history.** Ingenuity made its last flight in January 2024 after one of its blades was damaged. It still stands on Mars, and engineers are now designing bigger helicopters to fly there someday.

#### **COMMON MISTAKES**

- Thinking drones are toys only. Many do important work for people.
- At the fair, only showing what worked. Engineers also tell what failed and how they fixed it.

**Make it a game • Zip-Line Delivery Race.** Slide a paper cup delivery on a string zip line and time how long it takes in seconds. Add a small load and time again. Say drone, hover and quadcopter. Tell your parent how Ingenuity flew on Mars and how drones help people. Make one fix to the zip line and beat your best time.

**Scripture.** “And whatsoever ye do, do it heartily, as to the Lord, and not unto men;” (Colossians 3:23, KJV)

This year you built bridges, towers, circuits, boats and flying machines. Whatever you make, make it with your whole heart, as a gift to God.

## ROBOTS AND INVENTIONS

A robot is a machine that can sense the world around it, follow a plan, and move to do a job. Inside every robot are the same simple machines you met this year: wheels, levers, gears and motors. In this unit you will see a clock with moving figures built more than eight hundred years ago, help drive a rover on Mars by writing step-by-step instructions, meet two little robot tortoises that followed a light, and learn how drones and the Mars helicopter fly and help people.

You will build a cam machine that makes a figure bob up and down, “program” a grown-up robot across the floor, wire a bump sensor that lights a bulb, and design a delivery drone. The year ends with a family engineering fair, where you show your best builds and explain how they work. *Fabricando fit faber*: by making, one becomes a maker.

### PREREQUISITES

- Knows wheels, levers and ramps (Unit 1)
- Can build a battery circuit with a switch (Unit 4)
- Knows the four forces of flight and how a helicopter rotor works (Unit 7)

### MASTERY CHECKLIST

- ☐ I can tell what makes a machine a robot: it senses, follows a plan and moves.
- ☐ I can build a cam and show how it changes turning into up-and-down motion.
- ☐ I can write step-by-step instructions to move a robot along a path, and fix a mistake in them.
- ☐ I can build a touch sensor that turns on a light.
- ☐ I can tell how drones help people and the safety rules for flying them.
- ☐ I can explain my best builds of the year at our family engineering fair.

## OPTIONAL KITS FOR THIS UNIT

- **Sphero indi:** Ages 4 and up. A small robot car that drives over colored cards and follows the instruction each color stands for, so children can program a path with no screen. Fits Lessons 8.2 and 8.3.
- **LEGO Education:** Ages 6 and up for the early robotics sets, which add a motor, a sensor and simple picture-block coding. Fits Lessons 8.1–8.3.
- **Snap Circuits Jr. (Elenco):** Ages 8 and up, or younger with a parent. Includes a press switch and a motor for building simple sensor and robot circuits. Fits Lesson 8.3.

Not required. Every project in this unit can be built with household materials. School Launch has no ties to these companies.

## LESSONS IN THIS UNIT

|                                                                 |                                                               |
|-----------------------------------------------------------------|---------------------------------------------------------------|
| <b>8.1 Machines Inside Robots: Al-Jazari’s Elephant Clock</b>   | 2 sessions of 30–40 minutes                                   |
| <b>8.2 Programming a Path: Driving a Rover on Mars</b>          | 2 sessions of 30–40 minutes                                   |
| <b>8.3 Robot Sensors: Grey Walter’s Tortoises</b>               | 2 sessions of 30–40 minutes                                   |
| <b>8.4 Drones, the Mars Helicopter and Our Engineering Fair</b> | 2 sessions of 30–40 minutes, plus the family engineering fair |

## UNIT 8 REVIEW

A parent asks these questions aloud. Your child may answer by telling, pointing, drawing or showing with the builds from this unit. There are no points. Listen for understanding and praise careful answers.

1. What three things can a robot do that a plain machine cannot?
2. Turn the crank on your cam machine. How does the cam make the figure move?
3. Give me a program to walk from the couch to the door. What do you do if I go the wrong way?

4. Show me your bump sensor. What sense is it like, and what did Grey Walter's tortoises use?
5. Why don't quadcopter drones twirl around? Name one way drones help people.
6. Tell me two drone safety rules.

**ANSWER KEY**

1. Sense the world, follow a plan (think), and move to do a job.
2. The cam's odd shape pushes the follower up and lets it drop as the cam turns around.
3. Any clear list of steps in order. If the robot goes wrong, find the bug in the steps and fix it (debug).
4. It is like touch. The tortoises used a touch sensor (the shell switch) and a light sensor.
5. Two rotors spin one way and two spin the other way. They check bridges and power lines, help farmers, search for lost people or carry medicine.
6. Any two: fly only with a grown-up; keep it in sight; stay under 400 feet; never fly over people, near airports or near power lines.

