

BioEdSM

Think like an

Engineer

TEACHER'S GUIDE

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BioEdSM

Teacher Resources from the Center for Educational Outreach at Baylor College of Medicine

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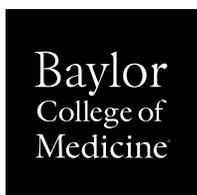
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* John W. Gardner Center for Youth and Their Communities at Stanford University. http://gardnercenter.stanford.edu/about_jgc/welcome.html



Unit Materials

Unless specified below, you will need the following materials and supplies to teach this unit with 24 students working in 6 groups. Refer to each activity for detailed information.

1. Ring Wing Gliders (p. 1)

Teacher Materials

- Computer with projector and Internet access
- Video: Engineer Your Life

Per Pair of Students

- 10 small paper clips
- 5 pennies, washers and other small weights
- Aluminum foil
- Clear tape
- Markers
- Metric ruler
- Pair of scissors
- Several sheets of paper in different sizes and weights (for example, newspaper, tracing paper, card stock, etc.; see step 6)
- Copy of “Ring Wing Glider 1” and “Ring Wing Glider 2” pages

Per Student

- 2 sheets of color copy paper (8.5-in. x 11-in.)
- Copy of “An Engineer’s Approach” page (p. vi)

2. Boomerangs (p. 7)

Per Student

- Pair of scissors
- Pencil with flat sides
- Sheet of 8.5-in. x 11-in. card stock
- Thick book
- Copy of “Finger Boomerangs” page
- Copy of “Four Wing Boomerang” page printed on card stock

Optional: Paint Stick Boomerang

Teacher Materials

- Hot glue gun with glue

Per Student

- 2–4 pennies
- 1 or 2 heavy rubber bands
- 2 wooden paint sticks

- 10-cm x 10-cm square of sandpaper
- Colored markers
- Safety goggles
- Copy of “Paint Stick Boomerang” page

3. Javelin Rockets (p. 14)

Teacher Materials

- 13 30-cm pieces of string
- 13 protractors
- 13 push pins
- 13 metersticks
- 8–9 narrow strips of duct tape, 3–4 cm in length
- 2 30-cm pieces of foam pipe insulation (for 3/4-in. diameter pipes)
- 2 rubber bands (large, sturdy)
- Hot glue gun and glue
- Manila folder (or thick card stock)
- Masking tape
- Pair of scissors

Per Pair of Students

- 8–9 narrow strips of duct tape, 3–4 cm in length
- 2 tennis balls
- 2 30-cm lengths of foam pipe insulation (for 3/4-in. diameter pipes)
- 2 manila folders (or thick card stock)
- 2 pairs of safety goggles
- 2 pairs of scissors
- 2 rubber bands (large, sturdy)
- Metric tape measure

Per Student

- Copy of “Make a Javelin Rocket,” “Launch Instructions,” and “Test Flight Data” pages

4. Catapults (p. 21)

Teacher Materials

- Bag of marshmallows or gummy bears
- Foam building blocks
- Masking tape

Per Student Group

- 2 survey flags or plastic orange cones
- Manual tennis ball thrower with tennis ball (available at pet stores)
- Bulls-eye target, or paper to create a target
- Tape measures or metersticks

Per Student

- At least 20 craft sticks, notched craft sticks, chopsticks, or wooden skewers with sharp ends removed
- 2 rubber bands
- Plastic spoon
- Safety goggles
- Copy of “Catapults,” and “Build a Spoonapult” pages

5. Wind-up Racers (p. 26)

Teacher Materials

- Tape measures or metersticks

Per Student

- 4 #32-size rubber bands
- Pencil or dowel
- Masking tape
- Metal washer
- 2 large paper clips
- 2 small paper clips
- Safety goggles
- Thread spool (large) and/or soft drink can
- Wooden or plastic bead (large)

Extra Materials for Modifications

- Different sizes of rubber bands
- Sandpaper
- Variety of large and small washers

6. Rocket Cars (p. 28)

Teacher Materials

- 10-meter strip of masking tape
- Meterstick

Per Student

- 2 coffee stirrers (axles)
- 2 non-bending straws
- 2 round, 12.7 cm (5-in.) balloons
- Flexible straw
- Masking tape
- Pencil
- Styrofoam™ tray (large, no sections)
- Copy of “Design Plan,” “Build a Rocket Racer,” and “Rocket Racer Data” pages

- Copy of “Wheel Patterns” page on card stock

7. Roller Coasters (p. 35)

Teacher Materials

- Computer with projector and Internet access
- Software: NoLimits Roller Coaster Simulation
- Videos: Roller Coasters, and World’s Second Greatest Paper Roller Coaster/Marble Run
- Web page: Paper Roller Coaster
- 9 6-ft lengths of foam pipe insulation (for 3/4-in. diameter pipes; see “Before You Start”)

Per Group of Students

- 3 pre-cut, 6-ft lengths of foam pipe insulation
- Marbles
- Masking tape
- Pair of scissors

Per Student

- 2 sheets of color copy paper (8.5-in. x 11-in.)
- Copy of “An Engineer’s Approach” (p. vi)

8. Kinetic Art (p. 38)

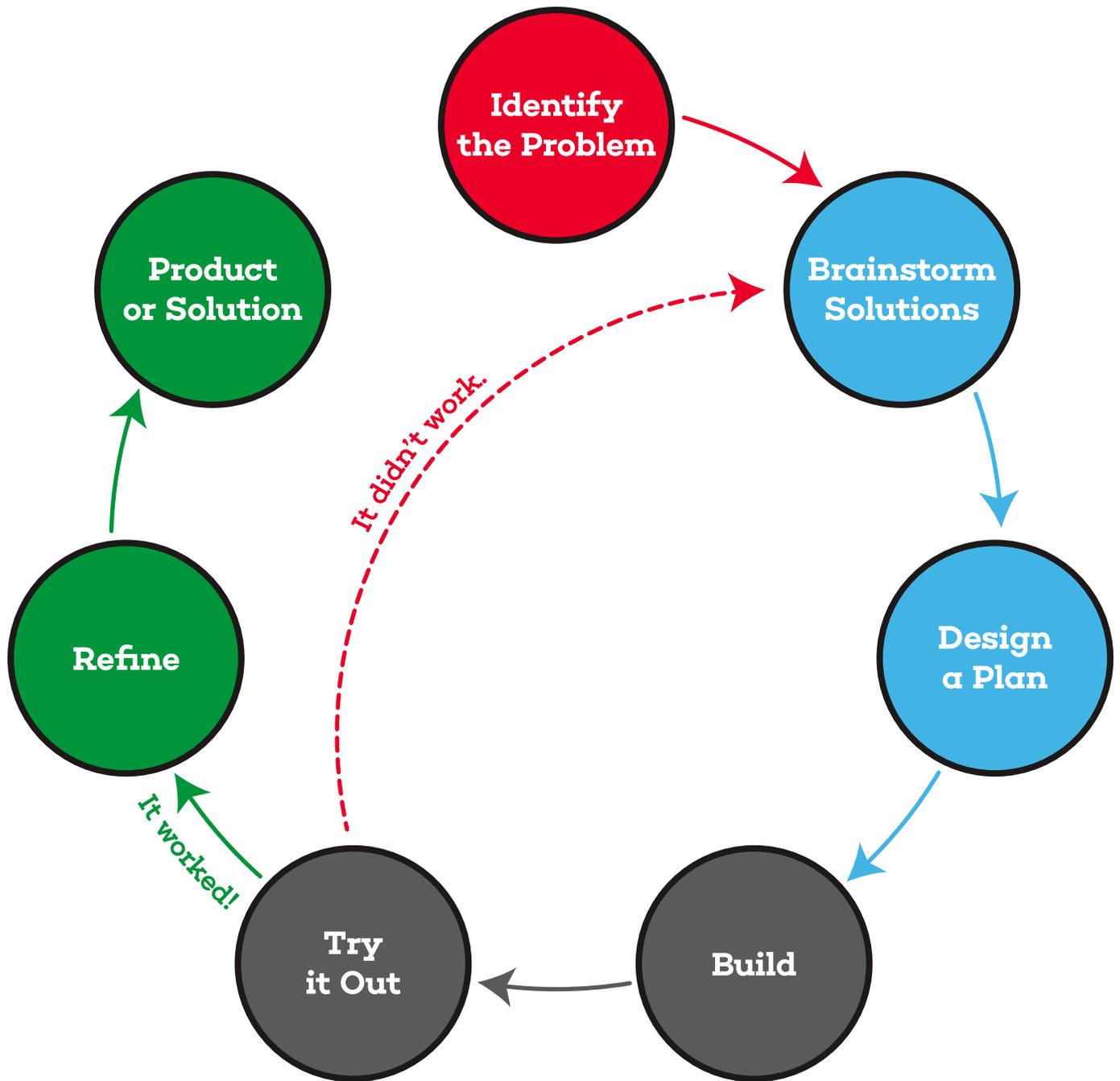
Teacher Materials

- Computer with projector and Internet access
- Online videos of kinetic artists and sculptures (select 1 or more from 7 videos)
- Crepe or tissue paper strips
- Electric fan
- Metal washers
- Nails, straight pins, or other devices to serve as pivot points
- Recycled materials (e.g., cardboard, cans, cups, etc.)
- Skewers
- String
- Tape

Per Student Group

- 10-cm x 10-cm sheet of paper (up to 15-cm x 15-cm square)
- Colored markers, crayons or decorative stickers
- Pair of scissors
- Pencil with full eraser
- Ruler
- Straight pin
- Copy of “Make a Kinetic Pinwheel” page

An Engineer's Approach



1

Ring Wing Gliders

Investigating Engineering

Time

1–2 sessions

Before You Start

Make samples of the two gliders. Practice throwing the gliders.

Make 24 copies of “An Engineer’s Approach” page (one per student).

You Need This Stuff

Teacher Materials

- Computer with projector and Internet access
- Video: Engineer Your Life

Per Pair of Students

- 10 small paper clips
- 5 pennies, washers and other small weights
- Aluminum foil
- Clear tape
- Markers
- Metric ruler
- Pair of scissors
- Several sheets of paper in different sizes and weights (for example, newspaper, tracing paper, card stock, etc.; see step 6)
- Copy of “Ring Wing Glider 1,” and “Ring Wing Glider 2” pages

Per Student

- 2 sheets of color copy paper (8.5-in. x 11-in.)
- Copy of “An Engineer’s Approach” page (p. vi)

What It’s About

This activity introduces students to engineering practice and encourages them to think like engineers. Students will learn about factors that affect flight as they design and build two types of flying cylinders. Then, they will use “An Engineer’s Approach” page to test and improve their gliders.



