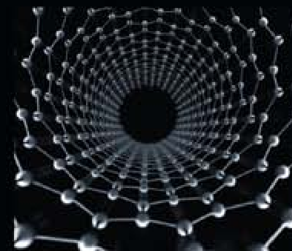
stronger

smaller



MAKING STUFF

WITH DAVID POGUE

Activity Guide

cleaner

smarter

NOVA PBS

MAKING STUFF Activity Guide

Contents

About MAKING STUFF

Each episode of NOVA's exciting four-part documentary series—*MAKING STUFF: Stronger, Smaller, Cleaner, Smarter*—shows how the field of materials science has changed history and is shaping the future with a new generation of amazing materials. *Making Stuff* is hosted by *New York Times* technology columnist and Emmy Award–winning CBS News correspondent David Pogue.

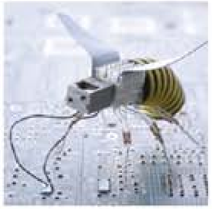
***Making Stuff* premieres January 19, 2011 (check your local listings at pbs.org).** PBS

Stronger

Search for the world's strongest stuff—from mollusks, Kevlar®, and carbon nanotubes to the beak of the toucan and spider silk.

Cleaner

Explore clean energy, like bio-based fuels and solar energy, and the alternative ways to generate, store, and distribute it for use in our cars, homes, and industry.



Smaller

Zoom in on nanocircuits and microrobots that may one day hold the key to saving lives and creating materials from the ground up, atom by atom.

Smarter

Learn about "smart" materials that can react and change. Follow materials scientists as they apply principles from the natural world to develop amazing new materials.

What Is Materials Science?

Materials science is the study of stuff. Almost everything around you and everything you use each day—the clothes you wear, the dishes you eat from, the computer you use, the bike or skateboard you ride—is made of materials. Materials can be natural, like wood, or synthetic, like plastic.

Who Are Materials Scientists and What Do They Do?

You've probably heard of a chemist, a biologist, or a physicist, but not a *materials scientist*. One reason is that materials science covers a wide range of activities and touches on many different fields—including chemistry, biology, and physics.

A materials scientist investigates how materials are put together, how they can be used, how they can be changed—and how they can be improved to do even more amazing things. Materials scientists also create materials that have never existed before! Sometimes materials scientists are called *ceramic* or *polymer engineers,* or *metallurgists*, and you can find them working in industries, labs, and universities all over the world.

In the past, people used and changed materials by trial and error. They worked on a big, visible scale—for example, heating, then rapidly cooling, chunks of iron to make it harder. Modern materials scientists manipulate and change materials based on fundamental understandings of how the materials are put together, often on the invisibly tiny scale of atoms. How small is that? You'd need trillions of atoms to make a speck as big as the period at the end of this sentence.

What Kinds of Materials Are There?

There are about 300,000 different known materials. If you named one every second, it would take you more than three days and nights just to get through the list! And, as materials scientists continue to create and combine materials in new ways, the number is always growing. Most materials fit into a few big, general categories: metals, ceramics, semiconductors, polymers, composites, biomaterials, and entirely new types of exotic and strange materials, such as carbon nanotubes, which are very tiny spheres or cylinders made of carbon atoms. Such nanotechnology is taking materials science into a new dimension, as scientists create new materials atom-by-atom and molecule-by-molecule—leading to properties and performance never before imagined.

MRS MATERIALS RESEARCH SOCIETY
Advancing materials. Improving the quality of life.

WGBH GRATEFULLY ACKNOWLEDGES THE CONTRIBUTION OF THE MATERIALS RESEARCH SOCIETY.

About This Activity Guide

The *Making Stuff Activity Guide* contains four materials science activities that can be used in afterschool or out-of-school programs, or other settings. The hour-long activities are geared toward children ages 10 to 12, but families and adults alike can enjoy them. The materials are inexpensive and readily available at grocery, hardware, home supply, and electronics stores.

No special science background is required to lead the activities. Comprehensive leader notes include detailed procedure steps and illustrations, science background, and answers to kids' questions noted in parentheses, so you can learn right along with the kids. The guide also includes activity sheets for kids, with easy-to-follow instructions. We recommend that you complete the activity before leading it with a group. At the end of each activity, download the related episode clip from pbs.org/nova/education/makingstuff to see some cutting edge materials science.

The Making Stuff Web Sites

For more educational resources, visit **pbs.org/nova/education/makingstuff**, where you can find episode clips related to each activity, plus a toolkit and other resources to hold a *Making Stuff* science event.

To find additional information about the show visit the *Making Stuff* Web site, **pbs.org/nova/makingstuff**.

National Science Education Standards

		Stronger	Smaller	Cleaner	Smarter
K-4	Science as Inquiry: Understanding about Scientific Inquiry	•	•	•	•
	Science as Inquiry: Abilities Necessary to Do Scientific Inquiry	•	•	•	•
	Physical Science: Properties of Objects and Materials	•	•	•	•
	Physical Science: Light, Heat, Electricity, and Magnetism		•	•	
	Physical Science: Position and Motion of Objects	•	•		•
	Science and Technology: Abilities of Technological Design	•	•	•	
	Science and Technology: Understanding about Science and Technology	•	•	•	•
5-8	Science as Inquiry: Understanding about Scientific Inquiry	•	•	•	•
	Science as Inquiry: Abilities Necessary to Do Scientific Inquiry	•	•	•	•
	Physical Science: Properties and Changes of Properties in Matter	•	•	•	•
	Physical Science: Transfer of Energy	•	•	•	
	Physical Science: Motions and Forces	•	•		•
	Science and Technology: Abilities of Technological Design	•	•	•	
	Science and Technology: Understanding about Science and Technology	•	•	•	•

Spoon Drop Strength Test

MATERIALS

For the activity (per pair or team)

- 1 container with a wide round opening (e.g., 1-lb. coffee can, 32-oz. yogurt, or 18-oz. oatmeal container, or other canister)
- 1 sheet or square of each of the following materials large enough to cover the container opening (about 8" x 8"):

  newspaper, plastic wrap, aluminum foil, photocopier or printer paper, wax paper, freezer paper*
- 1 roll masking tape
- 1–2 thick rubber bands large enough to fit around the container opening
- 1 yard or meter stick
- 1 metal spoon (teaspoon or tablespoon)
- activity sheet

For the group

- 1 tennis ball
- 1 piece of string, 18 inches
- 1 balloon, over-inflated
- 1 wire coat hanger
- 1 piece of chalk
- video clip available at pbs.org/nova/education/makingstuff
- video display equipment

Note: *Freezer paper (a white paper wrap with a plastic coating on one side) is available in most grocery stores.

Time: Prep: 15 minutes; Activity: 45 minutes

Activity Description

Kids drop a spoon to break some common materials to test their toughness—how much energy they can absorb before breaking.

Learning Goal

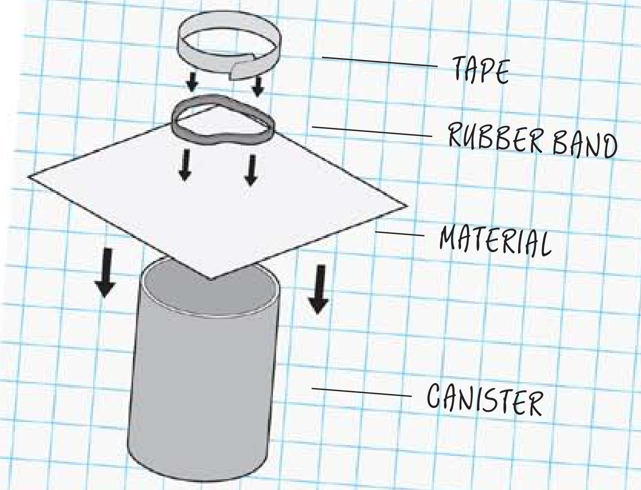
To learn about the physical properties of some everyday materials and how materials scientists test the properties of materials to determine how safe they are, how best to use them, and how to design better ones.