**PORTFOLIO PIECE: OUR FAMILY ENGINEERING FAIR**

Hold a family engineering fair with one build from each unit of the year, set out with its notebook pages. Practice telling the story of each build: the person from history who inspired it, what you tested, what went wrong and how you made it better. Invite family or friends, let them try your builds, and answer their questions.

| LOOK FOR                       | WHAT IT MEANS                                                          |
|--------------------------------|------------------------------------------------------------------------|
| <b>A build from every unit</b> | Showed at least one build or photograph from each of the eight units.  |
| <b>Telling the story</b>       | Told the history behind each build in his or her own words.            |
| <b>Testing and improving</b>   | Explained what was tested, what failed and what was changed.           |
| <b>Speaking to guests</b>      | Spoke clearly, let guests try the builds and answered their questions. |

## TOY LAB: THE PHYSICS OF PLAY

Some of the best engineering in the world is hiding in your toy box. In this bonus unit you will meet the people who invented four famous toys and find out how each one works. A naval engineer watched a spring tumble off a shelf and invented the Slinky. The son of a great architect invented Lincoln Logs, and a stonecutter invented Tinkertoys. The swing and the seesaw are really a pendulum and a lever. And a young cabinetmaker in Chicago built the little red wagon.

You will stretch springs and measure them, build notched-log cabins and stick-and-spool frames, time a pendulum, and build a wagon with better bearings. Do this unit after the family engineering fair, over the summer, or any week that needs something fun. “And the streets of the city shall be full of boys and girls playing.”

### PREREQUISITES

- Knows levers, wheels and axles, and friction (Unit 1)
- Knows that triangles are strong (Unit 2)
- Can measure with a ruler and time with a stopwatch, with help

### MASTERY CHECKLIST

- ☐ I can tell how the Slinky was invented and how a spring stores energy.
- ☐ I can tell how Lincoln Logs and Tinkertoys fit together, and why triangles make a frame stiff.
- ☐ I can show that a swing is a pendulum and a seesaw is a lever.
- ☐ I can tell how a wagon’s wheels, axles and bearings make it roll easily.
- ☐ I can name toy safety rules: small parts away from babies, and never open toys with button batteries or plugs.

## OPTIONAL KITS FOR THIS UNIT

- **CrunchLabs Build Box:** Ages 8 and up. Mark Rober’s monthly toy kits, each built around one physics idea, with a video that explains it. Fits the whole Toy Lab.
- **K’NEX building sets:** Ages 7 and up. Rods and connectors that work much like Tinkertoys, for frames, wagons and moving toys. Fits Lessons 9.2 and 9.4.
- **KiwiCo Kiwi Crate:** Ages 5–8. Many crates are toys you build and then play with, such as rolling cars and spinners. Fits Lessons 9.3 and 9.4.

Not required. Every project in this unit can be built with household materials. School Launch has no ties to these companies.

## LESSONS IN THIS UNIT

|                                     |                             |
|-------------------------------------|-----------------------------|
| 9.1 The Slinky: A Spring That Walks | 2 sessions of 30–40 minutes |
| 9.2 Lincoln Logs and Tinkertoys     | 2 sessions of 30–40 minutes |
| 9.3 The Swing and the Seesaw        | 2 sessions of 30–40 minutes |
| 9.4 The Little Red Wagon            | 2 sessions of 30–40 minutes |

## UNIT 9 REVIEW

A parent asks these questions aloud. Your child may answer by telling, pointing, drawing or showing with the builds from this unit. There are no points. Listen for understanding and praise careful answers.

1. How was the Slinky invented?
2. Show me your spring stretch table. What happened each time you added 5 pennies?
3. Why do notches help a log cabin stand? Why do triangles help a Tinkertoy frame?
4. What made your pendulum swing faster: a shorter string or more weight?
5. What does a bearing do in a wagon wheel?

6. Tell me two toy safety rules.

**ANSWER KEY**

1. Richard James, an engineer, saw a spring fall off a shelf and tumble end over end. He and Betty tested springs for two years and made it a toy.
2. The spring stretched about the same amount more each time, and it went back when the pennies came out.
3. Notches lock the logs so they cannot slide. Triangles keep their shape, so the frame is stiff.
4. A shorter string. The weight made almost no difference.
5. It lets the wheel turn smoothly on its axle with less rubbing (less friction).
6. Keep small parts away from babies under 3; never open toys with button batteries, lithium batteries or plugs; do teardowns only with a grown-up.

**PORTFOLIO PIECE: INVENT A TOY**

Invent your own toy using one idea from this unit: a spring, notched or snap-together pieces, a pendulum or lever, or wheels and axles. Draw a plan, build it from household materials, test it three times and make it better. Then tell your family what it does, the physics that makes it work, and how you made it safe.

| LOOK FOR       | WHAT IT MEANS                                                  |
|----------------|----------------------------------------------------------------|
| <b>Plan</b>    | Drew a labeled plan before building.                           |
| <b>Physics</b> | Could tell which idea from the unit makes the toy work.        |
| <b>Testing</b> | Tested the toy three times and improved one thing.             |
| <b>Safety</b>  | Thought about small parts, sharp edges and who the toy is for. |

## 9.1 THE SLINKY: A SPRING THAT WALKS

### OBJECTIVES

- Tell how Richard James invented the Slinky.
- Explain that a spring stores energy when it is stretched or squeezed.
- Measure how much a spring stretches as you add pennies, and look for a pattern.