Individual civil French jet AOK Spacejet (closed wing design) at the 2013 Paris Air Show.

About Flight

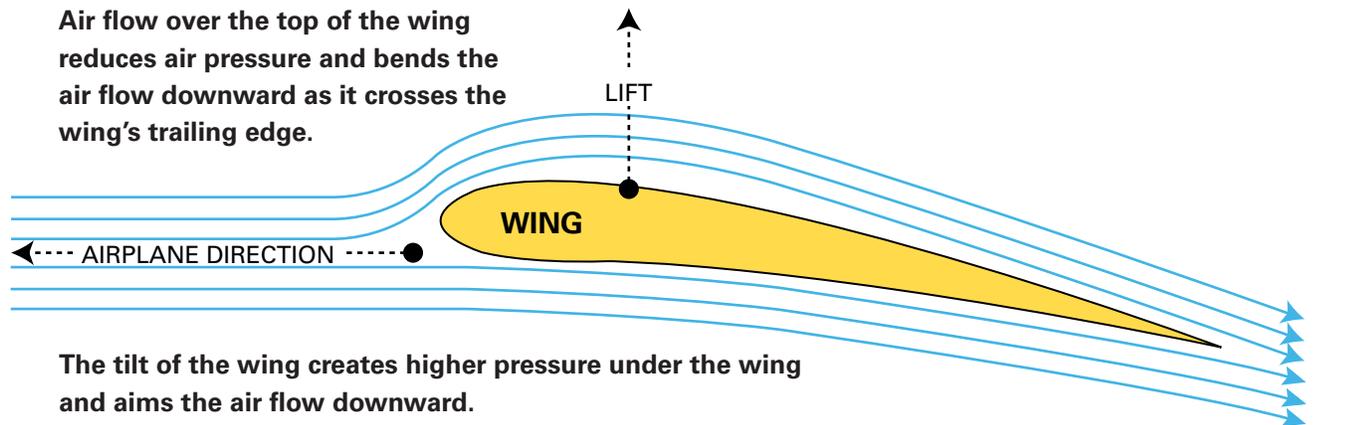
Airplanes come in many sizes and shapes. Most have a body, one or more sets of wings, a tail section and one or more engines. As long as the plane achieves flight, almost anything goes!

Aeronautical engineers must account several factors when designing a new airplane: lift, weight, thrust and drag. These are called the four forces of flight.

Lift is what gets an airplane off the ground. In most planes, lift is generated by the shape of the

Newton's Third Law of Motion

For every action there is an opposite and equal reaction. Air forced downward by the wing (action) produces an equal and opposite force (reaction) that provides lift to an airplane.



wings. As a plane moves forward, its wings push air downward. The downward push is known as an “action force.” Simultaneously, the airplane experiences an equal and opposite “reaction force” that pushes it up. Aeronautical engineers call this reaction force “lift.”

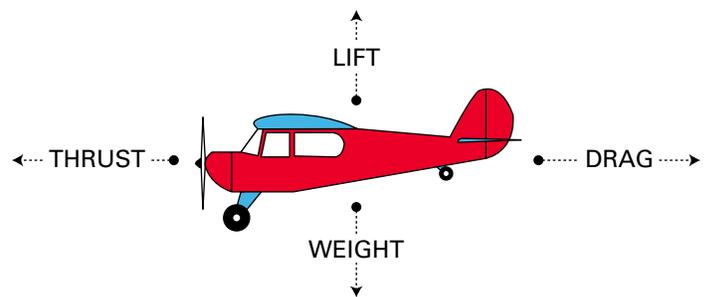
Most airplane wings are curved on top, flat on the bottom and tilted slightly downward towards the back. The forward edge of the upper surface is rounded, while the backward edge of an airplane wing is gently sloped. As a plane moves forward, some air moves above its wings and some flows beneath the wings. Because the upper surface is curved, air pressure over the wing is reduced by the airflow. This causes the air to bend downward as it passes the wing's trailing edge, producing a downward force. At the same time, air beneath the wing also is pushed downward by the slightly tilted underside. The downward force produced by the upper and lower wing surfaces creates the opposite and equal force that lifts the plane off the ground (see illustration above).

The faster the airplane moves forward, the greater the lift produced. This is why an airplane accelerates on the runway. When speed and lift have increased to sufficient levels, the plane will become airborne. Conversely, a plane coming in for a landing must be slowed to reduce lift. To compensate for the lower air speed, the pilot tilts segments

of the wings downward, thereby pushing more air from under the wings and maintaining sufficient lift to prevent the plane from falling out of the sky.

A second force, weight, opposes lift. Weight is the measure of gravity's effect on the airplane's mass. Earth's gravity “pulls” the plane down toward the ground. To overcome the force of gravity and achieve flight, an airplane must generate more lift than the total weight of the plane, its fuel, and all its contents. If an airplane loses its lift, weight (gravity) causes it to come crashing down.

Four Forces of Flight



The other two forces of flight are thrust and drag (see illustration above). Thrust is the forward force created by the propellers or jet or rocket engines as they blow air or exhaust backward to propel the plane. Drag—friction with the air while a plane is

moving forward—works in the opposite direction. To fly forward, an airplane must produce thrust greater than the forces of drag impeding it. Aeronautical engineers try to streamline their airplane designs so that planes cut through the air smoothly. A plane with a lot of drag will not be very efficient. As long as lift is greater than weight and thrust is greater than drag, any shape of airplane will fly.

In this activity, students will make and test flying tubes, called ring wing gliders. Students' muscle power will provide thrust, and lift will come from their gliders' shape.

What's the Question?

Can you work like an engineer?

What To Do

1. Ask students if they know what engineers do. Write their ideas on the board. Then ask them to identify similarities among the jobs listed. Explain that engineers work with materials to solve problems. Some build bridges across rivers. Others design structures to support heavy loads under many different conditions. Still others create roads over mountain passes and tunnels through mountains. But engineers do more than build things; they apply all types of science to solve a wide variety of problems. Not surprisingly, there are many kinds of engineers: civil, biological, structural, geomechanical, municipal, biomaterials, mechanical, chemical, computer, agricultural, climate, and even laptop carrier engineers.
2. Distribute copies of "An Engineer's Approach," to students (p. vi) and discuss the process. Then show students the video (URL below) of Judy Lee, a mechanical engineer and product designer. She explains what it's like to be an engineer and the process she and her colleagues follow to design a new product. After viewing the video, *Engineer Your Life*, have students share what they learned about Ms. Lee and her work.

<http://www.engineeryourlife.org/cms/6167/6196.aspx?eylprofile=Video>

3. Explain to students that they will begin investigating the world of engineering by

learning how things work. Using the step-by-step instructions on the "Ring Wing Glider 1" page, have students follow as you model the process for forming the paper into a glider. Do not tell them what they are making. When the glider is completed ask, *What is this?* Students will have a variety of answers. After they have had a chance to examine the cylinder and offer all their ideas, throw the glider across the room. The best way to achieve a "good" flight is to throw it like a football—but don't share this technique with students just yet.

4. Have students throw their cylinders. Do not give them advice or instructions; Instead let them experiment with different techniques. After students have had sufficient time to test different throwing styles, regroup and have them share their observations. Ask, *How did you throw the cylinder to make it fly the farthest or stay in the air the longest?* Students will discover that for best results, the cylinder should be thrown with the heavy end facing forward. You can demonstrate why by holding a sheet of paper horizontally and letting it fall. Students will observe that the paper wobbles as it drops to the ground. Add a couple of large paper clips to one end and the sheet of paper starts gliding as it falls. Have students test their cylinders again with this new information.
5. Have students make and test a second glider of a different design, using the set of instructions on the "Ring Wing Glider 2" page.
6. After students have tested and explored the flight of each cylinder, ask, *Could you modify your cylinders to make them fly further or stay in the air longer?* Have students brainstorm and discuss ways to improve the performance of their gliders. They may suggest adding weight to the front, changing shapes, using different types of paper or other modifications.
7. Let students work in pairs to design a new cylinder that will fly further and/or longer. Each team should draw a diagram of its new cylinder, label the parts, and consider possible modifications they could make after testing to improve its flight. Then, have students choose materials from those available (card stock, newspaper, paper clips, etc.) to build their new gliders.

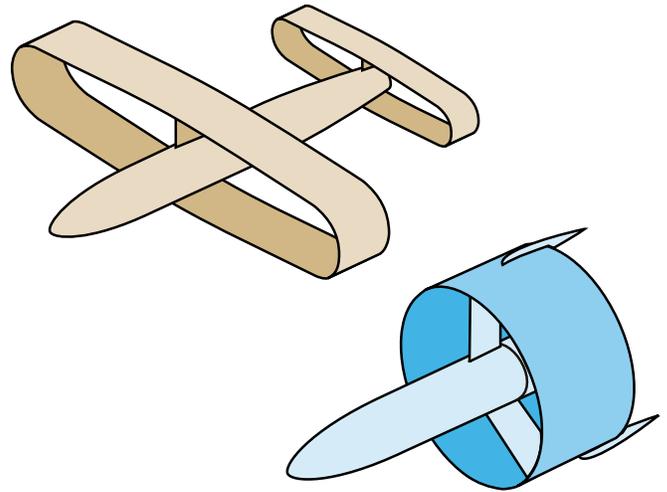
8. Teams should test their new fliers, record the results, and adjust their designs, as necessary.
9. To debrief, have each team present its results and explain the reasons for any adjustments to its design. Ask students to describe the challenges encountered when designing their fliers, and how they addressed those challenges. Refer back to the four forces of flight. Ask, *How did your team improve lift, decrease weight, improve thrust, and reduce drag in your flier?* Have each team compare its design and testing process to the list created for step 1. Ask, *What engineering jobs did you perform?*

Wrapping Up

Hold a class discussion about the potential of ring wings for future airplanes. Ask, *What are the advantages and disadvantages of this design? How would the planes look? Would you want to fly in one?*

Extras

- Challenge students to build ring wing gliders from other materials (e.g., aluminum foil) and/or