Introduction

All materials have certain physical properties, which determine how best to use them. For example, concrete is rigid and doesn't compress much, making it ideal for buildings and sidewalks, but a poor choice for sneakers, which need to be soft and flexible. To determine the best use for a material, scientists test it for different types of strength, including toughness. Toughness is how much energy a material can absorb before breaking. In this activity, kids explore the properties of some everyday materials and test them to see which is toughest by dropping a spoon from different heights. The greater the height, the more gravitational potential energy the spoon has when dropped. And the more kinetic energy it has when it hits the material.

Advance Preparation

- Gather the materials.
- Cut squares of the materials.
- Set out the tennis ball, string, inflated balloon, wire coat hanger, and piece of chalk for the demonstration in step 1 of the procedure.
- Prepare to demonstrate the spoon drop activity in step 2 of the procedure. Secure a square of newspaper over the opening of one of the containers with a rubber band and then place a long piece of tape, over the rubber band, around the container.



Procedure

1. Introduce the topic.

Ask: *What does it mean to be strong?* (Answers will vary.) Explain that there are many different types of strength and materials can be strong in different ways. Some types of strength are:

- **compression strength**—how much a material can be compressed or squeezed (Squeeze the tennis ball.)
- **tensile strength**—how much a material can be pulled apart (Pull the string taut and, if you can, break it.)
- **toughness**—how much energy a material can absorb before breaking (Press the over-inflated balloon against a table or wall and break it.)

Ask: *Why is it important for car body materials to be strong?* (To make a car safer in a crash.) *Do seatbelts need to be strong?* (Yes, they have to be strong to hold people in their seats.) *Are seatbelts strong in the same way that the outside of a car is?* (No. Cars bodies are designed to crumple, or deform, to absorb energy from the crash and keep the people inside as safe as possible. They are tough. Seatbelts are designed to resist pulling, stay tight, and not break. They have high tensile strength.)

To design the best material for the job, scientists test materials to see which have the best type of strength and other properties that suit the task. They ask:

- How much deformation, or strain, can a material withstand? (To deform means to bend, stretch, or change shape.)
- How does it deform? (A material that deforms slowly before breaking is **ductile**. A material that deforms quickly before breaking is **brittle**.)

A ductile material can bend or stretch a lot before breaking, like a piece of rubber or a wire coat hanger. (Bend the wire coat hanger back and forth, breaking it if possible.) In order for a material to be tough, it must also be somewhat ductile.

A brittle material doesn't bend or stretch much before breaking, like a coffee mug dropped on the floor or a piece of chalk. (Break the piece of chalk in two.)

2. Demonstrate the spoon drop test.

Explain that you will be doing your own toughness test to see how much energy a material can absorb before breaking. Ask a volunteer to come up and help you. Have him or her hold the measuring stick next to the can. Explain that you're going to test the strength of the newspaper by dropping the spoon on it. The higher the drop height, the more energy the spoon will have.

Drop the spoon from 5 inches above the can. The newspaper should not break. Ask kids what they observed. Continue the test, increasing the drop height until the newspaper tears. Ask the kids what they observed. (The newspaper tore easily.) *What can you conclude from this?* (Newspaper can't absorb much energy and is not very tough.)

3. Facilitate the activity.

Pass out the activity sheets and follow the steps. Kids will explore the materials, predict which ones will be the easiest and hardest to break, and rank them. (Final results may vary, but the order from easiest to hardest is roughly: newspaper=1, wax paper=2, aluminum foil=3, plastic wrap=4, photocopier/printer paper=5, freezer paper=6.)

4. Analyze the results.

When all the pairs have finished testing, discuss how the kids' predictions compare with their results.

- *Which materials were dented or stretched before breaking?* (plastic wrap, aluminum foil, and freezer paper—these materials are ductile and stretch out before breaking)
- *Which material was the easiest to break?* (newspaper or wax paper)
- *Which was the toughest—able to absorb the most energy before breaking?* (freezer paper) *Why?* (The freezer paper is the toughest to break because it is a composite—two materials, plastic and paper, put together.) Explain that when you put two materials together, you can take advantage of the best properties of both.

5. Conclude the activity.

Explain that materials scientists are always looking for ways to make stronger materials.

- *Why is knowing the strength of a material important?* (To determine the best way to use it and how safe it is.)
- *What could you use the strongest material for? What about the weakest?* (Accept all answers.)
- *What other types of tests might materials scientists do on different materials?* (Compression strength tests—squeezing or crushing a material until it breaks; Tensile strength tests—pulling a material apart until it breaks; Deformation tests—stretching or bending a material until it will not return to its previous shape)
- *What are some other ways you can make a material stronger?* (Add layers, change the shape, or change the structure, for example, by folding, weaving, or bending, like corrugated cardboard.)

If time permits, have kids try the variations above or the "Extend the test" step on the activity sheet. Conclude by showing the clip from NOVA *Making Stuff: Stronger,* available at pbs.org/nova/education/makingstuff, in which host David Pogue participates in a demolition derby to explore the toughness of steel car bodies.

MAKING STUFF

Spoon Drop Strength Test

NOVA PBS

MATERIALS

- 1 container with a wide round opening (e.g., 1-lb. coffee can, 32-oz. yogurt, or 18-oz. oatmeal container, or other canister)
- 1 sheet or square of each of the following materials large enough to cover the container opening (about 8" x 8"):

  newspaper, plastic wrap, aluminum foil, photocopier or printer paper, wax paper, freezer paper*
- 1 roll masking tape
- 1–2 thick rubber bands large enough to fit around the container opening
- 1 yard or meter stick
- 1 metal spoon (teaspoon or tablespoon)

*Freezer paper (a white paper wrap with a plastic coating on one side) is available in most grocery stores.

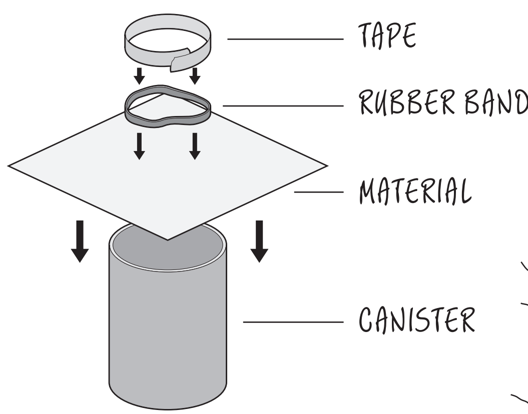
Materials scientists look at the different properties of materials, including strength and toughness, to determine the best way to use them. Toughness is how much energy a material can absorb before it breaks. **Test some everyday materials to see which is toughest by dropping a spoon from different heights until the materials break.**

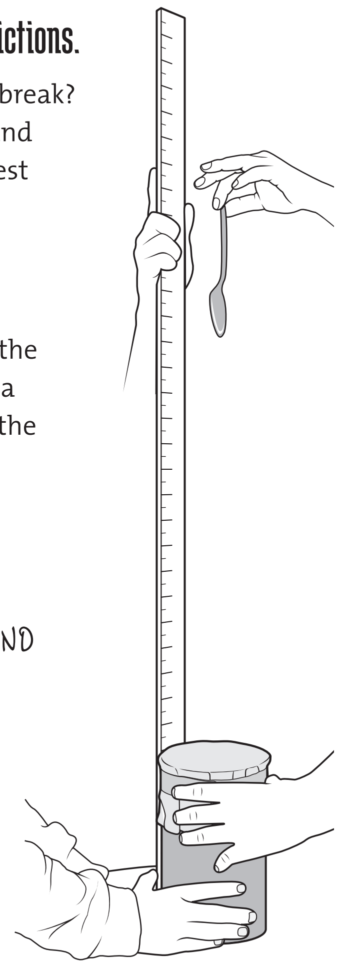
1. Examine the materials and make predictions.

Which material will be the easiest to break? The hardest? Make your predictions and rank the materials in order from easiest to hardest in the table.

2. Set up the test.

Select a material to test. Place it over the top of the canister and secure it with a rubber band. Put a strip of tape, over the rubber band, around the container.





3. Do the test and record observations.

Hold the covered container next to the yard or meter stick. Hold the spoon by the handle, with *the bottom of the spoon* 5 inches (12.7 cm) above the top of the container. Drop it straight down onto the material. What happens to the material when the spoon hits it? (e.g., Does it dent or tear?) Write your observations in the table.