**Warm-up.** Press down on a sofa cushion, then let go. Squeeze a sponge, then let go. Pull a rubber band, then let go. What do all three do? Where do you think the push comes from?

### WATCH

#### How Does a Slinky Work? | Design Squad

Design Squad • 2:34

<https://www.youtube.com/watch?v=JyTeAAflrMQ>

### WHEN TO WATCH

After the story.

### BACKUP VIDEO

#### How the Slinky Was Made - CNN

Slinky Toys • 2:19

<https://www.youtube.com/watch?v=H3Fj3SbHgJo>

With the engineering paragraph, to see the factory where Slinkys are still made.

### KEY TERMS

#### **spring**

A coil of wire or other bendy thing that pushes back when you stretch or squeeze it.

#### **coil**

A wire wound around and around in rings.

#### **stored energy**

Energy saved up, ready to make something move, like a stretched spring.

#### **stretch**

To pull something longer.

## CORE IDEAS

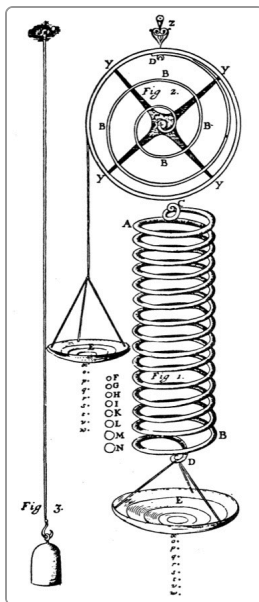
**The story.** In 1943, a young engineer named Richard James was working at a shipyard in Philadelphia. He was trying to make springs that would hold delicate instruments steady on ships as they rolled in the waves. One day a spring fell off a shelf. Instead of just landing, it flipped end over end, from the shelf to a stack of books, to the table, to the floor. Richard watched and thought, “That could be a toy!”

**How he figured it out.** Richard and his wife, Betty, spent about two years testing. Richard tried different kinds of steel wire, thick and thin, and different numbers of coils, until he found a spring that walked well down stairs and did not tangle too easily. Betty looked through the dictionary for a name and chose “Slinky,” which means smooth and graceful. In November 1945, they showed it at a big store in Philadelphia. In the first hour and a half, they sold four hundred! They kept the toy simple and the price low, so many children could have one.

**The physics.** When you stretch or squeeze a **spring**, it pushes or pulls back, trying to get back to its own shape. While it is stretched, it holds **stored energy**. Let go, and that energy makes it move. When a Slinky walks down stairs, gravity pulls the top coils over and down to the next step. The coils stretch, then spring back, and the motion travels along the Slinky like a wave, one coil after another.

**The engineering.** Toy makers must make a toy that is fun, strong and safe, and cheap enough to sell. The Slinky factory winds steel wire into coils on special machines, very quickly and all exactly alike. Springs are not only for toys. They are in pens, mattresses, car wheels, doors and scales. Engineers choose the wire and the size of each spring for its job. A good toy is also safe: the ends of a Slinky’s wire are smooth so they will not scratch little hands.

## PICTURE STUDY



*Robert Hooke's Springs*, Robert Hooke, 1678 · Engraving · From Hooke's book *De Potentia Restitutiva* ("Of Spring"), London

Image: [Wikimedia Commons](#), public domain

About 270 years before the Slinky, an English scientist named Robert Hooke studied springs very carefully. He drew this picture to show his experiments. He found a simple rule: the more weight you hang on a spring, the more it stretches, in steady steps.

### Look closely

- Find the long coiled spring. What hangs from the bottom of it?
- Find the little marks beside it. What do you think they measure?
- Find the round, flat spring at the top. Where might you find a spring like that?
- Find the weight on the long wire. Even a wire stretches a tiny bit!

### Talk about it

1. What do you think happens to the spring when more weights go in the dish?
2. How is Hooke's spring like a Slinky?
3. Why would a scientist write down careful measurements of springs?

**Safety first.** Wear safety glasses when stretching springs and rubber bands, in case one slips. Do not stretch a Slinky so far that it bends out of shape.

## BUILD

### The Spring Stretch Test

You will hang a cup from a spring, add pennies a few at a time, and measure how far the spring stretches each time. You will look for a pattern, just like Robert Hooke.

#### You will need

- A Slinky (metal or plastic), or a long spring from an old toy or pen, or a rubber band if you have no spring
- A paper cup with a string or paper-clip handle
- About 50 pennies
- A ruler and tape
- A table edge or a sturdy shelf to hang it from
- Engineer's notebook

#### Steps

1. Tape the top of the spring to the edge of a table so it hangs down. Hang the empty cup from the bottom.
2. Tape the ruler upright beside the spring. Write where the bottom of the spring is now.
3. **Predict.** How far will the spring stretch with 10 pennies? With 20? Write your guesses.
4. Add 5 pennies. Measure where the bottom of the spring is now. Write it down.
5. Keep adding 5 pennies at a time, up to 30 or 40. Measure each time.
6. Make a table: number of pennies and how far it stretched. Do you see a pattern? Does each 5 pennies stretch it about the same amount?
7. Take the pennies out. Does the spring go back to where it started?
8. **Improve.** If you have a Slinky, find the best stair or stack of books for it to walk down. Change the height of the step and count how many steps it walks before it stops.