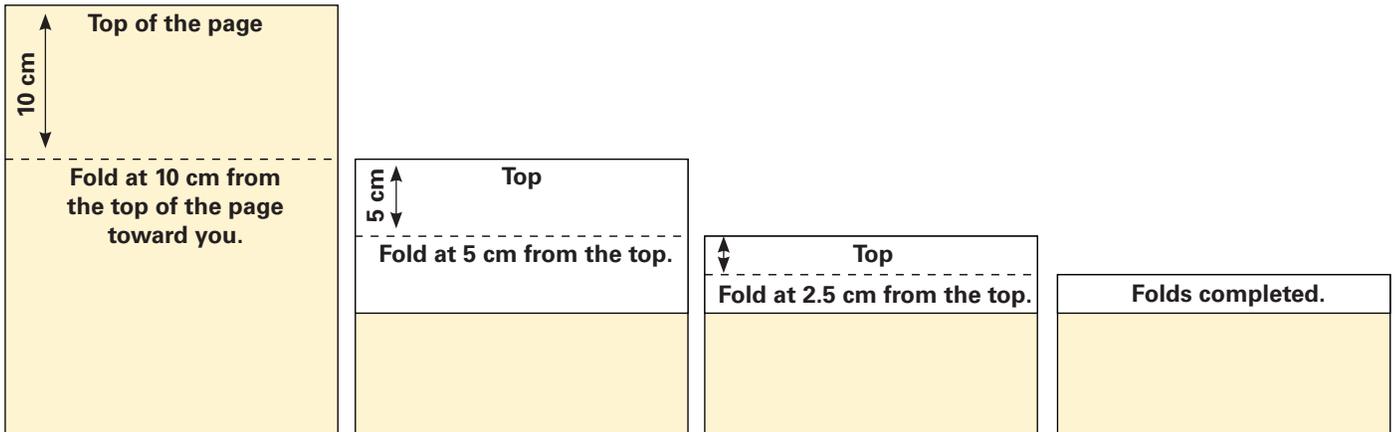
make gliders in different sizes and shapes (see illustrations above).

- Play the video, *Aeronautical Oddities* (URL below), which shows newsreel collections of unusual airplanes, including one version of a ring wing that actually flies.

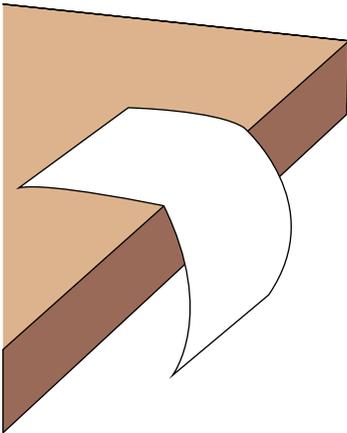
http://archive.org/details/aeronautical_oddities ■

Ring Wing Glider 1

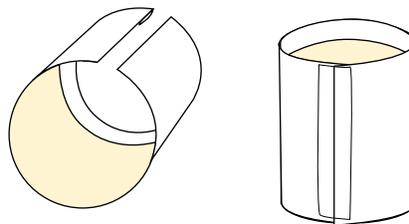
1. Lay a sheet of copy paper on the table. Measure and make the following three folds towards you, using the dimensions given. Use your fingers to make a strong crease for each fold.



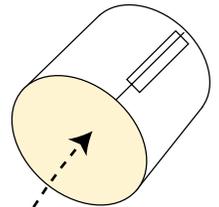
2. Hold the paper with the unfolded side toward you. Rub the sheet against the edge of a table to make a tube shape.



3. Bring the edges of the paper together to form a cylinder. Gently slide one band inside of the other band. Tape the seam shut.

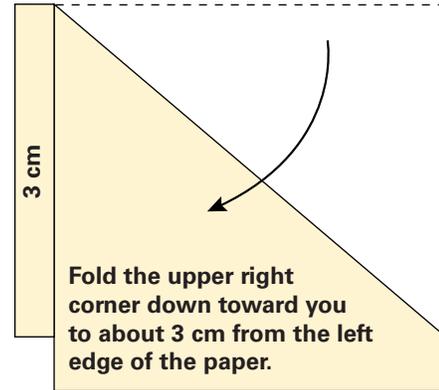
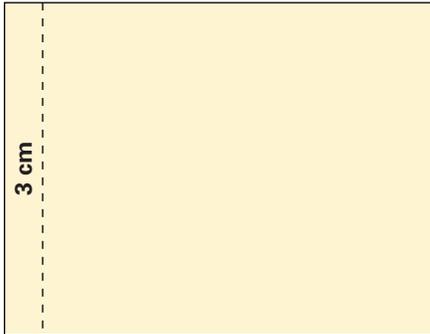


4. Fly the glider.

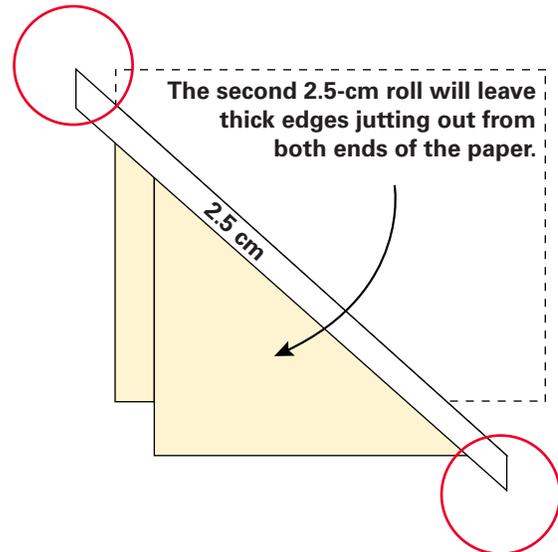
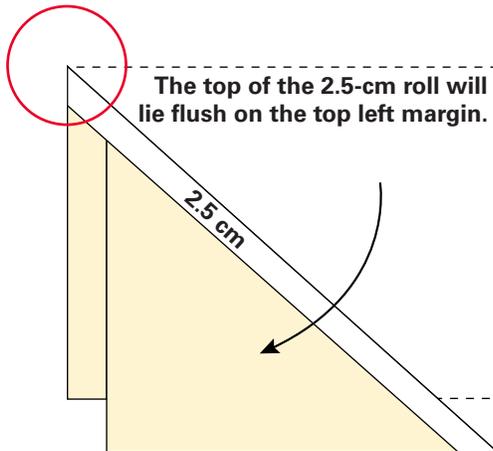


Ring Wing Glider 2

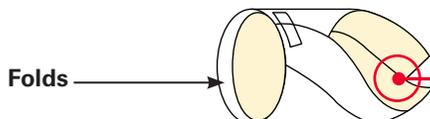
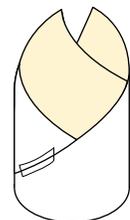
1. Lay a sheet of copy paper on the table. Measure and make the following fold toward you, using the dimensions given. Use your fingers to make a strong crease on the folded edge.



2. Roll the angled edge toward you to make a 2.5 cm fold, as shown below. The top of the angle will rest on the left margin. Make a strong crease on the folded edge. Repeat.



3. Curl the folded edges and tuck one end point inside of the other to form a cylinder. Secure the cylinder with a small piece of tape.
4. Grasp the glider lightly between the two pointed ends and fly it!



Folds →

Grasp lightly between the points and toss gently.

2

Boomerangs Many Happy Returns

Time

1–2 sessions

Before You Start

Create one set of boomerangs for demonstration. Test-fly them to practice your launch technique and to ensure the boomerangs return.

Make copies of the “Four Wing Boomerang” page on card stock (one per student).

If conducting the optional activity, obtain 48 wooden paint sticks (used to mix paint) and sandpaper (40–60 grit) from a hardware store. Cut the sandpaper into 10-cm x 10-cm squares (1 per student).

You Need This Stuff

Per Student

- Pair of scissors
- Pencil with flat sides
- Sheet of 8.5-in. x 11-in. card stock
- Thick book
- Copy of “Finger Boomerangs” page
- Copy of “Four Wing Boomerang” page on card stock

Optional Activity: Paint Stick Boomerang

Teacher Materials

- Hot glue gun with glue

Per Student

- 2–4 pennies
- 1 or 2 heavy rubber bands
- 2 wooden paint sticks
- 10-cm x 10-cm square of sandpaper
- Colored markers
- Safety goggles
- Copy of “Paint Stick Boomerang” page

What It's About

Most students may envision boomerangs as wooden throwing sticks, but these fascinating flying devices can be made of many different materials, including metal, plastic and even paper. Some boomerangs are designed to return, but others do not. Both tools have been used for millennia.

The non-returning boomerang goes back to the Stone Age. Used as a throwing stick for hunting, it was shaped to travel long distances on a very straight flight path. Versions of the non-returning boomerang were used in Europe, Australia and Egypt, and among some western Native American tribes.

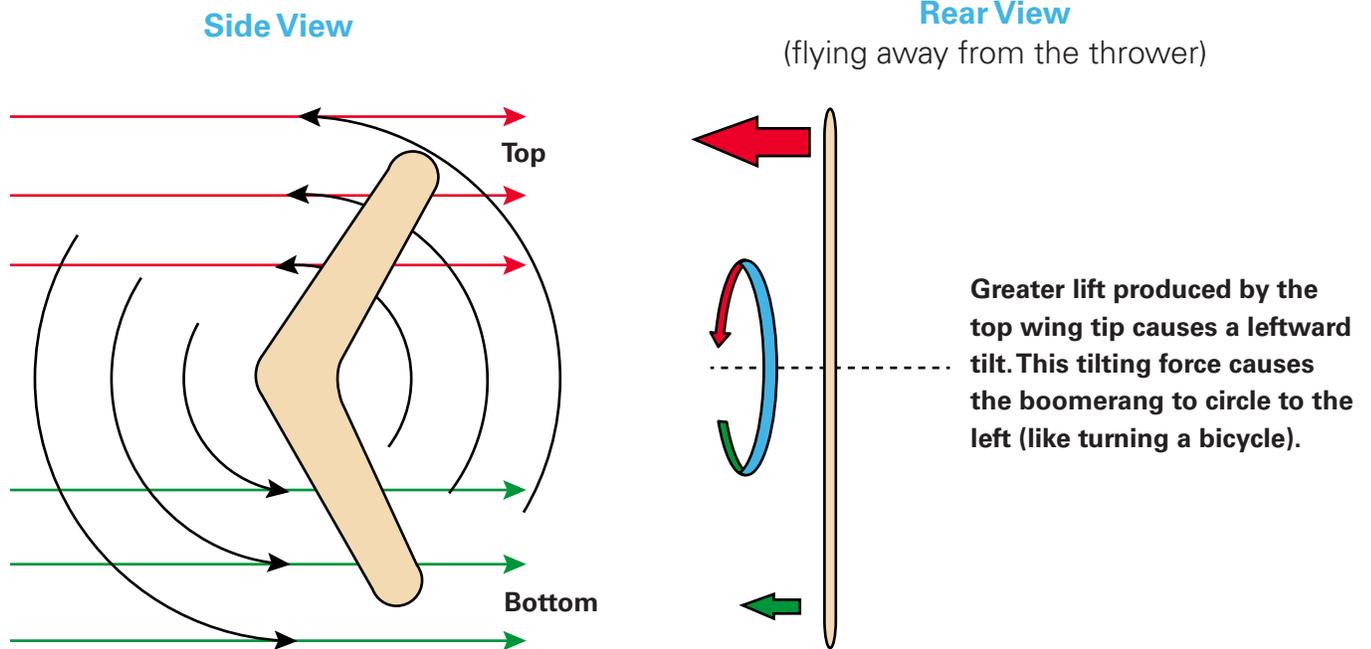


Aboriginal boomerangs in the rain forest near Cairns, Australia.