If the material does not break, place the *bottom of the spoon* 10 inches (25.4 cm) above the canister and drop it again. Record your observations. Keep increasing the drop height by 5 inches (12.7 cm) until the material breaks. Record any new observations and write the final drop height in the table. (Don't forget to subtract the height of the container to get the exact distance that the spoon fell.)

4. Repeat the test for each material.

Remove the broken material and do the same test with a different material.

5. Analyze your results.

Remember, the higher the drop height, the more energy the spoon had when it hit.

- Which material was the easiest to break?
- Which was the toughest—able to absorb the most energy before breaking?
- Which materials were dented or stretched before breaking?
- How did your predictions compare with the results?

6. Think like a materials scientist.

Materials scientists are always looking for ways to make stronger materials.

- Why is knowing the strength of a material important?
- Based on the results of your test, what are some ways you could use the strongest material? the weakest?
- What other types of tests might materials scientists do on different materials?

7. Extend the test.

- What are some ways that you could make a material stronger? Design and build a stronger material and test it.
- It took several spoon drops to break most of the materials, which may have deformed (dented or stretched) the material. Predict if a new piece of the same material would break if you dropped the spoon from the final drop height. Test your prediction.

Material	**Prediction** Rank materials in order from weakest to strongest (1-6).	**Final Drop Height** (inches or centimeters)	**Observations** (What happened to the material when the spoon hit it?)	**Results** Rank materials in order from weakest to strongest (1-6).
aluminum foil				
freezer wrap				
newspaper				
photocopier/ printer paper				
plastic wrap				
wax paper				

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Magnetic Microbot Models

MATERIALS

For the activity (per pair or team)

- 1 wide-mouth, clear plastic container, at least 3 inches deep (e.g., cylindrical cover from a stack of CDs or DVDs, or a food storage container)
- 2 magnets (e.g., refrigerator magnets)
- 1 washer, not zinc-plated, 1.5 inches wide
- assortment of gadgets: paper clips (large and small); brass fasteners; washers (large and small); nuts and bolts; LED lights; small alligator clips (provide two or three of each of these items per pair)
- clear tape (double-sided, if possible) or quick-drying glue (if the magnets do not need to be reused)
- activity sheet

For the group

- 1 plate (if paper, use one with a water-resistant coating)
- ¼ cup glycerin or shampoo
- 1 toy bristlebot (e.g., HEXBUG®, available at electronics stores, or learn how to make your own at: evilmadscientist.com/article.php/bristlebot)
- video clip available at pbs.org/nova/education/makingstuff
- video display equipment

Note: The gadgets are stand-ins for robot parts, tools, and equipment. LEDs, even unlit, can be sensors and also have convenient wires for attachment. Alligator clips make great pincers or grabbers. Paper clips are easily bent into antennae, legs, and arms.

Time: Prep:15 minutes; Activity: 45 minutes

Activity Description

Kids are challenged to build a model of a small magnet-powered robot that's loaded with as many gadgets as possible, but still able to scale the wall of a container.

Learning Goal

To learn about: magnets and their properties; how materials scientists are building extremely small robots by replacing bulky mechanical parts, like motors, with magnetic materials; how materials scientists are using design ideas from nature to overcome the weird, wacky forces that tiny robots encounter.

Introduction

Materials scientists are building tiny robots that can travel inside the human body to deliver medicine or perform surgery, but there are some challenges to building small. Extremely tiny motors can be hard to build and can make the robot too big or too heavy. Also, because forces affect very small objects differently, moving through water is like slogging through mud. Materials scientists are inventing new ways to power and move micro-robots, or microbots. Some have replaced motors with magnetic materials that allow them to make robots as small as a human hair. The magnetic microbots are moved by powerful magnets located outside the body and do not require any moving parts, such as motors, gears, or wheels.

Advance Preparation

Gather the materials.

Procedure

1. Engage the kids.

Ask: *Why might scientists want to make robots that are as small as—or smaller than—an ant? What could these tiny robots do?* (Some answers are: they can go into tiny places—like inside the human body; they can scale walls; they can run on less power than big robots; they can be numerous—picture massive swarms of them exploring oceans and planets!)

Safety Notes

- Due to the use of small parts, this activity is not suitable for young children.
- Avoid parts that are sharp or otherwise pose a hazard.

2. Explore the materials.

Allow the kids to explore the magnets and other materials while you review some basic facts about magnets: Ask: *What is a magnet?* (Accept all answers.) If needed, explain:

- A magnet is an object that attracts and repels materials that contain iron, nickel, or cobalt (magnetic materials).
- Magnets exert a force (a push or a pull) on magnetic materials. This force is called *magnetic force* or *magnetism*.
- Each magnet has two poles: a north pole and a south pole. The magnetic force is strongest at the poles.
- Opposite poles (north/south) attract and like poles (north/north or south/south) repel.

3. Present the challenge.

Point out the gadgets and explain that the challenge is to build a model of a robot that can be guided and moved with no motor or other moving parts. It moves due to magnetic force. The model robot must carry as many gadgets as possible, to represent the tools and functions that a real robot would have, and still be able to climb the wall of a container.

Ask: *What parts of a robot could these gadgets represent?* (Some answers are: tiny lightbulbs could be "sensors," alligator clips could be grabbers, and paper clips could be antennae, legs, and arms.)

4. Design, build, and test the model microbots.

Allow about 25 minutes for the kids to brainstorm a design, build it, and test it. Ask them to think about:

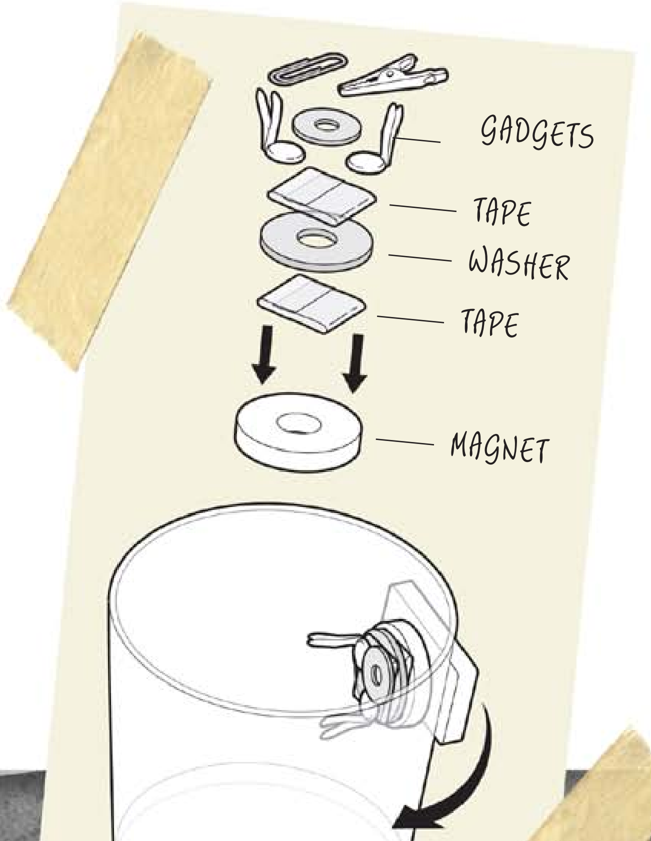
- how the size, shape, and placement of the gadgets will influence how the microbot moves (heavier or bulkier attachments will require more magnetic force to move)
- how to position the magnets to take advantage of their magnetic force (opposite poles to use attraction; like poles to use repulsion)

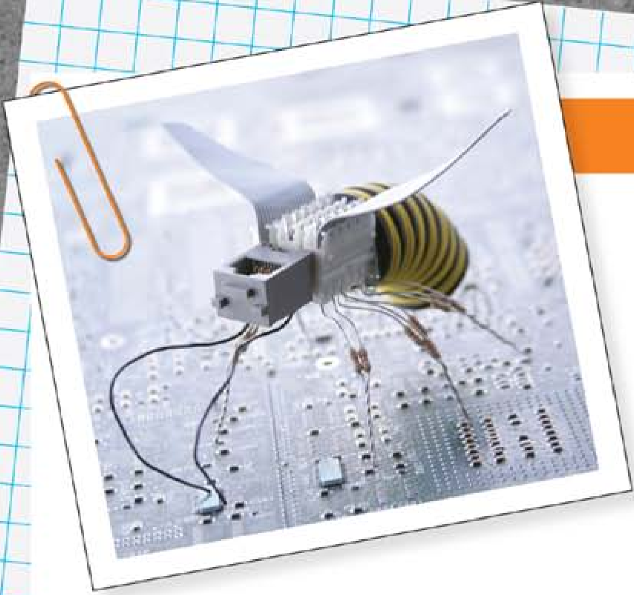
Kids may need help securely taping or gluing the materials together. One basic design is shown in the illustration. It has a washer taped to one magnet and the gadgets taped to the washer. The second magnet is used outside the container to power the robot. If a team's microbot model fails to climb the wall, encourage them to think about what went wrong and redesign their model.