### Tips

- Add the pennies gently and let the spring stop bouncing before you measure.
- Read the ruler at eye level.

### Check your work

- ☐ I can tell how Richard James invented the Slinky.
- ☐ I can tell what stored energy is.
- ☐ I can show the pattern in my spring stretch table.

### ENGINEER'S NOTEBOOK

1. Draw your spring with the cup and ruler. Label the spring, the cup, the pennies and the ruler.
2. Make a bar graph: pennies along the bottom, how far it stretched going up.
3. Draw five things in your house that have springs inside.

**From history.** Betty James later ran the Slinky company for many years. She kept the Slinky simple and its price low, and the toy is still made in Pennsylvania today.

### COMMON MISTAKES

- Measuring while the spring is still bouncing.
- Stretching a spring too far. Then it bends for good and will not spring back.

**Make it a game • Spring Stretch Measure.** Stretch a spring or rubber band along a ruler and pull to two different lengths. Release it and see which snaps back harder. Predict first, then compare. Say spring, coil and stored energy. Tell your parent how Richard James invented the Slinky when a spring fell from a shelf. Beat your own distance.

**Scripture.** “And the streets of the city shall be full of boys and girls playing in the streets thereof.” (Zechariah 8:5, KJV)

God promised His people a city full of children at play. Play is a good gift, and toys are one way engineers serve families.

## 9.2 LINCOLN LOGS AND TINKERTOYS

### OBJECTIVES

- Tell how John Lloyd Wright invented Lincoln Logs and how Tinkertoys were invented.
- Explain how notches lock logs together and why triangles make a frame stiff.
- Build and test a notched-log cabin and a stick-and-spool frame.

**Warm-up.** Try to stack four pencils into a square “cabin” wall, two on two. What happens when you bump the table? Now hold two craft sticks crossed in an X. Why might notches help them stay?

### WATCH

#### Lincoln Logs’ Wright Connection - Decades TV Network

Decades TV Network • 6:01

<https://www.youtube.com/watch?v=4yb1cEWHzds>

### WHEN TO WATCH

After the story.

### KEY TERMS

#### **notch**

A small cut in the edge of a log or stick where another piece fits.

#### **interlock**

To fit together so the pieces hold each other in place.

#### **spool**

A round wheel with holes, like the hub in a Tinkertoy set.

#### **frame**

A framework of sticks or beams that holds a shape.

### CORE IDEAS

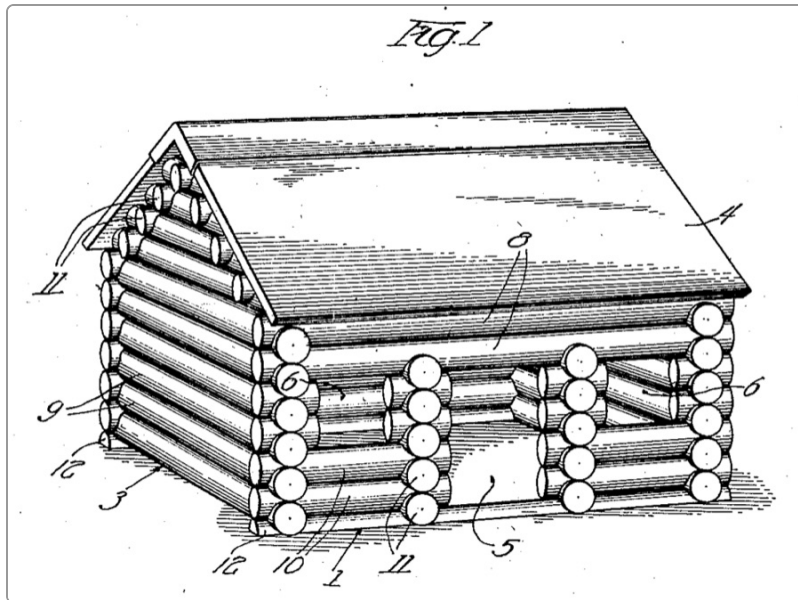
**The story.** John Lloyd Wright was the son of Frank Lloyd Wright, one of America’s most famous architects. In 1917 John went with his father to Tokyo, Japan, where his father was designing a great hotel. Japan has many earthquakes, so the hotel had to be built to shake without falling. John watched the workers fit heavy timbers together with notches so they locked in place. He got an idea for a toy.

**How he figured it out.** Back home, John made small wooden logs with a notch near each end. The notches let the logs stack crosswise and lock together, like a real log cabin. He named the toy Lincoln Logs, after the log cabin where Abraham Lincoln was born. He received a patent for it in 1920. A few years earlier, in 1914, a stonecutter named Charles Pajeau in Illinois had watched children playing with pencils and empty thread spools. He made a toy of wooden sticks and round spools with holes all around their edges, so the sticks could go in at many angles. He called it the Tinkertoy.