The returning boomerang was raised to a high art by the Australian Aborigines. It was used for hunting, and as a battle club, musical instrument and even fire-starter. Hunters would

Net Air Speed

The net air speed of the top wing tip (spinning into the wind) is greater than the net air speed of the bottom wing tip (spinning with the wind).



throw returning boomerangs near roosting birds, seeking to scare them into flight so they could be caught in nets. Hunters also would throw boomerangs through flocks of flying birds, hoping to clip a wing and bring down dinner.



Boomerangs today are formed using different materials and come in various shapes and sizes.

Both forms of boomerang are amazing aeronautical devices, basically rotating wings curved like an airfoil. All non-returning boomerangs are straight, but the returning variety can have many

designs. The classic returning boomerang has a lazy “L” shape, but some look like a question mark. Some returning boomerangs have three or four wings (like a cross). The different features determine how quickly a boomerang returns when thrown. Large, open designs tend to travel furthest, while tighter shapes and boomerangs with extra wings tend to follow shorter paths.

Several physical processes make a returning boomerang work: aerodynamic lift, gyroscopic precession, drag and gravity. The proper way to throw a boomerang is in a vertical plane, tossed slightly upward and with a rapid spin. The spin produces a gyroscopic effect that keeps the boomerang moving along its plane without flipping and fluttering. As the boomerang travels forward, the rapid spinning of its wing tips produces a strong lifting force. Because the boomerang is oriented vertically, the lift pushes sideways, causing the boomerang to turn and return to the thrower.

The forces influencing the flight of a boomerang are similar to the gyroscopic effect that keeps a bicycle upright and stable. To turn a bike, the

rider merely tilts to one side or the other. This puts a sideways force on the spinning wheels, causing them to turn in the direction of the rider's lean.

The leaning force on the boomerang is caused by an imbalance in the lift between the top and bottom wings as they spin forward through the air. The top wing moves against the airflow and produces a strong sideways lift. Simultaneously, the lower wing is moving in the same direction as the airflow, which produces a weaker sideways lift. The difference in lifting forces causes the boomerang to lean sideways. As with a bicycle wheel, the gyroscopic effect of the boomerang lean causes the boomerang to turn in a circle and return to the thrower.

What's the Question?

Will a boomerang always come back, no matter how it is thrown?

What To Do

1. Ask students, *Do you know what a boomerang is? What does it do? Have you ever seen one thrown, or have you thrown one yourself?* Discuss the shape of airplane wings and compare them to boomerang wings. Ask, *What does an airplane wing look like from the side?* (Refer to the wing diagram from the activity, "Ring Wing Gliders") Remind students of how airplane wings produce lift. Point out that boomerangs are rotating wings, similar to the blades of a helicopter or a ceiling fan.
2. Have students make finger boomerangs out of card stock paper. Use the patterns on the "Finger Boomerangs" sheet as a starting point. Review the instructions on how to launch these boomerangs as a class, and have students fly their own. Although the blades of these boomerangs are flat, they become airfoils when spinning, and generate lift.
3. Ask, *Are there other boomerang shapes that will return?* Have students use the rest of their card stock to design boomerangs of other shapes, cut them out, and test-fly them. Lead a class discussion of which shapes worked, which didn't, and students' speculation about the reasons for these outcomes.



Young woman in Australia learning how to throw an Aboriginal-style boomerang.

4. Tell students they have "graduated" to a larger boomerang. Have them cut out their four-wing boomerangs. Demonstrate for students how to throw this boomerang, then have them fly theirs. Ask, *Do you think there is a limit to how big you can make this kind of boomerang from card stock? If you wanted a larger boomerang, would you have to use different materials or add something to make it work?* Discuss their ideas.

Optional: Paint Stick Boomerang

1. Have students build more advanced wooden boomerangs from paint sticks. With this kind of boomerang, it is critical that students understand how to shape the wings, because paint sticks are much heavier than paper and must generate more lift to work. Refer to the "Paint Stick Boomerang" page for diagrams and instructions about which edges should be rounded or sloped. Caution students to be careful not to mix up the edges. OR, as a guide, mark or label the edges of the paint sticks to be sloped or rounded. Have students use sand paper to shape the stick edges. (If necessary, scissors can be used instead.)
2. When all the edges are shaped, have students assemble the boomerangs.
3. Distribute colored markers and let students decorate their boomerangs.
4. Fly the wooden boomerangs in a room with a

high ceiling (like a gym) or outside, preferably when the wind is not blowing. If there is a gentle breeze, prompt students to throw the boomerangs into the wind, not with it. As always, a boomerang should be thrown in the vertical plain, not horizontally (see student sheet), and with a chopping motion that spins the boomerang as it is released. The rounded side of the boomerang should face left when held vertically, and it will fly in a counter-clockwise circle.

Note: Left-handed students should hold the rounded side of the boomerang facing right, and it will curve to the right in a clockwise direction.

5. Ask students, *Would a paint stick boomerang fly differently if it weighed more? If so, how?* Use a small amount of hot glue to attach a couple of pennies to the undersides of the boomerang wings. Tell students the boomerang is kept in balance if the pennies are placed

at the same point on each wing. (Hot-glued pennies can be removed and tested in different locations without damaging the wings.)

Wrapping Up

Lead a class discussion on how boomerangs can be improved. Ask, *What can be done to make your boomerangs stay in the air longer or travel out farther? What other materials might be used to make boomerangs?*

Extras

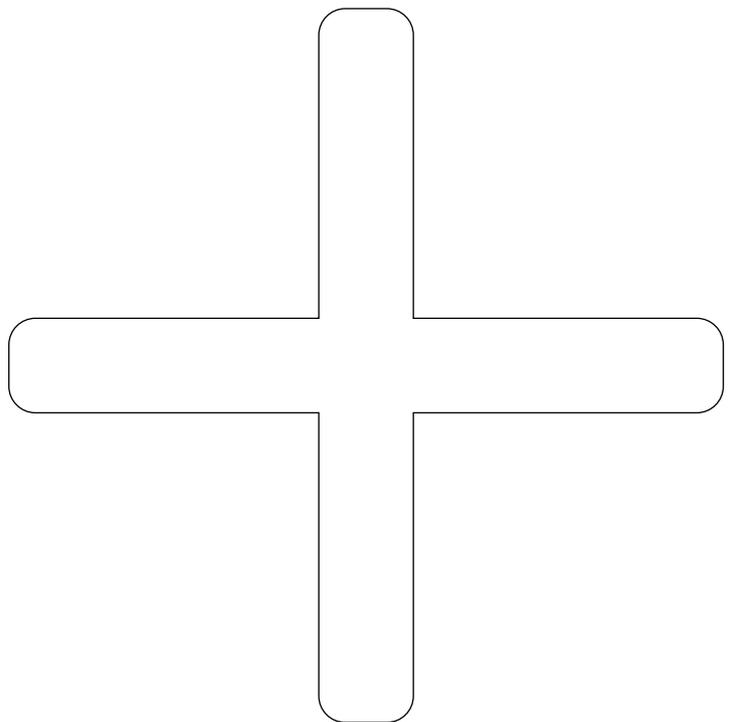
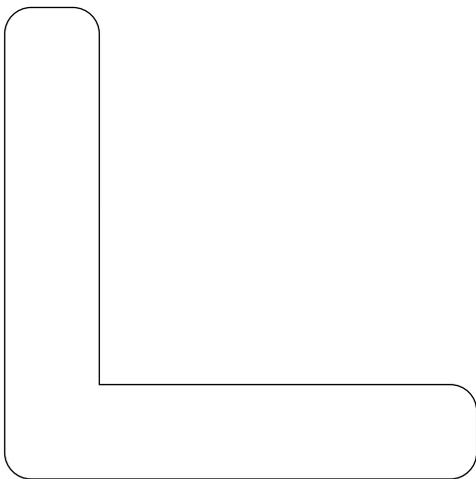
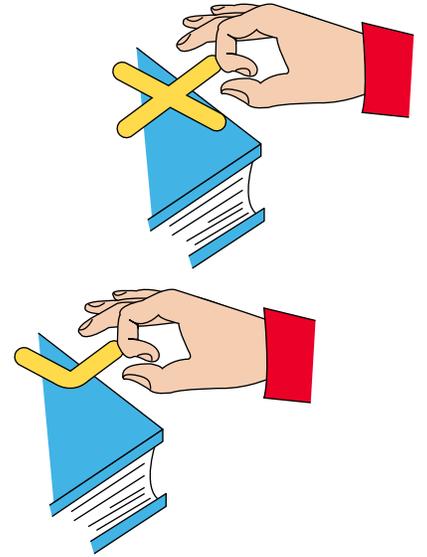
Advanced boomeranging: Teach students how to catch boomerangs. Explain that they should not try to catch a boomerang by grabbing one of its wings. Their knuckles will get banged! Instead, instruct students to wait until the boomerang is still spinning, and just about to drop the ground. They can catch a boomerang by clapping their hands together, with one under the boomerang and one above it. the wings. ■

Finger Boomerangs

You will need card stock, a pair of scissors and a pencil with flat sides. You also will need a thick book.