5. Discuss the results.

As a group or by team, have kids present their designs. Discuss:

- *What property of magnets is used to power the microbots?* (Magnetic force, either attraction or repulsion, depending on the design.)
- *Why can the microbot defy gravity?* (The magnetic force of the magnet is stronger than the force of gravity acting on it.)
- *How many gadgets was each robot able to carry?* (Answers will vary.)





- *Which gadget materials did they choose—and why?* (Small, lightweight gadgets fit better and are easier to lift. The number of gadgets is limited by both space and weight. E.g. some real microbots must carry their own power supply in the form of heavy batteries.)
- *How could you power a robot with more tools (gadgets)?* (Use more magnets or larger, more powerful magnets to drive it.)
- *What are some other ways you could power a robot?* (Accept all answers.)

6. Conclude the activity.

Tell kids these are just a few of the challenges that materials scientists are overcoming as they design smaller and smaller robots. See some real magnetic microbots in a clip from NOVA's *Making Stuff: Smaller*, available online at pbs.org/nova/education/makingstuff. And, if time permits, present the optional extension demonstration on how the world is a very different place when you're microscopic.

EXTENSION DEMONSTRATION

Q: When is moving through water like swimming in mud? **A:** When you're microscopic!

Advance Preparation

Pour the glycerin onto the plate. Make sure the bristlebot is working.

1. Engage kids.

Ask: *Think about how you move through water in the bathtub or a swimming pool. Is it hard for you to push it out of the way with your body or hand?* (No. The water offers some resistance but kids are big enough to overcome it.)

2. Think small.

But what do you think it would be like if you were very, very small? (Accept all answers, then explain it would be like trying to swim through mud or quicksand. Very small organisms or objects, like bacteria or microbots, are not able to overcome the resistance of the water. To them, the water is very viscous, like syrup or molasses is to us. It resists flow. A bacterium is a million times smaller than a human, so, to it, the water is a million times more viscous or resistant to flow.)

3. Demonstrate the bristlebot.

Turn on the bristlebot and let it move around the table. Say: *This is what it is like for this toy robot to move in air. Air is much less viscous than water.* Place the bristlebot in the glycerin; it will not move much, but will continue to vibrate. *For very small objects or organisms, this is what it is like to move through water.*

4. Conclude the demonstration.

Explain: In nature, tiny organisms have evolved different ways to deal with this problem. For example, some bacteria have whip-like tails called flagella that swivel around to push them through the water. Materials scientists often take ideas from nature to solve engineering problems. For example, one microbot that has been designed is shaped like a tiny corkscrew or spring, just like a flagella. Magnets cause it to spin to propel it. It could one day swim through the bloodstream to deliver medicine or perform surgery. Download and view the NOVA *Making Stuff: Smaller* video clip at pbs.org/nova/education/makingstuff to see some real magnetic microbots.

A bristlebot moving through glycerin demonstrates the difficulty that small organisms or objects have moving through water.

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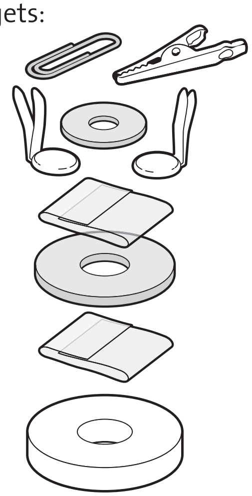
MAKING STUFF Magnetic Microbot Models

NOVA PBS

MATERIALS

- 1 wide-mouth, clear plastic container, at least 3 inches deep (e.g., cylindrical cover from a stack of CDs or DVDs, or a food storage container)
- 2 magnets (e.g., refrigerator magnets)
- 1 washer, not zinc-plated, 1.5 inches wide
- assortment of gadgets: paper clips (large and small); brass fasteners; washers (large and small); nuts and bolts; LED lights; small alligator clips (provide two or three of each of these items per pair)



- clear tape (double-sided, if possible) or quick-drying glue (if the magnets do not need to be reused)

Tiny robots could travel inside the human body to deliver medicine or perform surgery, but it's difficult to build very tiny motors with enough power. Some materials scientists are replacing motors with magnetic materials so they can use magnetic force to power the microbots from a distance. **Design and build a small robot powered by magnets. It must carry as many gadgets as possible and still be able to climb the wall of a container.**

1. Brainstorm a design for your magnetic microbot model and sketch it here.

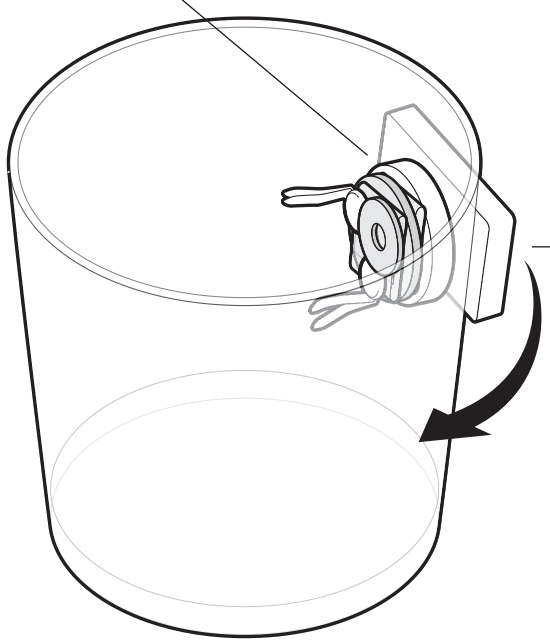
The gadgets are stand-ins, or models, for the parts and tools that a real robot would have. What robot part or tool could the tiny lightbulbs represent? What about alligator clips? Paper clips? Brass fasteners?

2. Brainstorm how to power your microbot.

Think about how you can use the properties of magnets to power your microbot. Remember, opposite poles (north/south) attract and like poles (north/north or south/south) repel.

3. Build your magnetic microbot model and test it.

Place the robot inside the container and test-drive it. Can you control how it moves? Can it climb the walls of the container? If not, make design changes and repeat the test.



4. Think about your results.

- Why do magnets move your microbot?
- How does the microbot defy gravity?
- How many gadgets was your microbot able to carry?
- Which gadget materials did you choose and why?
- What design changes would you have to make to power a robot carrying even more tools (gadgets)?

5. Think like a materials scientist.

What are some other ways you could power a tiny robot?

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DAVID H. KOCH HHMI Corporation for Public Broadcasting A private corporation funded by the American people MATERIALS RESEARCH SOCIETY Advancing materials. Improving the quality of life.

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Build a Cleaner Battery

MATERIALS

For the activity (per pair or team)

- warm water
- 3 tablespoons salt
- plastic cup
- 1 strip of copper plumber's strap, about 1 inch taller than your cup
- 1 zinc (plated or galvanized) screw, at least 2 inches long
- 6 inches of insulated wire, with ends stripped to expose wire
- 1 large alligator clip
- 1.5-volt buzzer
- activity sheet

For the group

- AA battery
- 1.5-volt LED light (optional)
- multimeter (optional)
- wire strippers
- paper towels
- video clip available at pbs.org/nova/education/makingstuff
- video display equipment

Note: Copper strip and zinc screws are available at hardware stores. Wire, alligator clips, buzzers, LED lights, and a multimeter can be found at electronics stores.