**The physics.** In a log cabin, each log sits in the notches of the logs below it. The notches stop the logs from sliding, and the weight of the logs on top presses them down tight. Gravity and friction hold the whole cabin together, with no nails or glue. In a Tinkertoy frame, the sticks can be set at slants to make triangles. As you learned in Unit 2, a triangle keeps its shape, so a frame of triangles is stiff.

**The engineering.** Good building toys must be made very exactly. Each notch must be the same size, and each hole in a spool must be just a little smaller than a stick, so the stick fits snugly but can still be pulled out. Toy makers also think about safety. Small pieces can choke a baby, so building sets with small parts are labeled “not for children under 3.” Big sister and big brother should keep their small pieces away from little ones.

## PICTURE STUDY



*Toy-Cabin Construction*, John Lloyd Wright, Patent filed 1920 · Patent drawing · U.S. Patent 1,351,086

Image: [Wikimedia Commons](#), public domain

When you invent something new, you can ask the government for a patent, which says the idea belongs to you. Inventors send careful drawings. This is John Lloyd Wright's drawing of his toy cabin.

### Look closely

- Find the corners where the logs cross. Can you see how they fit into each other?
- Find the door and the window. How did he make a gap in the wall?
- Find the small numbers. What do you think they are for?
- Find the roof. What holds it up?

### Talk about it

1. Why do the logs need notches?
2. How is this toy like a real log cabin?
3. What would you add to make a stronger cabin?

**Safety first.** An adult should cut any notches with scissors or a craft knife. Keep small building pieces away from babies and toddlers.

## BUILD

### Notched Logs and a Stick-and-Spool Frame

You will build a cabin wall from cardboard tube “logs,” first without notches and then with notches, and see which stands up to a shake. Then you will build a frame from straws and clay balls and test squares against triangles.

#### You will need

- About 16 cardboard tubes cut into equal “logs,” or rolled-paper logs taped shut
- Scissors (with a grown-up)
- Straws or wooden skewers (blunt ends) and modeling clay or play-dough balls for spools
- A tray or a piece of cardboard for a shake table
- A book for a load
- Engineer’s notebook

#### Steps

1. **No notches.** Stack logs crosswise into a square cabin four logs high. Set it on the tray.
2. Gently slide the tray back and forth five times as an “earthquake.” Count how many logs fall.
3. **Predict.** Will notches help the cabin stand? Write your guess.
4. **With notches.** Have a grown-up cut a small half-circle notch near each end of every log. Build the cabin again so the logs sit in each other’s notches. Shake it the same way. Count the logs that fall.
5. **Stick and spool.** Build a cube with straws and clay balls. Press gently on the top corner. Does it lean?
6. Add straws across the faces of the cube to make triangles. Press again. Set a book on top. Does it hold?
7. Write all your results in a table.
8. **Improve.** Build the tallest stick-and-spool tower you can that holds a book. Use triangles where it wobbles.

### Tips

- Shake the tray the same way each time, so the test is fair.
- Push the straws deep into the clay so the joints are firm.

### Check your work

- ☐ I can tell who invented Lincoln Logs and Tinkertoys.
- ☐ I can tell why notches help a log cabin stand.
- ☐ I can show that triangles make my frame stiff.

### ENGINEER'S NOTEBOOK

1. Draw two logs crossing at a corner, with their notches fitting together.
2. Write your table: cabin with no notches, cabin with notches, and how many logs fell.
3. Draw your stick-and-spool tower and circle every triangle.

**From history.** The Imperial Hotel in Tokyo, which John Lloyd Wright helped with, was finished in 1923. That same year a great earthquake shook the city, and the hotel stood, which added to Frank Lloyd Wright's fame.

### COMMON MISTAKES

- Making notches too deep. Then the logs are weak and break.
- Thinking a frame needs lots of sticks. It needs triangles in the right places.

**Make it a game • Lock the Logs.** Build a mini wall from notched cardboard logs and a frame from sticks and spools. Push on each one. Which stays stiff? Say notch, interlock and frame. Tell your parent how John Lloyd Wright invented Lincoln Logs. Add triangles to the frame and test it again. Score a point for each fix.

## 9.3 THE SWING AND THE SEESAW

### OBJECTIVES

- Explain that a swing is a pendulum and a seesaw is a lever.
- Tell how Galileo noticed that a swinging lamp keeps a steady beat.
- Test whether the length of the string or the weight changes how fast a pendulum swings.

**Warm-up.** Go to a swing with a grown-up. Count how many times you swing back and forth in 15 seconds while you sit still and someone gives one push. Now try a shorter swing, if there is one. Did the count change?

### WATCH

#### Swings, Slides, and Science | Physics for Kids

SciShow Kids · 3:38

<https://www.youtube.com/watch?v=JvSCIZ3vHOI>

### WHEN TO WATCH

After the warm-up.

### KEY TERMS

#### **pendulum**

A weight hanging from a string or rod that swings back and forth.

#### **swing**

One trip of a pendulum, over and back.

#### **lever**

A bar that turns on a fulcrum, like a seesaw.

#### **balance**

When both sides of a lever stay level.

### CORE IDEAS

**The story.** More than four hundred years ago, a young student named Galileo was sitting in the great cathedral in Pisa, Italy. The story says he noticed a lamp hanging from the high ceiling, swinging gently back and forth on its long chain. Sometimes it swung in big arcs and sometimes in small ones. He timed it with the beat of his own pulse. To his surprise, a big swing and a small swing took the same amount of time!