Use the templates below to make boomerangs, or create two designs of your own (approximately the same size as the templates).

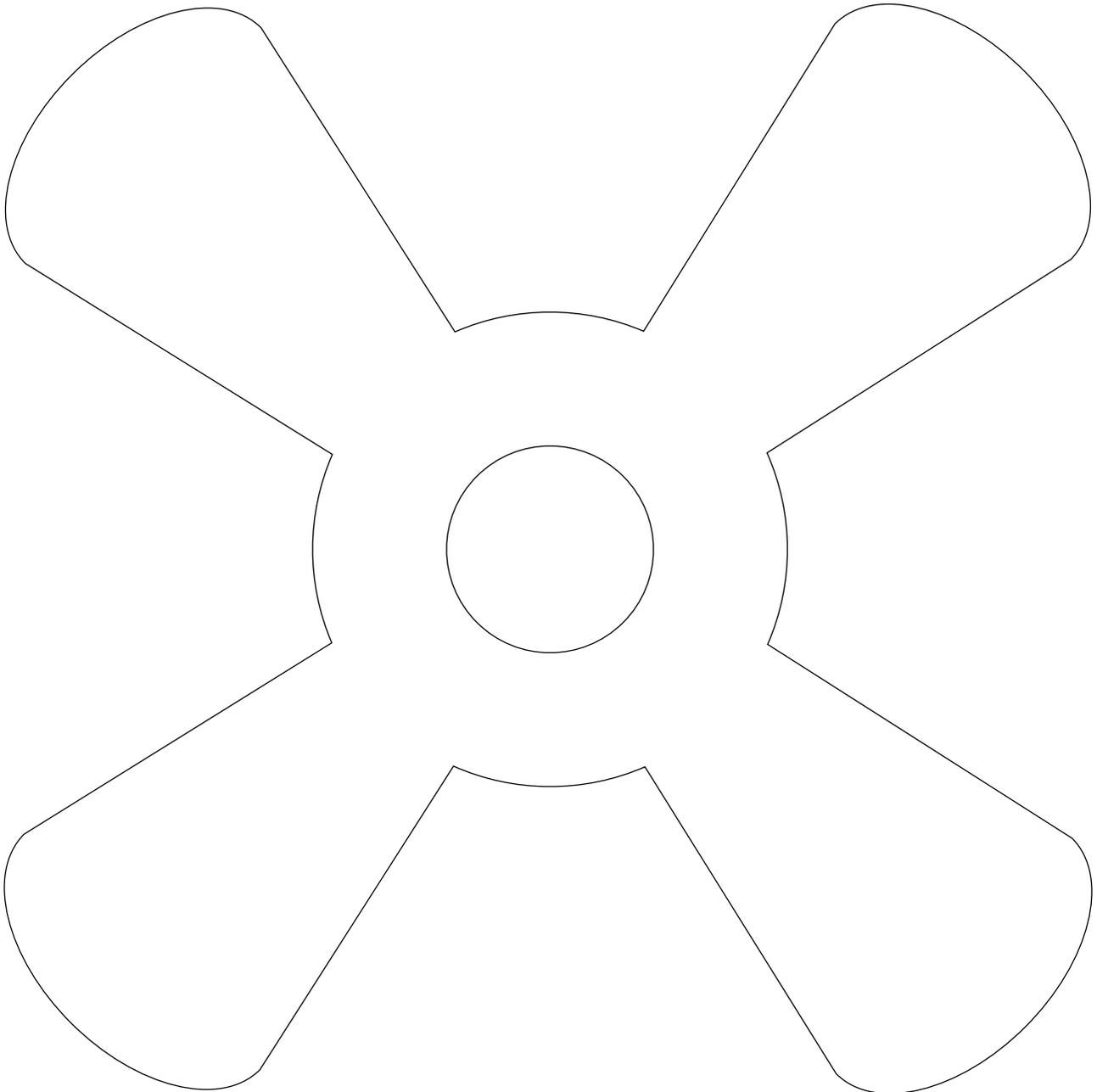
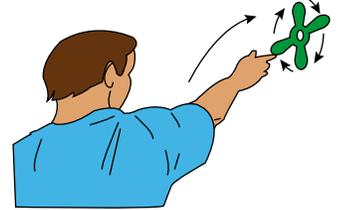
1. Cut out the templates below and trace each shape onto card stock. Cut out the boomerangs from the card stock.
2. Place the pencil underneath one end of the book to lift it slightly. Lay the boomerang on the raised edge of the book.
3. Use your index finger and flick one wing of the boomerang so that it spins rapidly as it flies off the book. The boomerang should gain some lift and then return to you.
4. Does it matter if you flick the boomerang so that it rotates clockwise or counterclockwise? Try it and find out.



Four Wing Boomerang

You will need a prepared sheet of card stock with the image below printed on it, and a pair of scissors.

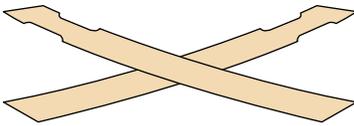
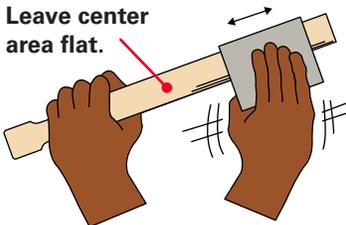
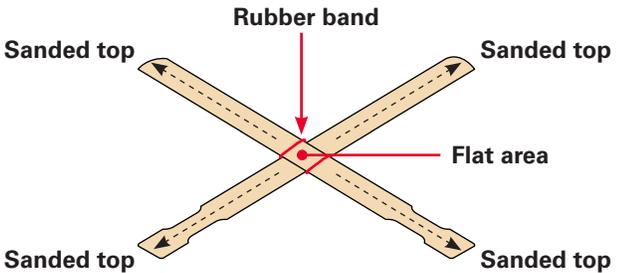
1. Cut the boomerang out of the sheet of card stock. Then cut out the center hole.
2. Hold the boomerang vertically by one wing. Spin the boomerang rapidly as you throw it straight forward. Your throw should resemble a chopping motion.
3. What happens when you throw the boomerang horizontally? Try it.



Paint Stick Boomerang

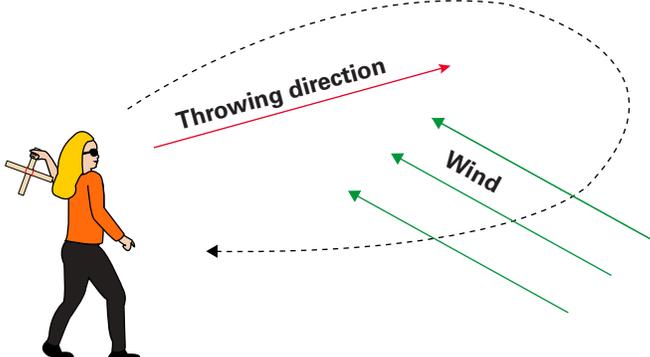
You will need two wooden paint sticks, sandpaper and one or two rubber bands.

How to Build a Paint Stick Boomerang

1. Examine your paint sticks. They probably will be slightly curved lengthwise because of warping. Use the side that is curved upward (like a smile) as the “top” of your sticks. This is the side you will shape with sandpaper. 
2. Before sanding, think of shaping the sticks into the form of airplane wings. 
3. Hold the first stick in one hand and use the sandpaper to smooth and shape just the edges on the “top” of your stick into a slope. Do not sand the bottom of the stick, nor its center area. Repeat with the other paint stick. 
4. After the sticks have been shaped, place one on top of the other in a cross pattern. The sanded sides of both sticks go in the “up” position. 

Hold the blades together with a rubber band. Slip the rubber band over one end of the top stick. Pull it under the cross stick and then slip the rubber band over the other end of the top stick. You may have to double the rubber band to make it tight enough to hold the two sticks together. The boomerang is ready for flight.

How to Throw the Boomerang

1. Stand in an open area. Grasp the boomerang at the end of one stick. Your thumb should lay across the top, “sloped” side of the boomerang. Raise the boomerang up, as though you’re about to throw a football. Aim slightly upward and throw the boomerang with a firm chopping motion, causing it to rotate rapidly as you release it. If you’re right-handed, the boomerang will circle to the left. If you’re left-handed, it will circle to the right. Be careful not to throw the boomerang if other people are nearby. 

2. A properly thrown boomerang will return to you and continue spinning as it drops to the ground. Catch it by trapping the boomerang between your hands. Don’t try to catch it by one of the blades. This can injure your fingers.

Tips

If the wind is blowing, face the wind and then turn about 45 degrees, or 1/8 of a circle, to the right or left (whichever hand you will using to throw). Throw the boomerang at that angle to the wind. If the wind is gusting or shifting, be prepared to chase the boomerang.

The boomerang will fly very differently if you throw it horizontally, like a Frisbee®. Try it and see what happens.

3

Javelin Rockets

Throwing to the Max

Time

1–2 sessions

Before You Start

See “What To Do in Advance.”

You Need This Stuff

Teacher Materials

- 13 30-cm pieces of string
- 13 protractors
- 13 push pins
- 13 metersticks
- 8–9 narrow strips of duct tape, 3–4 cm in length
- 2 30-cm pieces of foam pipe insulation (for 3/4-in. diameter pipes)
- 2 rubber bands (large, sturdy)
- Hot glue gun and glue
- Manila folder (or thick card stock)
- Masking tape
- Pair of scissors

Per Pair of Students

- 8–9 narrow strips of duct tape, 3–4 cm in length
- 2 tennis balls
- 2 30-cm lengths of foam pipe insulation (for 3/4-in. diameter pipes)
- 2 manila folders (or thick card stock)
- 2 pairs of safety goggles
- 2 pairs of scissors
- 2 rubber bands (large, sturdy)
- Metric tape measure

Per Student

- Copy of “Make a Javelin Rocket,” “Launch Instructions,” and “Test Flight Data” pages

What It’s About

This activity is a common personal challenge. Through experience, we learn to throw a ball at the correct angle and speed to reach our target.