Time: Prep: 15 minutes; Activity: 45 minutes

Activity Description

Kids build environmentally cleaner batteries from saltwater, a zinc screw, and a copper strip, and then connect them all in a series circuit to increase the voltage and power small electrical devices.

Learning Goal

Kids learn about batteries, circuits, environmental problems with battery disposal, and the efforts of materials scientists to build cleaner batteries.

Introduction

Batteries are devices that store and convert chemical energy to electrical energy. They are used in many household electrical devices and personal electronics. They are cleaner than petroleum-based energy, but many batteries contain chemicals that are hazardous if they are not disposed of properly and get into the air, water, or soil. Powerful batteries are also very big and heavy. Small and light batteries do not have much power. Materials scientists are working to design new kinds of batteries, including smaller and more powerful ones that will provide clean energy for a new generation of electric vehicles. For example, materials scientists have developed rechargeable molten (hot) salt batteries that are more efficient than current batteries and could one day be used to power electric cars.

Advance Preparation

- Gather the materials.
- Bend the copper strip back and forth to break it into strips that are about an inch taller than the cup. File any rough edges.
- Cut the 6-inch lengths of wire and use the wire cutters to strip the ends to expose half an inch of metal wire.
- You can mix pitchers of saltwater, using 3 tablespoons of salt per cup of water, or have kids mix up their own.

Procedure

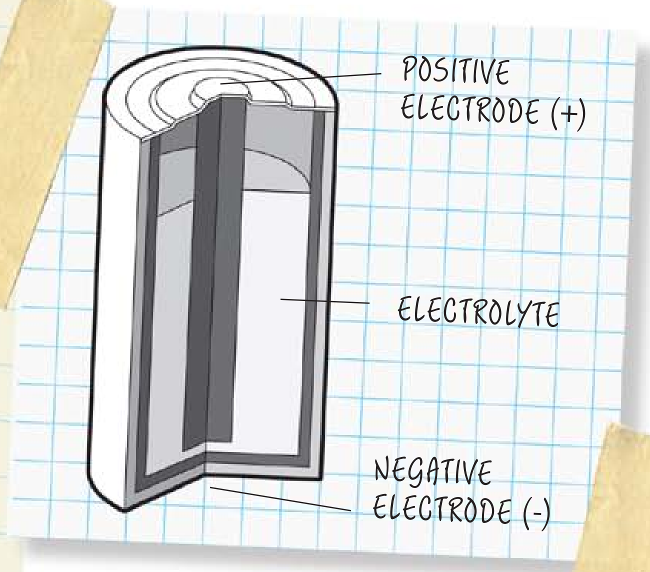
1. Introduce the topic.

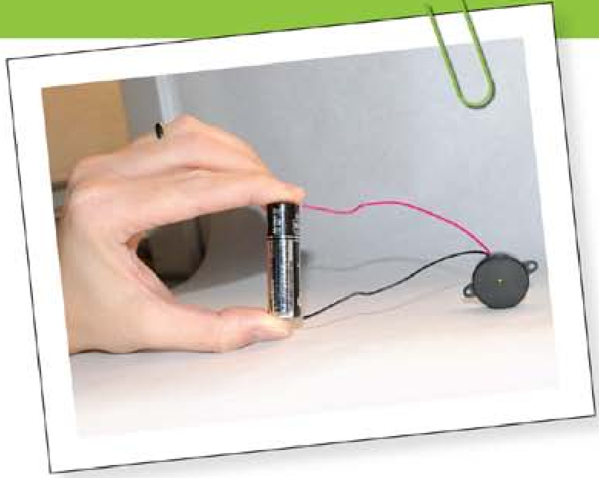
Ask kids: *What are some things that we use batteries for?* (Accept all answers.) *What happens to batteries after they are used up?* (Some can be recharged, and some are recycled, but many are thrown away.) Explain that batteries are an environmental problem because they contain chemicals that can be hazardous if they get into the air, water, or soil, which can happen when batteries are thrown away improperly or burned in waste incinerators.

2. Define a battery.

Hold up a AA battery and ask: *What is a battery?* (Answers will vary.) Explain that a battery is a device that stores and converts chemical energy into electrical energy. A battery is made up of an electrolyte, which is a chemical solution or paste inside the battery, and two electrodes, or connectors:

- a positive (+) electrode (top)
- a negative (-) electrode (bottom)





3. Show how batteries work.

Ask: *How does a battery work?* (Accept all answers.) With your thumb and forefinger, hold the red buzzer wire against the positive electrode on top of the battery and the black wire against the negative electrode on the bottom of the battery. The buzzer will sound.

When a battery's electrodes are connected, for example by the buzzer, a chemical reaction inside the battery causes positive and negative charges to separate and build up at the electrodes. The difference in the amount of charge built up in each area is called the electric potential difference, or voltage. Charge flows from areas with more charge to areas with less. So the greater the voltage, the greater the energy a battery provides to the charges. The AA battery has a voltage of 1.5 volts.

4. Discuss circuits.

Tell the kids that when you touched the buzzer wires to the battery electrodes above, you created a circuit. When the parts of a circuit are all connected one after another in a line, it is called a series circuit. The battery and buzzer are a series circuit. Another example of a series circuit is a flashlight in which the batteries are stacked on top of each other. When batteries are connected in series, the voltage adds together. Three 1.5-volt batteries connected in series have a total voltage of 4.5 volts.

5. Facilitate the activity.

Distribute the activity sheet and the materials. Explain that each team or pair of kids will make a battery. Review the activity sheet, including the illustration, and help kids follow the steps as needed. When they've completed assembling their batteries, ask: *Can anyone identify the parts of this battery?* (The copper strip is the positive electrode, the zinc screw is the negative electrode, and the saltwater is the electrolyte.)

Safety Notes

- Break the copper strip cleanly. Do not leave sharp edges.
- Caution kids not to drink the saltwater.

6. Test the saltwater batteries.

Have the kids use the buzzers to test the battery (touch the buzzer's red wire to the copper strip and the black wire to the zinc screw). They may hear a faint buzz or no buzz at all due to the battery's low voltage. If you have a multimeter, set it to the lowest setting for DCV (Direct Current Voltage) and have each pair or team use it to test their battery (touch the red probe to the copper strip and the black probe to the zinc screw). It should detect a very low voltage (less than 1 volt), but the movement of the needle will be apparent.

7. Power up.

When all the kids have tested their batteries, ask: *Did you get your buzzer to work?* (Some kids will say no, some will say a little bit.) Ask: *Why do you think that happened?* (The individual saltwater batteries have very low voltage.) Ask: *How can we get more power from our batteries?* (By connecting the batteries together in series.) Have the kids bring their batteries to one area and arrange them in a circle. Use the 6-inch lengths of wire to connect the batteries in a series circuit. Attach the zinc screw in one cup to the copper in the next (see activity sheet illustration).

After connecting the first two or three cups, check the voltage using the multimeter or a buzzer (touch the red wire or probe to the copper in the first cup and the black wire or probe to the zinc screw in the last cup). Connect the rest of the cups. When the cups are all connected, close the loop with a buzzer.

If the buzzer doesn't work, see the Troubleshooting tips. When the battery works, try to light a small LED light (touch the longer wire to the copper strip and the shorter wire to the zinc screw.) LEDs use very low voltage, so it should light if all the connections are working.

8. Discuss the results.

Ask:

- *How is the saltwater battery better than the AA battery?* (no toxic chemicals, environmentally friendly, easy to make)
- *What are the drawbacks?* (The saltwater battery is bigger than a AA battery and not easy to carry around.)
- *How many saltwater batteries do you think it would take to power a computer or an electric car? Why?* (Accept all responses.) *Do you think that would be a practical power source?*

Explain that, in addition to the danger of chemicals, size is another big problem for batteries. Powerful batteries are also very big and heavy. Small and light batteries do not have much power. Materials scientists are working to solve these problems and to make small, powerful batteries that are safe for the environment.