**How he figured it out.** Galileo went home and tested it. He hung weights on strings of different lengths and counted their swings. He found that a long string swings slowly and a short string swings quickly. Changing the weight on the end made almost no difference. Years later, the Dutch scientist Christiaan Huygens used this idea to build the first pendulum clock, which kept much better time than any clock before.

**The physics.** A swing at the playground is a **pendulum**. Gravity pulls you down and forward, you swing up the other side, and gravity pulls you back. The length of the chains decides how fast you swing. A seesaw is a **lever**, like the ones you built in Unit 1. The middle is the fulcrum. A heavy person sitting close to the middle can **balance** a light person sitting far out at the end.

**The engineering.** Playground engineers think about all of this. They choose chain lengths so swings feel smooth. They make seesaws strong, put handles on them, and put soft wood chips or rubber under the swings and slides, so a fall is not as hard. They space the swings far enough apart so children do not bump into each other. Good playground design is engineering that loves our neighbor's children.

## PICTURE STUDY



*The See-Saw*, Winslow Homer, About 1873 · Watercolor · Gloucester, Massachusetts

Image: [Wikimedia Commons](#), public domain

Winslow Homer painted many pictures of children playing by the sea in Gloucester, Massachusetts. These boys made their own seesaw from a plank and a rock.

### Look closely

- Find the rock under the plank. What part of the lever is it?
- Find the boy standing on the plank. Where is he standing, and what is he doing?
- Find the two boys sitting on one end. Who might be on the other end?
- Look at the plank. Is it level, or tipped?

### Talk about it

1. How could the boy in the middle make the seesaw tip one way or the other?
2. If one boy got off, what would happen?
3. What would make this homemade seesaw safer?

**Safety first.** On a real swing or seesaw, hold on with both hands, stay seated, and keep clear of a moving swing. Swing a pendulum only where it cannot hit anyone.

## BUILD

### The Pendulum Timer

You will make a pendulum from a string and some washers. You will count its swings and test whether the length of the string or the weight makes it swing faster.

#### You will need

- String, about 3 feet
- Metal washers or nuts (or a small bag of pennies) for weights
- Tape and a pencil
- A table edge to hang it from
- A ruler and a stopwatch or phone timer
- Engineer's notebook

#### Steps

1. Tie two washers to one end of the string. Tape the other end to a pencil and tape the pencil to the edge of a table so the string hangs down 24 inches.
2. Pull the weight to one side and let it go. Do not push it.
3. Count how many times it swings over and back in 15 seconds. Do it three times. Write the numbers.
4. **Predict.** Will a shorter string swing more times or fewer? Will more washers swing more times or fewer? Write your guesses.
5. **Length test.** Shorten the string to 12 inches, then 6 inches. Count the swings in 15 seconds each time.
6. **Weight test.** Go back to 24 inches. Use four washers instead of two. Count again.
7. Make a table of all your tests. Which change made a difference?
8. **Improve.** Can you make a pendulum that swings exactly once every second? Change the length a little at a time until it does. (Hint: it is close to 10 inches.)

#### Tips

- Start each swing from the same small pull-back, about a hand's width.

- A helper can count while you watch the timer.

#### Check your work

- ☐ I can tell what Galileo noticed about the swinging lamp.
- ☐ I can tell what changes how fast a pendulum swings.
- ☐ I can tell why a seesaw is a lever.

#### ENGINEER'S NOTEBOOK

1. Draw your pendulum and label the string, the weight and the pencil.
2. Make a table: string length, number of washers and swings in 15 seconds.
3. Draw a seesaw with a big person and a small person balanced. Show where the fulcrum goes.

**From history.** A grandfather clock has a long pendulum inside that takes one second to swing each way, so the clock ticks once every second. The clock's gears count the swings and move the hands. Some old clocks with pendulums are still keeping time after two hundred years.

#### COMMON MISTAKES

- Pushing the weight instead of letting it go.
- Changing the length and the weight at the same time.

**Make it a game • Pendulum Beat Timer.** Tie a washer to a string and swing it for ten seconds, counting each swing. Make the string shorter and count again. Say pendulum, swing and balance. Tell your parent how Galileo noticed a swinging lamp keeps a steady beat. Then play seesaw: sit two toys on a ruler and make it balance.

## 9.4 THE LITTLE RED WAGON

### OBJECTIVES

- Tell how Antonio Pasin built the Radio Flyer wagon.
- Explain how wheels, axles and bearings make a wagon easy to pull.
- Build a model wagon and test how better axles help it roll farther.

**Warm-up.** If you have a wagon, a stroller or a toy car, turn it over and spin a wheel. How long does it spin? Find the axle. Is it tight or loose? Never take apart anything with a battery or a plug.

### WATCH

#### Radio Flyer History.

Radio Flyer • 4:08

<https://www.youtube.com/watch?v=Y5Y7jwDa8Gc>

### WHEN TO WATCH

After the story.