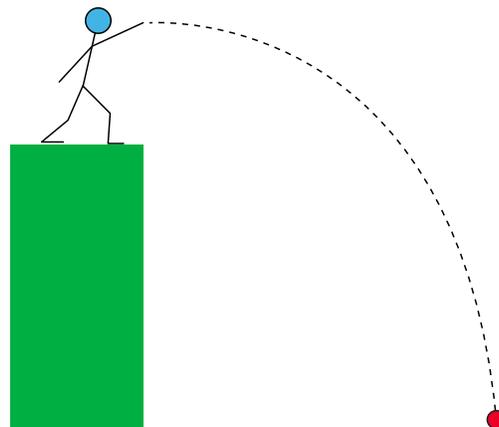
Bregje Crolla in competition, 2010. A javelin thrower must throw the javelin overhand, over his or her shoulder or upper arm, toward a sector extending outward from the arc at the end of the runway.

Of course, many sports involve throwing or hitting balls or other implements as far and accurately as possible. In baseball, a center fielder has to pick up a ground ball and throw it at the right angle and speed to the catcher waiting at home plate. A quarterback must be able to pass the football to a receiver running full speed toward the end zone. A golfer selects a driver with the right angle on the club face to launch a golf ball toward the hole. Athletes who throw javelins try to throw a javelin farther than their competitors.

In this activity, student teams will construct javelin rockets and use them to investigate the relationship between launch angle and range. They

Gravity and the Flight of Balls

Earth's gravity bends the trajectory of objects thrown horizontally across its surface. It also causes falling objects to accelerate. At the end of one second of falling, a ball will be traveling 9.8 meters per second. At the end of two seconds, it will be traveling 19.6 meters per second. After three seconds, it will be traveling at a speed of 29.4 meters per second. As a ball thrown horizontally accelerates toward Earth's surface, its downward curve becomes increasingly steep. To compensate for the effects of gravity, a ball thrown a long distance must be aimed upward so that its curved path ends at the target.



will discover that the best launch angle for the javelin also is the angle at which a ball should be thrown or hit to travel the maximum distance.

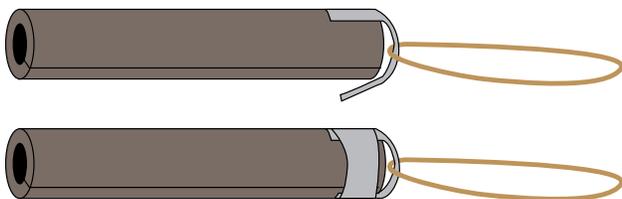
What's the Question?

Does launch angle affect the distance a javelin rocket travels?

What To Do in Advance

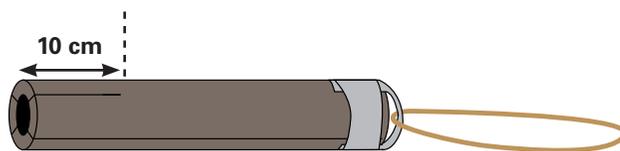
1. Build a model javelin rocket and launcher using the instructions below (illustrations are not to scale). Prepare the pieces for a second rocket javelin, but do not assemble it. You will use this second javelin to demonstrate how to build and assemble a rocket javelin.

- a. Cut a 30-cm piece of foam pipe insulation. This tube will serve as the javelin rocket body.

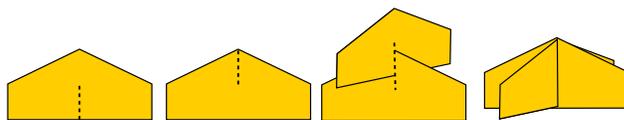


- b. Cut a narrow strip of duct tape and affix one end of it to one end of the tube. Slide a rubber band through the unattached end of the tape. Secure the unattached end of tape on the other side of the tube. Place a second strip of tape around the tube to hold the first strip in place.

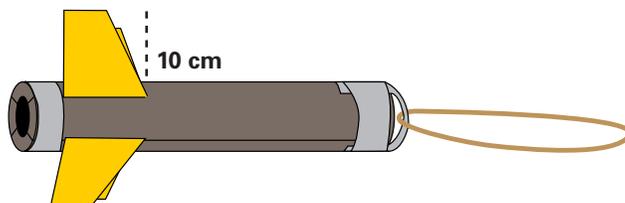
- c. You will need four slits in the opposite end of the tube. Use the pre-cut manufacturer's slit as the first slit. Make three additional cuts into the end of the tube, spaced at 90° intervals. The three cuts need to be approximately 10 cm long.



- d. Make fins from a manila file folder. Cut slits in the fins so they can be nested, with four fin tips oriented at 90° angles to each other.

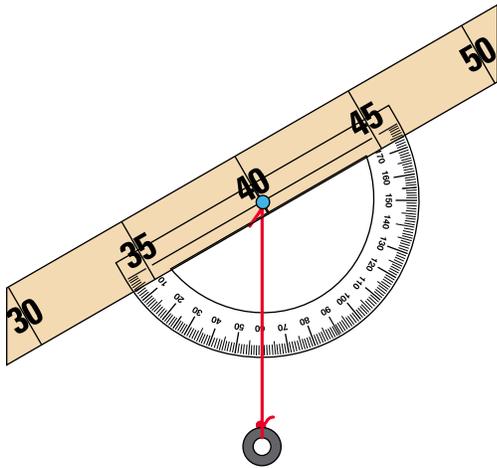


- e. Slide the fins into the four slits in the back end of the tube. Place a narrow strip of duct tape around the bottom of the tube to hold the fins in place.



2. Cut one 30-cm length of foam pipe insulation for each student.

3. Construct enough rocket launchers for the entire class (one launcher for every two students), and one for you to use for demonstration.
 - a. Hot glue a protractor to the middle of a meterstick.
 - b. Insert a push pin through the hole at the protractor's apex, into the meterstick.
 - c. Hang a string loop around the push pin and tie a metal washer to the other end of the string. The launcher is ready.



To determine the angle, subtract the number of degrees on the protractor from 90. In this case, the launch angle is 30° (see p. 19).

4. Place team materials in a central location for students to pick up. Have students work in teams of two.

What To Do: Ball Toss

1. Prompt students to talk about the seemingly simple process of throwing a ball. Ask, *How do you throw a ball to someone standing close to you? How do you throw a ball to someone far away? What is the difference?* Bring students to a large open area and separate them into small groups. Direct two students from each group to toss a tennis ball back and forth, while the other students observe the ball's flight path from the side. The students playing catch should start about five yards apart and slowly double the distance with subsequent throws. Have observer students switch with the



throwers so that all can throw and observe the ball's flight path. Afterward, have students diagram the ball's path on the board or in their notebooks.

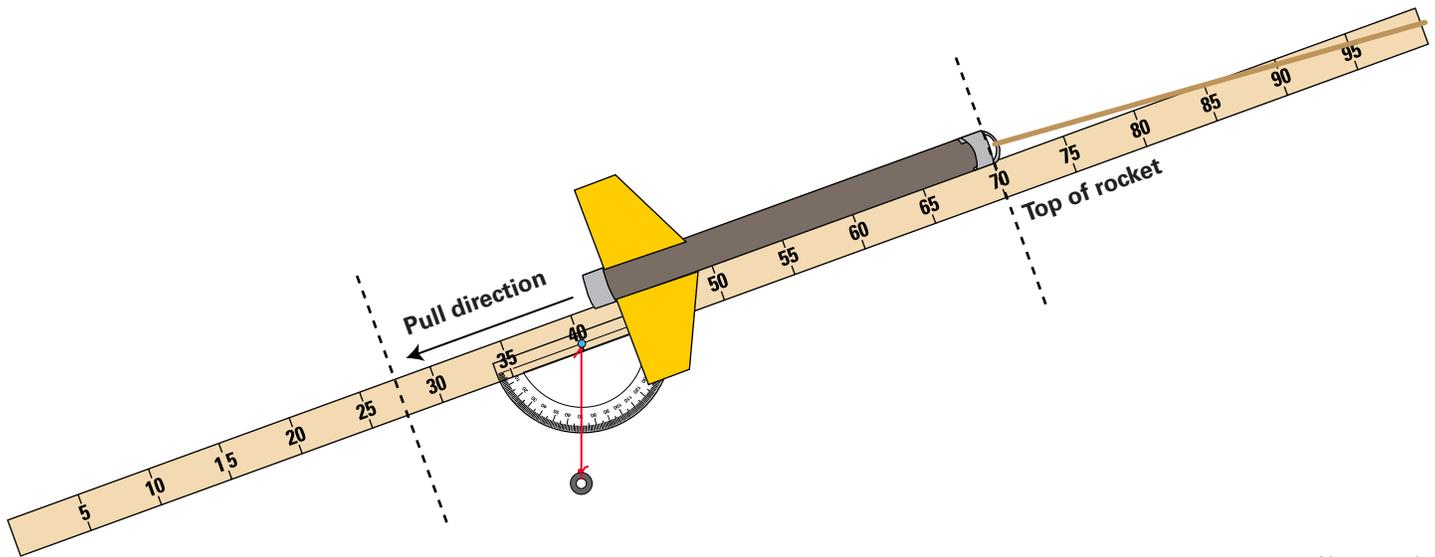
2. Draw three stick figures on a white board. Have two figures about two feet apart, with the first at the left edge of the board. Place the third figure at the right edge of the board. Invite students to draw lines estimating the path of a ball thrown from the figure at the left board edge to the nearest figure, and also to the figure at the right edge of the board. In each case, the ball's trajectory (path through the air) should be curved. Ask, *Why is the path curved?* (gravity)

What To Do: Build/Test Javelin Rockets

1. Tell students they will make and fly javelin rockets, and investigate the best launch angle to achieve maximum distance. Show the completed rocket javelin to the class, explaining the different parts. Next, show how to mount the rocket javelin on the launcher and launch the rocket javelin. Point out the protractor and string/weight, and explain how to measure the launch angle. Also explain to students that they can control for launch force by stretching the rocket javelin back to the exact same point on the meterstick each time they launch.
2. Distribute the student sheets and have students begin assembling their rockets, using the instruction diagram as a guide. While they work, assemble the second model javelin rocket, discussing each step and checking to make sure students are following the instructions properly.

Tip: Peel off narrow lengths of duct tape in advance and stick them to table edges for students to access easily when needed.
3. When all students have completed their rockets,

Javelin Rocket Positioned on the Launcher



Not to scale.

demonstrate the launch technique once again. Move students to an open area where they can safely attempt test flights and become familiar with the launchers. Set up a launching line. Measure two-meter intervals from 0 to 16 meters. Mark each interval with a strip of masking tape.