9. Conclude the activity.

Ask: *How could you increase the power of your saltwater battery without increasing its size?* Some answers are: add more salt or use warmer water —both increase the rate of the chemical reaction.) If time permits, have kids try these variations. Then, show the clip from NOVA *Making Stuff: Cleaner* about smaller more powerful batteries that may soon power electric cars. The clip is available at pbs.org/nova/education/makingstuff.

TROUBLESHOOTING

After the batteries (cups) are linked, there should be a significant increase in voltage and a sharp, clear buzz. If not, make sure:

- the wires are securely attached to each electrode (copper strip is positive electrode and zinc screw is negative electrode) and wrapped in a way that touches exposed metal
- the ends of the wire are out of the water
- the zinc and copper are not touching each other in the cups
- the wires connect the copper strip in one battery to the zinc screw in the next

MAKING STUFF

Build a Cleaner Battery

NOVA PBS

MATERIALS

(per simple battery)*

- warm water
- 3 tablespoons salt
- plastic cup
- 1 strip of copper (plumber's strap), about 1 inch taller than your cup
- 1 zinc (plated or galvanized) screw, at least 2 inches long
- 6 inches of insulated wire, to attach batteries together
- 1 large alligator clip
- 1.5-volt buzzer

Batteries are all around us. They are cleaner than some forms of energy, such as petroleum, but they can be hazardous to the environment if not disposed of properly. Materials scientists are working to make smaller, more powerful, and environmentally friendly batteries. **Build simple batteries. Connect them together to make a super battery with more power!**

1. Build a saltwater battery.

Use the saltwater provided, or put 3 tablespoons of salt in the cup and fill it with warm salt water, to about an inch from the top. Put a copper strip and a zinc screw in the saltwater solution, using an alligator clip to secure the screw to the cup.

2. Connect a buzzer to your battery.

Touch the RED wire to the copper strip and the BLACK wire to the screw. How loud was the buzzer?

If you have a multimeter, measure and record the voltage. Set the multimeter to DCV and touch the RED probe to the copper strip and the BLACK probe to the screw.

Record the voltage: ____________ volts

Most electrical devices use more than one battery and their voltages add up. How could you increase the voltage of your battery and get the buzzer to buzz louder?

3. Make more power.*

Connect two batteries together by wiring one of your electrodes to the opposite electrode in another battery. Wrap one end of a wire around the copper strip in your battery. Wrap the other end around the zinc screw (or clip it under the alligator clip) on another.

Test the buzzer again by touching the wires to the remaining unattached electrodes (the RED wire to the copper strip and the BLACK wire to the screw).

- How loud was it?

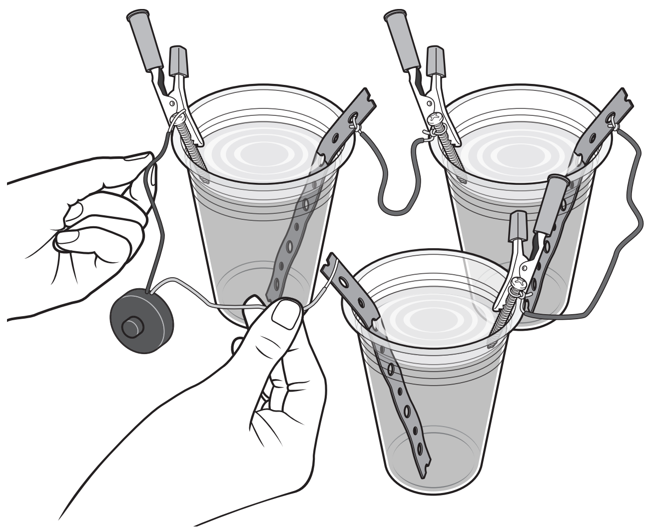
If you have a multimeter, use it again and record the voltage:

_____________ volts

- What do you think happened?
- How could you increase the voltage of your battery even more?

4. Build a super battery.*

Gather all the batteries in a circle and connect them into a series circuit—a circuit in which all the parts follow one another (see illustration). After each connection, measure the voltage or test the buzzer. Make sure your wires are securely attached and out of the water, and that the electrodes are hooked up in opposite pairs.



5. Test the super battery.

Touch a buzzer to the unattached electrode in the first battery and the unattached electrode in the last battery. (If you're using an LED, connect the longer wire to a copper strip and the shorter wire to the zinc screw.) What happened?

If you have a multimeter, use it again and record the voltage:

_____________ volts

Why did the voltage increase as you added batteries?

6. Think like a materials scientist.

- How is the saltwater battery better than the AA battery? How is it worse?
- How could you increase the power of your saltwater battery without increasing its size?
- How many saltwater batteries do you think it would take to power a computer or an electric car? Why?

*If doing this activity at home, make several more simple batteries.

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Smart Glove

MATERIALS

For the activity (per pair or team)

- 1 wide-mouth, clear plastic container, at least 3 inches deep (e.g., cylindrical cover from a small stack of CDs or DVDs, or a food storage container)
- 1 plastic cup
- 1 box cornstarch
- water
- 1 spoon, to stir
- 1 marble
- newspaper (to cover surfaces)
- paper towels
- activity sheet

For the group

- 2 wide-mouth, tall, clear plastic containers, at least 6 inches deep (e.g., cylindrical cover from a large stack of CDs or DVDs, or a food storage container)
- 1 box cornstarch
- water
- 1 marble
- 2 quart-sized ziptop freezer bags
- tape (masking, duct, or electrical)
- video clip available at pbs.org/nova/education/makingstuff
- video display equipment

Note: This activity can be messy, but the material (cornstarch and water) will dry, flake, and can be vacuumed up. It can also be washed off of clothes, hair, and skin.

Time: Prep:15 minutes; Activity: 45 minutes

Activity Description

Kids mix up a batch of a smart material and explore its unusual properties using a glove for a truly hands-on experience.

Learning Goal

To learn that materials vary in how they respond to forces and that some *smart materials* respond in unusual ways that materials scientists are using to design new products and materials.

Introduction

Materials respond to forces or changes in their environment. Most fluids follow Newton's Law of Viscosity. Viscosity is a property of a fluid that describes its resistance to flow. For example, syrup and molasses resist flowing; they have high viscosity. Simply stated, Newton's Law says that the harder or faster a fluid, like water, is pushed, the faster it flows. But some fluids do not follow Newton's Law—they are called *non-Newtonian fluids*.

This activity investigates a non-Newtonian fluid that is also a smart material—a mixture of cornstarch and water, often called oobleck. When a force is rapidly applied to oobleck, not only does it not flow faster—it suddenly turns solid! Its viscosity (resistance to flow) increases. Some other non-Newtonian fluids are latex paint, honey, mayonnaise, and ketchup. When sitting still, these fluids exhibit high viscosity (they resist flowing), but once they are moving, they flow easily. That's why a knife is sometimes needed to get the ketchup moving before it will flow out of the bottle. Latex paint is designed to thin out and flow as it is brushed onto a surface, but to resist flowing once in place, so there are fewer drips down the wall.

Advance Preparation

- Gather the materials.
- Spread newspaper on any surfaces you want to keep clean.
- Set up the introductory demonstration. Fill one tall container with about 4 inches of water and another with 4 inches of cornstarch.
- Build the "glove." Make a small batch of oobleck: mix 2 cups of cornstarch with 1 cup of water. Pour into a quart-sized resealable ziptop freezer bag. Turn another freezer bag inside out and insert into the first bag over the oobleck. Line up the opposite zipper seals on the two bags so they will seal. Zip the bags together and cover the seal with tape to prevent leakage.

1. TURN THE SECOND BAG INSIDE OUT AND INSERT IT INTO THE FIRST BAG, ON TOP OF THE OOBLECK.

2. LINE UP THE OPPOSITE SIDES OF THE ZIPPER SEALS, SO THEY WILL MESH.

3. SEAL BAGS AND PLACE TAPE OVER THE SEAL TO PREVENT LEAKAGE.

Procedure

1. Engage the kids.

Have you ever used a straw to drink water? What happens if you suck on the straw? (The water flows.) *What happens if you suck harder?* (The water flows faster.) Explain that how fast the water flows is proportional to how much force is applied. A force is a push or a pull. The scientist who discovered this was Isaac Newton. Kids may have heard that an apple fell on his head, leading him to discover gravity. He also figured out the laws that describe how fluids move and respond to forces, including the Law of Viscosity above. So we call fluids that obey those laws Newtonian fluids. Fluids that don't behave this way are called non-Newtonian fluids.