**Note:** Made by the wagon company itself, with old photographs and films of its factory.

### BACKUP VIDEO

#### What Is a Ball Bearing? | How Ball Bearings Work Simple Explanation |

Engineers Guidebook • 2:26

[https://www.youtube.com/watch?v=u-1lkQsgz\\_I](https://www.youtube.com/watch?v=u-1lkQsgz_I)

With the physics paragraph, to see the balls turning inside a bearing.

### KEY TERMS

#### **wagon**

A cart with four wheels and a handle for pulling.

#### **axle**

The rod that wheels turn on.

**bearing**

A part, often with little balls inside, that lets a wheel turn smoothly on its axle.

**stamping**

Pressing a sheet of steel into a shape with a giant machine, like a cookie cutter.

**CORE IDEAS**

**The story.** In 1914 a boy named Antonio Pasin came to America from Italy. His family had been cabinetmakers, and he was good with wood. In Chicago he rented a small one-room workshop and built wooden wagons. At night he made them, and in the daytime he carried them around town to sell. He named his wagon the Liberty Coaster.

**How he figured it out.** Antonio watched the car factories of his day. They made cars quickly by stamping steel parts with big machines. In 1927 he named his wagon the Radio Flyer, after two exciting new things of his time: radio and flight. Then he decided to make wagons the same way the car factories made cars. In 1930 he began making them from **stamped** steel, so they were strong and could be made fast and sold cheaply. At the 1933 World's Fair in Chicago, his company built a giant statue of a boy riding a wagon, so tall that people could see it from far away.

**The physics.** A wagon is wheels and **axles**, the simple machine you met in Unit 1. Rolling makes much less friction than sliding, so even a small child can pull a heavy load. Where the wheel turns on its axle, there is still some rubbing. A **bearing** makes that rubbing smaller. A ball bearing has little steel balls between the wheel and the axle, so the wheel rolls on the balls instead of rubbing. It is the same idea as the bronze balls under the Thunder Stone in Lesson 1.3!

**The engineering.** A good wagon must be strong, steady and safe. The handle is a lever that steers the front wheels. Wheels far apart make the wagon hard to tip. Toy engineers round off sharp edges, cover places where fingers could get pinched, and test wagons by loading them and rolling them over bumps again and again. When you take apart an old toy to see how it works, called a teardown, do it with a grown-up, and never open anything with a button battery, a lithium battery or a wall plug.

## PICTURE STUDY



*The Auto-Wheel Coaster, The Buffalo Sled Company, April 1920 · Magazine advertisement · North Tonawanda, New York*

Image: [Wikimedia Commons](#), public domain

About the time Antonio Pasin started his workshop, many companies made wooden coaster wagons for children. This advertisement from 1920 tells a story about Jack and Jill and their wagon.

### Look closely

- Find the big drawing of the wagon. Count its wheels.
- Find the axles that hold the wheels.
- Find the handle. How does it connect to the front wheels?
- Find the children in the small pictures. What are they doing with their wagons?

### Talk about it

1. Why are the front wheels able to turn, but not the back ones?
2. What could make these wooden wheels roll more easily?
3. How is this wagon different from a steel Radio Flyer?

**Safety first.** An adult should poke holes and cut skewers. For any toy teardown, work with a grown-up, use the right screwdriver, and never open anything with a button battery, a lithium battery or a wall plug.

## BUILD

### A Wagon with Better Bearings

You will build a small wagon from a box with skewer axles. First the axles will rub on the cardboard. Then you will add straw “bearings” and test whether the wagon rolls farther.

#### You will need

- A small box, such as a tea box, for the wagon bed
- Two wooden skewers with the sharp tips cut off, for axles
- Two drinking straws, a little wider than the skewers
- Four bottle caps or cardboard circles for wheels, and modeling clay
- A string handle, tape and about 20 pennies for a load
- Your ramp from Lesson 1.2 and a tape measure
- Engineer’s notebook

#### Steps

1. **Rubbing axles.** Have an adult poke the skewers straight through the sides of the box near each end. Fix a wheel on each end of each skewer with clay. The axles rub on the cardboard holes.
2. Put 20 pennies in the wagon. Let it roll down the ramp from three books. Measure how far it goes. Do it three times.
3. **Predict.** Will straw bearings help the wagon roll farther? Write your guess.
4. **Straw bearings.** Take out the skewers. Tape two pieces of straw across the bottom of the box. Slide the skewers through the straws and put the wheels back on.
5. Test it the same way, three times, with the same 20 pennies.
6. Make a table of both tests. Which wagon rolled farther?
7. **Improve.** Try one more change: bigger wheels, a drop of cooking oil on the axles, or wheels set farther apart. Test it. Then tie on a string handle and pull your wagon with a load across the floor.

#### Tips

- Make sure the wheels do not rub on the sides of the box.
- Let the wagon go from the same spot every time. Do not push it.

#### Check your work

- ☐ I can tell how Antonio Pasin made the Radio Flyer.
- ☐ I can tell what a bearing does.
- ☐ I can tell the toy safety rules for teardowns.

#### ENGINEER'S NOTEBOOK

1. Draw your wagon from below. Label the wheels, axles and bearings.
2. Make a table: rubbing axles and straw bearings, and how far each rolled.
3. Draw a ball bearing: a ring with little balls inside.