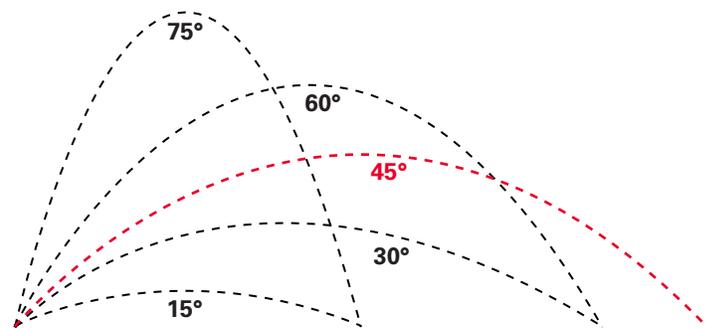
4. Divide the class into teams of two and have each team launch its rockets. One student should launch while the other checks the launch angle. For each launch angle used, teams should record the distances their rockets fly. Be sure they measure distance to the landing point, not the point at which the rockets come to rest after sliding on the floor.

Caution: Warn students not to aim their rockets at anyone. Always aim for an open area.

Wrapping Up

Ask your students, *What is the best launch angle for long-distance flights?* If they can't agree on a number, average students' responses. Compare their results to the actual ideal angle: 45 degrees. Anything more or less than 45 degrees will produce shorter flights (see illustration, right). Ask, *How*

does this discovery apply to sports? (Throwing or hitting a ball the longest distance requires launching it upward at an angle of 45 degrees.)



Extra

Hold a launch competition. Set a basketball or other target on the floor about 10 meters from a launch line. Challenge students to hit the target—on the fly—with their rockets (sliding into the target does not count). Instruct students to adjust their launch angles as needed to reach the target. To launch the rocket with more or less force, students also can change how far back they pull their launchers before release. ■

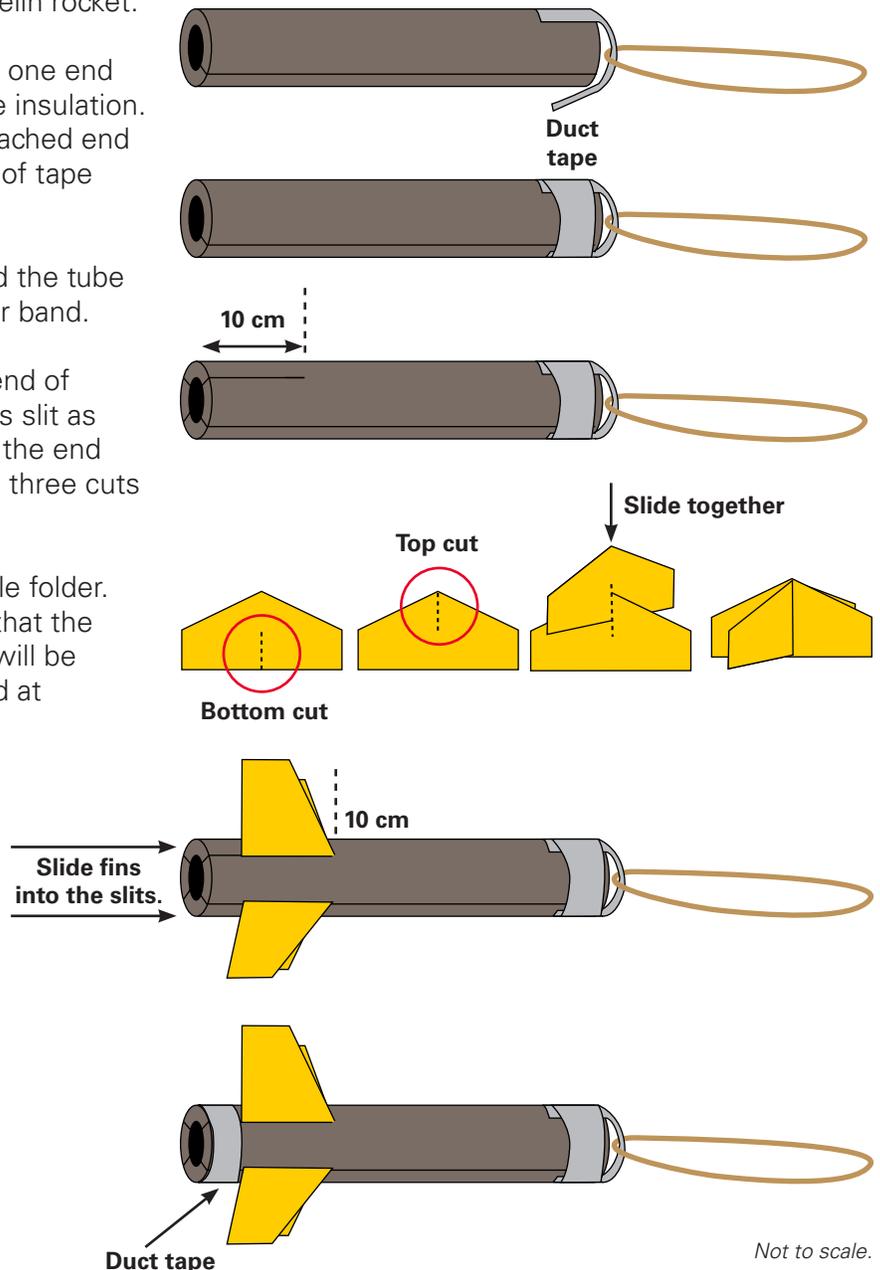
Make a Javelin Rocket

You will need the following materials to build a javelin rocket.

- 30-cm length of foam pipe insulation
- 4–5 narrow strips of duct tape, 3–4 cm in length
- Large, sturdy rubber band
- Manila file folder (or thick card stock)
- Pair of scissors
- Metric tape measure

Use the illustrations as guides to build a javelin rocket.

1. Cut a narrow strip of duct tape and affix one end of it to one end of the tube of foam pipe insulation. Slide the rubber band through the unattached end of the tape. Secure the unattached end of tape to the other side of the tube.
2. Place a second strip of duct tape around the tube to firmly secure the first strip and rubber band.
3. You will need four slits in the opposite end of the tube. Use the pre-cut manufacturer's slit as the first slit. Make three more cuts into the end of the tube, spaced at 90° intervals. The three cuts need to be approximately 10 cm long.
4. Cut two identical fins from the manila file folder. Make one cut in each fin as shown, so that the fins can be nested together. The result will be one set of fins with four fin tips oriented at 90° angles to each other.
5. Slide the fins into the four slits in the back end of the tube.
6. Cut one or two narrow strips of duct tape. Place them around the bottom of the tube to hold the fins in place.



Not to scale.

Launch Instructions

You will need a completed javelin rocket and a launcher. You also will need a data sheet to record your tests and results.

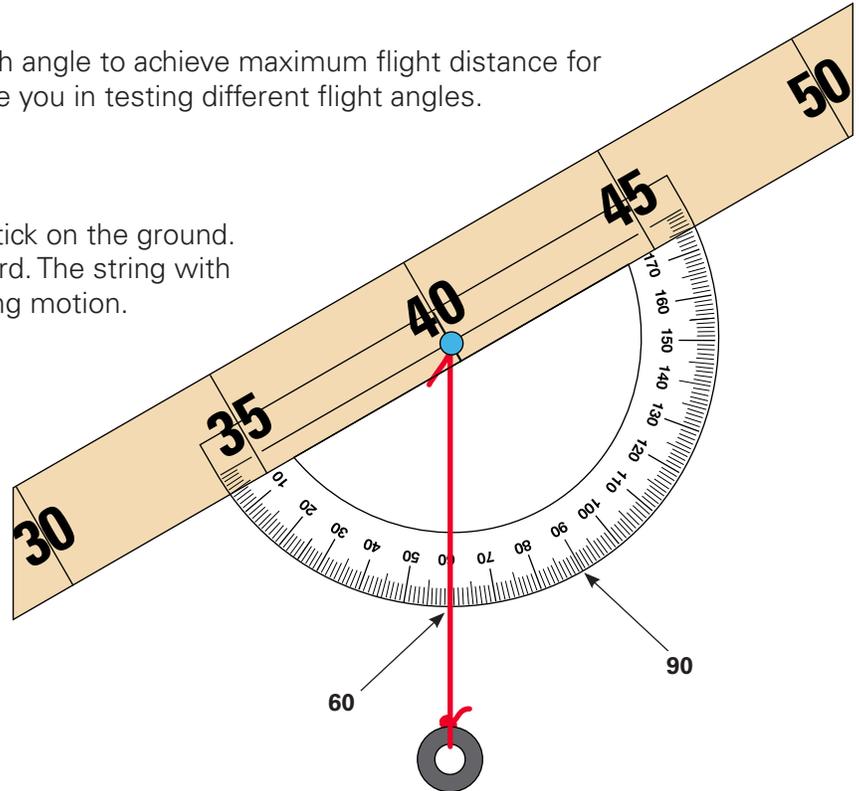
The goal of the tests is to find the best launch angle to achieve maximum flight distance for the javelin rocket. Use the illustration to guide you in testing different flight angles.

How to Find the Angle on the Launcher

1. Place the number "1" end of the meterstick on the ground. Tilt the other end of the meterstick upward. The string with the metal washer will move with the tilting motion.
2. Look at the number on the protractor where the string stops.
3. Subtract that number from 90. In the example given, the number is 60.