2. Demonstrate liquids and solids.

Explain that the containers hold water and cornstarch. The cornstarch is a solid in powder form. Ask for predictions of what will happen when you drop the marble into the cornstarch, then into the water. (The marble will stop in a solid, but will fall through a liquid.) Ask: *So how is a solid different from a liquid?* (A solid keeps its shape when a force is applied. A liquid flows and doesn't have a shape of its own.) *What do you think will happen when we combine these two materials?* (Accept all answers.)

3. Facilitate the activity.

Divide kids into pairs or teams. Have them mix small batches of oobleck and predict how it will respond when they perform the marble test on it. Have them record their observations on the activity sheet.

Pass around the glove that you made earlier and have them insert their hands in the inner bag to explore the mixture between the layers. Ask: *What happens when you squeeze, punch, or poke it?*

4. Discuss the results.

Ask kids: *What did you predict would happen in your marble test? What actually happened?* (The material flows like a liquid when you apply a force slowly, such as stirring it with a spoon, but hardens like a solid when you apply a force quickly, like dropping a marble on it.)

Ask kids: *Why do you think this happened?* (Accept all answers.) Explain that when force is applied quickly to the oobleck, the water is squeezed out from between the grains of cornstarch. This creates more friction between the grains as they rub against each other. The material becomes more viscous—the grains can't flow out of the way fast enough and the material behaves like a solid. When the pressure is released, the water flows back in between the grains, and the material behaves like a liquid again. It does not follow Newton's Law, which is why it's called a non-Newtonian fluid.

5. Explain smart materials.

Materials that respond to forces or changes in their environment in very specific, often unusual, ways are called smart materials. Materials scientists are using smart materials, and designing new materials that have smart properties, to make helpful products.

How could you use the cornstarch and water mixture in a new product? (Accept all answers.) Explain that a material with similar properties is being used in a prototype of a new lightweight bulletproof vest. The material allows the wearer more freedom of movement, but solidifies when impacted, offering protection when needed.

6. Conclude the activity.

Share some other applications of smart materials (in box on activity sheet). Show the video clip from the *Making Stuff: Smarter* episode, in which host David Pogue and a group of students mix a batch of oobleck in a cement mixer, fill a dumpster, and try to run across it, demonstrating its smart properties. The clip is available at pbs.org/nova/education/makingstuff.

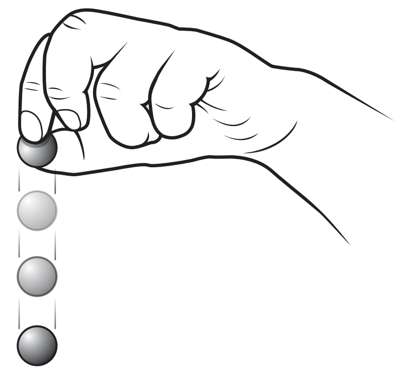
MAKING STUFF Smart Glove

NOVA PBS

MATERIALS

- 1 wide-mouth, clear plastic container, at least 3 inches deep (e.g., cylindrical cover from a stack of CDs or DVDs, or a food storage container)
- 1 plastic cup
- 1 box cornstarch
- water
- 1 spoon, to stir
- 1 marble
- newspaper (to cover surfaces)
- paper towels
- resealable plastic sandwich bag*

Viscosity is a fluid's resistance to flow. Water flows easily; it has low viscosity. Syrup and molasses resist flowing; they have high viscosity. Most fluids follow Newton's Law of Viscosity, which says that the harder or faster a fluid is pushed, the faster it flows—but some do not. They are known as non-Newtonian fluids. **Investigate a non-Newtonian fluid—a mixture of cornstarch and water, often called oobleck—that exhibits some strange properties.** Materials like oobleck that respond to forces in unique ways are called smart materials.



1. Set up the test.

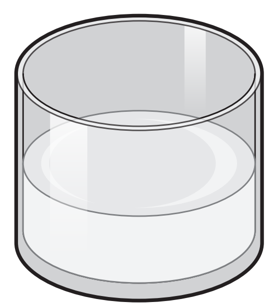
Mix the water and cornstarch together in the container. What do you notice as you mix them?

2. Make a prediction.

Predict what will happen when a marble is dropped into the mixture, a combination of a solid and a liquid.

3. Do the test.

Hold the marble above the mixture and drop it. What happens when it hits the mixture? Use the spoon to get the marble out. Repeat the test to confirm your observations. Does the same thing happen again?



4. Explore the smart glove.*

Insert your hand into the inner bag and punch, pinch, poke, and probe the oobleck. Record your observations.

5. Think about the results.

How would you describe the cornstarch and water mixture—is it a liquid, a solid, or both?

- What properties does it have when it is being poured? When sitting still?
- What properties does it have when something impacts, or hits, it?

6. Think like a materials scientist.

Brainstorm some ways that you could use a mixture that behaves like a liquid until a force is applied to it quickly.

*If doing this activity at home, after the marble test, create a modified "smart glove" by pouring the oobleck from the container into a resealable plastic sandwich bag. Seal firmly and secure the seal with tape.

HOW DOES IT WORK?

When a force is applied quickly to the oobleck, the water is squeezed out from between the grains of cornstarch. This creates more friction between the grains of cornstarch as they rub against each other. The grains of cornstarch can't flow out of the way fast enough and the oobleck behaves like a solid. When the pressure is released, the water flows back in between the grains, and the oobleck behaves like a liquid again. Because it responds to forces in this way, oobleck is a smart material.

Some other smart materials are:

- a special kind of wire used in some dental braces that, when heated, bends itself into a memorized shape to keep teeth in line without painful tightening. Such materials are called *shape memory alloys*.
- a fluid containing iron used in the shock absorbers of some vehicles. It solidifies in response to a magnetic field to smooth out a car ride on very bumpy roads. The material is called a *magnetorheological fluid*.
- some salts and crystals such as quartz (which is common in sand) that produce electricity when squeezed. These materials are called *piezoelectric materials*. Piezoelectric sensors are used in airbags. They sense the impact and send an electric signal to deploy the airbag.

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Additional Resources

All listed resources are appropriate for ages 9-12.

Materials Science

BOOKS

Ward, D.J. *Materials Science*. Minneapolis, MN: Lerner Publications, 2009.

Woodford, Chris. *Cool Stuff 2.0 and How It Works*. New York, NY: Dorling Kindersley, 2010.

ON THE WEB

Strange Matter Exhibit
strangematterexhibit.com/
Based on a traveling museum exhibit, this site invites visitors to explore materials science concepts.

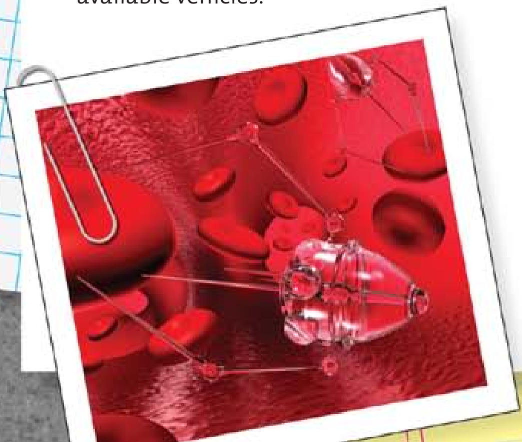
Making Stuff: Stronger

BOOK

Hillman, Ben. *How Strong Is It? A Mighty Book All About Strength*. New York, NY: Scholastic Reference, 2008.

ON THE WEB

The Insurance Institute for Highway Safety: 2010 Top Safety Picks
youtube.com/iihs#p/u/2/AZakukRsDW4
A look at the different types of car strength tested by this organization that rates the safety of commercially available vehicles.