**From history.** The giant boy-on-a-wagon statue at the 1933 World's Fair was called the Coaster Boy. Inside the company's fair building, visitors could buy a small model wagon for twenty-five cents. Today the company is still run by Antonio Pasin's family.

#### COMMON MISTAKES

- Taping the axle so tight that it cannot turn.
- Changing the load between tests.

**Make it a game • Wagon Bearing Roll-Off.** Roll two cardboard wagons across the floor, one with bare axles and one with bead or washer bearings. Count how far each rolls from the same push, using your heel-to-toe steps. Say wagon, axle and bearing. Tell your parent how Antonio Pasin built the Radio Flyer wagon. Beat your best distance.

## TOY LAB: THE PHYSICS OF PLAY

Some of the best engineering in the world is hiding in your toy box. In this bonus unit you will meet the people who invented four famous toys and find out how each one works. A naval engineer watched a spring tumble off a shelf and invented the Slinky. The son of a great architect invented Lincoln Logs, and a stonecutter invented Tinkertoys. The swing and the seesaw are really a pendulum and a lever. And a young cabinetmaker in Chicago built the little red wagon.

You will stretch springs and measure them, build notched-log cabins and stick-and-spool frames, time a pendulum, and build a wagon with better bearings. Do this unit after the family engineering fair, over the summer, or any week that needs something fun. “And the streets of the city shall be full of boys and girls playing.”

### PREREQUISITES

- Knows levers, wheels and axles, and friction (Unit 1)
- Knows that triangles are strong (Unit 2)
- Can measure with a ruler and time with a stopwatch, with help

### MASTERY CHECKLIST

- ☐ I can tell how the Slinky was invented and how a spring stores energy.
- ☐ I can tell how Lincoln Logs and Tinkertoys fit together, and why triangles make a frame stiff.
- ☐ I can show that a swing is a pendulum and a seesaw is a lever.
- ☐ I can tell how a wagon’s wheels, axles and bearings make it roll easily.
- ☐ I can name toy safety rules: small parts away from babies, and never open toys with button batteries or plugs.

## OPTIONAL KITS FOR THIS UNIT

- **CrunchLabs Build Box:** Ages 8 and up. Mark Rober’s monthly toy kits, each built around one physics idea, with a video that explains it. Fits the whole Toy Lab.
- **K’NEX building sets:** Ages 7 and up. Rods and connectors that work much like Tinkertoys, for frames, wagons and moving toys. Fits Lessons 9.2 and 9.4.
- **KiwiCo Kiwi Crate:** Ages 5–8. Many crates are toys you build and then play with, such as rolling cars and spinners. Fits Lessons 9.3 and 9.4.

Not required. Every project in this unit can be built with household materials. School Launch has no ties to these companies.

## LESSONS IN THIS UNIT

|                                     |                             |
|-------------------------------------|-----------------------------|
| 9.1 The Slinky: A Spring That Walks | 2 sessions of 30–40 minutes |
| 9.2 Lincoln Logs and Tinkertoys     | 2 sessions of 30–40 minutes |
| 9.3 The Swing and the Seesaw        | 2 sessions of 30–40 minutes |
| 9.4 The Little Red Wagon            | 2 sessions of 30–40 minutes |

## UNIT 9 REVIEW

A parent asks these questions aloud. Your child may answer by telling, pointing, drawing or showing with the builds from this unit. There are no points. Listen for understanding and praise careful answers.

1. How was the Slinky invented?
2. Show me your spring stretch table. What happened each time you added 5 pennies?
3. Why do notches help a log cabin stand? Why do triangles help a Tinkertoy frame?
4. What made your pendulum swing faster: a shorter string or more weight?
5. What does a bearing do in a wagon wheel?

6. Tell me two toy safety rules.

**ANSWER KEY**

1. Richard James, an engineer, saw a spring fall off a shelf and tumble end over end. He and Betty tested springs for two years and made it a toy.
2. The spring stretched about the same amount more each time, and it went back when the pennies came out.
3. Notches lock the logs so they cannot slide. Triangles keep their shape, so the frame is stiff.
4. A shorter string. The weight made almost no difference.
5. It lets the wheel turn smoothly on its axle with less rubbing (less friction).
6. Keep small parts away from babies under 3; never open toys with button batteries, lithium batteries or plugs; do teardowns only with a grown-up.

**PORTFOLIO PIECE: INVENT A TOY**

Invent your own toy using one idea from this unit: a spring, notched or snap-together pieces, a pendulum or lever, or wheels and axles. Draw a plan, build it from household materials, test it three times and make it better. Then tell your family what it does, the physics that makes it work, and how you made it safe.

| LOOK FOR       | WHAT IT MEANS                                                  |
|----------------|----------------------------------------------------------------|
| <b>Plan</b>    | Drew a labeled plan before building.                           |
| <b>Physics</b> | Could tell which idea from the unit makes the toy work.        |
| <b>Testing</b> | Tested the toy three times and improved one thing.             |
| <b>Safety</b>  | Thought about small parts, sharp edges and who the toy is for. |