Making Stuff: Smaller

BOOKS

Murphy, Ken. *The Blinkybug Kit: Make Your Own Electronic Insects*. San Francisco, CA: Chronicle Books, 2010.

Jefferis, David. *Micro Machines: Ultra-small World of Nanotechnology*. New York, NY: Crabtree, 2006.

ON THE WEB

How Small Can Robots Be?
nisenet.org/catalog/programs/how-small-can-robots-be
Engaging presentation script and resources about the ever-shrinking scale of robots. There's an extensive list of Web links to robotics labs and projects.

Instructables: Robots
instructables.com/tag/type-id/category-technology/channel-robots/
Section of "do-it-yourself" Web site with a collection of user-generated articles, videos, and images on how to make a variety of robots.

NISE Network
vimeo.com/channels/nisenet#12114645
Watch a magnetic microbot crawl across a dime, and view other videos of small robots in action.

Making Stuff: Cleaner

BOOKS

Bearce, Stephanie. *All About Electric and Hybrid Cars and Who's Driving Them*. Hockessin, DE: Mitchell Lane Publishers, 2009.

Fridell, Ron. *Earth-Friendly Energy*. Minneapolis, MN: Lerner Publications, 2009.

ON THE WEB

Burrito (Aluminum Air) Battery
exo.net/~pauld/activities/AlAirBattery/alairbattery.html
Make a battery using aluminum foil and activated charcoal.

Fruit-Powered Battery
www.seed.slb.com/labcontent.aspx?id=9824
Use lemons and pennies to make a battery.

Making Stuff: Smarter

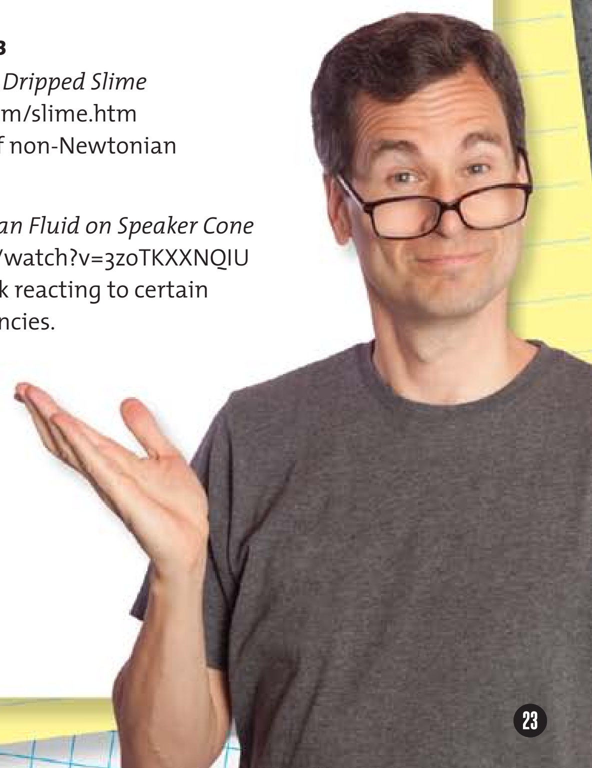
BOOKS

Beals, Kevin, and Bergman, Lincoln. *Oobleck: What Do Scientists Do?* GEMS (Great Explorations in Math and Science) series. Berkeley, CA: Lawrence Hall of Science, 2008 (revised edition).

ON THE WEB

The Page that Dripped Slime
bizarrelabs.com/slime.htm
A collection of non-Newtonian fluid recipes.

Non-Newtonian Fluid on Speaker Cone
youtube.com/watch?v=3zoTKXXNQIU
Watch oobleck reacting to certain sound frequencies.



Check out these other PBS and WGBH resources.

PEEP and the Big Wide World

Ages 3-6
Celebrate the curiosity and adventure of young children with simple science explorations.
peepandthebigwideworld.org

Curious George

Ages 3-6
Discover science, engineering, and math along with Curious George.
pbskids.org/curiousgeorge

FETCH! with Ruff Ruffman

Ages 6-10
Try the great FETCH activities based on challenges from the show.
pbskidsgo.org/fetch

THE GREENS

Ages 9-12
Investigate environmental issues and take action to protect the planet.
pbskidsgo.org/greens

DESIGN SQUAD as built on TV

Ages 9-13
Unleash your kids' ingenuity and get them thinking like engineers through hands-on activities.
pbskidsgo.org/designsquad

NOVA / NOVA scienceNOW

Ages 11 and up
Dig deep into science topics with classroom-ready resources from the most-watched science television series on PBS.
pbs.org/nova/teachers

dot diva

Ages 14 and up
Check out this career site for teen girls who believe in the potential of computing to build a better world.
dotdiva.org

Engineer Your Life™ Dream big. Love what you do.

Ages 14-18
Meet inspiring women engineers who make a real difference in the world. Find out if engineering might be your dream job.
engineeryourlife.org

teachers'domain

Educators
Use this media-rich library of teaching resources to make concepts come alive in engaging and interactive ways.
teachersdomain.org

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Director, Educational Outreach
Julie Benyo

Associate Director, Educational Outreach
Thea Sahr

Director of Education, NOVA
Rachel Connolly

Educational Content Manager
Sonja Latimore

Senior Editor
Sara Pratt

Associate Editor
Claudette Dawes

Outreach Coordinator
Jennifer Larese

Writer
Lorraine Hopping Egan/
Hopping Fun Creations

Creative Director
Alison Kennedy

Designer
Danielle Pierce

Illustrator
Jim Kopp

Print Production
Lenore Lanier Gibson

Advisors
Zak Elgart
Education & Life Skills Director
West End House Boys & Girls Club
Allston, MA

Kathleen Fadigan, Ed.D.
Assistant Professor, Science Education
The Pennsylvania State University

Kate L. Pickle
National Program Manager, STEM
Girl Scouts of the USA

Reviewers
Carol Lynn Alpert
Director, Strategic Projects
Museum of Science, Boston

Megan Frary, Ph.D.
Assistant Professor, Materials Science and Engineering
Boise State University

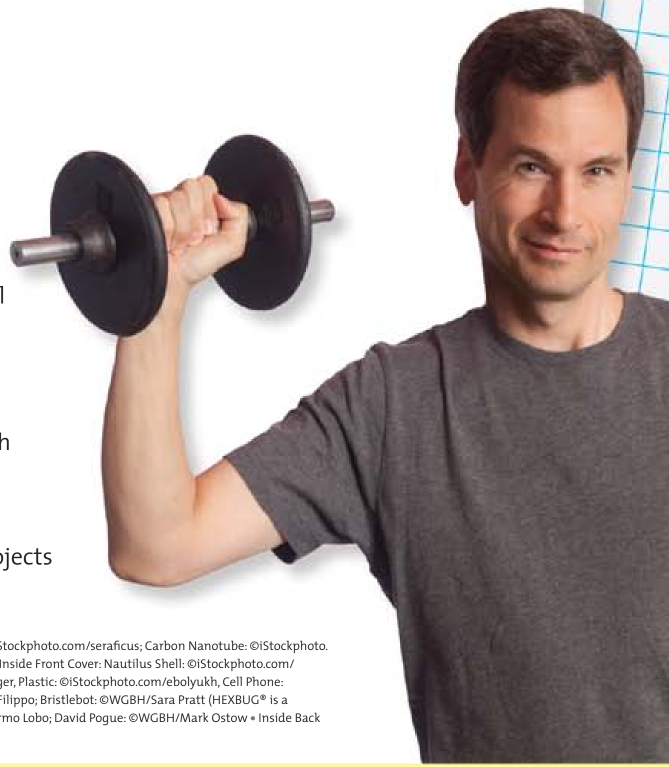
Amy Moll, Ph.D.
Professor, Materials Science and Engineering
Boise State University

Greta Zenner Petersen
Director of Education
University of Wisconsin MRSEC

Ainissa Ramirez, Ph.D.
Associate Professor of Mechanical Engineering & Materials Science
Yale University

Richard Souza
Manager, Education and Outreach
Materials Research Society

Karine Thate
Education Associate, Strategic Projects
Museum of Science, Boston



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