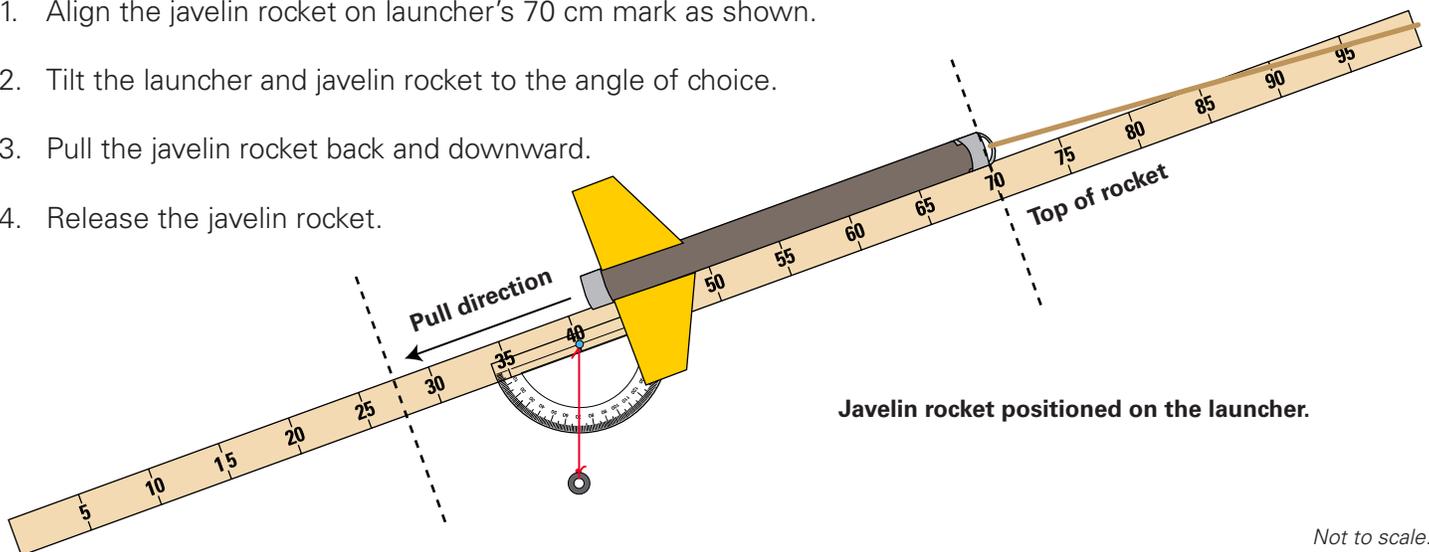
$$90 - 60 = 30$$

The launch angle in this example is 30°.



Launching the Javelin Rocket

1. Align the javelin rocket on launcher's 70 cm mark as shown.
2. Tilt the launcher and javelin rocket to the angle of choice.
3. Pull the javelin rocket back and downward.
4. Release the javelin rocket.



Javelin rocket positioned on the launcher.

Not to scale.

Test Flight Data

Name

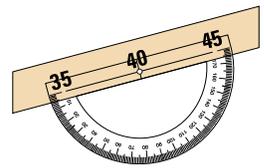
Name

You and a partner will conduct tests to examine the relationship between a rocket's launch angle and flight distance. Try launching at low to high angles—and everything in between!

- Place a piece of masking tape where the base of the launcher will rest on the ground/floor. Adjust the rocket and launcher for the first flight angle. Have your partner record the angle in degrees on the chart to the right. Launch your rocket.
- Use a piece of masking tape to mark the spot where the rocket first hits the ground or floor—not where it comes to a stop after sliding. Measure the distance the rocket traveled and have your partner record the distance on the chart.
- Switch roles so that you are now the distance recorder for your partner's test.
- Continue switching roles as you both complete the chart with flight data.
- What is the best angle for obtaining the longest flight distance?

_____ °

Flight Launch Log



Launch Number	Launch Angle	Distance Traveled
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		

Catapults

Powering a Projectile

Time

1–2 sessions

Before You Start

Prepare bags of materials for each team of students.

You Need This Stuff

Teacher Materials

- Bag of marshmallows or gummy bears (to use as projectiles)
- Foam building blocks
- Masking tape

Per Student Group

- 2 survey flags or plastic orange cones
- Bulls-eye target, or paper to create a target
- Manual tennis ball thrower with tennis ball (available at pet stores)
- Tape measures or metersticks

Per Student

- At least 20 craft sticks, notched craft sticks, chopsticks, or wooden skewers with sharp ends removed
- Plastic spoon
- Rubber bands
- Safety goggles
- Copy of “Catapults,” and “Build a Spoonapult” pages

What It's About

Throughout history, warriors and hunters have developed weapons to aid in their battles and pursuit of food. War machines, in particular, have been a focus of technological innovation. As warfare grew more complex, so did weapons. Javelins and boomerangs were tools for both hunting and war. Another device, the atlatl, extended the throwing arm and greatly increased throwing force. Eventually, catapults were invented. Catapults harness physical and/or mechanical energy to launch projectiles. Examples of catapults include slingshots, hurling devices used in castle sieges, and even steam-powered machines that launch airplanes off aircraft carriers.



NOAA uses a pneumatic catapult to launch the ScanEagle, an unmanned monitoring aircraft.

Catapult technology, first thought to have been developed in Greece as early as 50 BCE, was initially used to increase the range and penetration of arrows. When released, a catapult would shoot a large arrow toward the enemy.

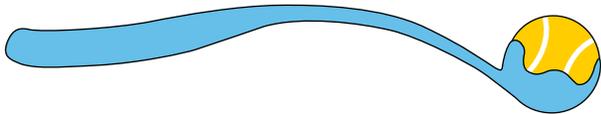
Later, more powerful catapults were able to launch large stones, biological weapons (e.g., a hornets' nest), incendiary bombs, and even terror projectiles like the heads of the captured! The history of catapults includes a large variety of designs, each with a different purpose.

What's the Question?

Can you design and construct a catapult that meets specific goals, such as being most accurate, firing the greatest distance, or launching the heaviest projectile?

What To Do: Launching Projectiles

1. Ask students, *How far do you think you can throw a tennis ball?* Take them outside and give all students a chance to throw the ball as far as they can. Use masking tape to indicate the distance achieved by each student.



A tennis ball thrower for dogs is a modernized variant of an atlatl. You can find one at most pet stores.

2. Next, ask *Is there any way you could throw the ball further?* Introduce the atlatl, a stick that extends from the arm of the thrower. The atlatl has been used by ancient Egyptians, Inuits of the Arctic Circle, and Aztecs of Mexico, among others.

A spear would be affixed to the end of the atlatl, which provided extra arm length that enabled the thrower to produce greater acceleration of the spear than would be possible without this tool. Modern day ball throwers for dog owners employ the same principle.

Have students use a ball thrower to throw the tennis ball again. Mark the new distances and compare them to the original measurements.

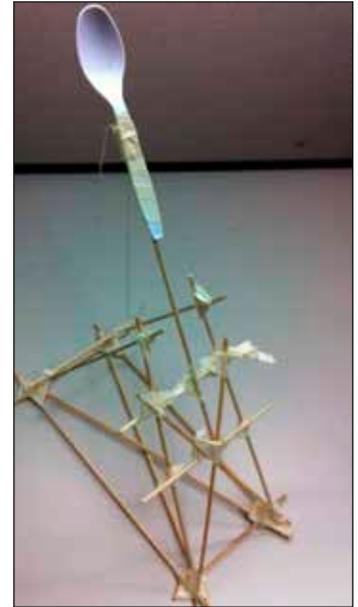
3. Return to the classroom and lead a discussion of students' observations. Ask, *How far could you throw the tennis ball using just your arm? How far did you throw it with atlatl? Do you think there is a limit to how long an atlatl can be and still work?*

Is there a limit to how heavy a projectile can be thrown with an atlatl?

What To Do: Spoonapults

1. Review students' experiences with the atlatl and remind them of their answers to the questions above.

Tell them that a catapult can launch a boulder hundreds of meters. In fact, the Greeks were engineering war machines as early as 400 BCE. They had perfected the bow and arrow, but for mass warfare, they sought more powerful weapons. Initially, the catapult was designed to launch several arrows at once, but over time, it was refined into a mighty machine that also could hurl large rocks, biological weapons and even the heads of enemies.



Student catapult

2. Show pictures of catapults and discuss key design characteristics. Have students use craft sticks to build an equilateral triangle and square base, and then test the stability of each design. Be sure they understand that



Student catapults

← ●

a catapult requires a stable base to launch projectiles.

3. Explain that students will investigate catapults by building and testing a “spoonapult,” which uses a plastic spoon to launch projectiles. Have each student team construct a spoonapult, following the illustrations on the student sheet. Then, direct teams to test their spoonapults by launching marshmallows toward a bullseye placed on the floor.
4. Discuss the results of students’ first spoonapult construction challenge. Ask, *How well did your spoonapult work? How far did it fling the marshmallows? Was your spoonapult accurate?*
5. Have student teams follow the engineering

model (p. vi) to build a better spoonapult. Remind teams that their development process should include sharing ideas (brainstorming solutions), designing a plan, building the new spoonapult, and then testing, evaluating and refining their designs.

6. Build a small castle out of foam blocks. Challenge teams to “destroy” the castle with their newly created spoonapults by launching projectiles from a distance of three meters.

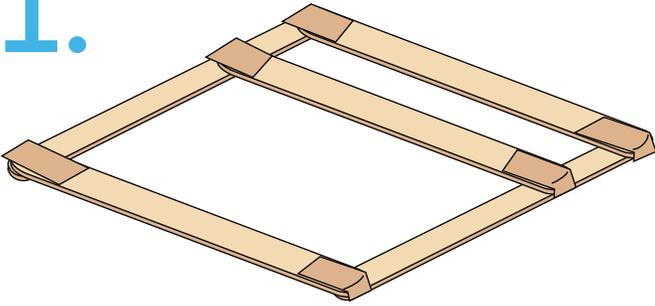
Extra

Have students bring in materials to make a larger catapult, capable of launching a tennis ball or small water-filled balloon at least 10 meters. ■

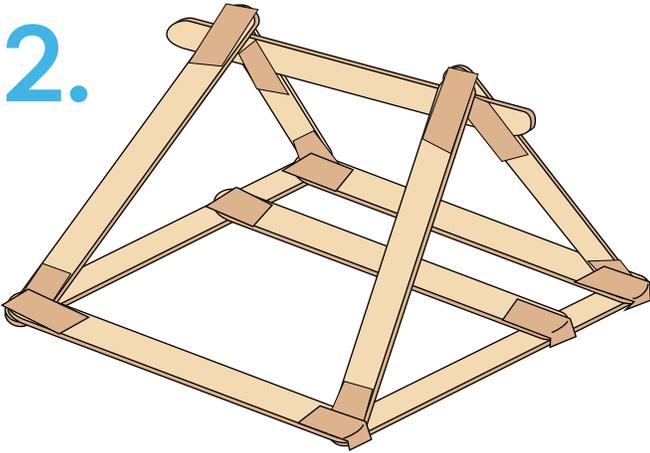
Build a Spoonapult

Use the illustrations below as a guide to build and test a spoonapult.

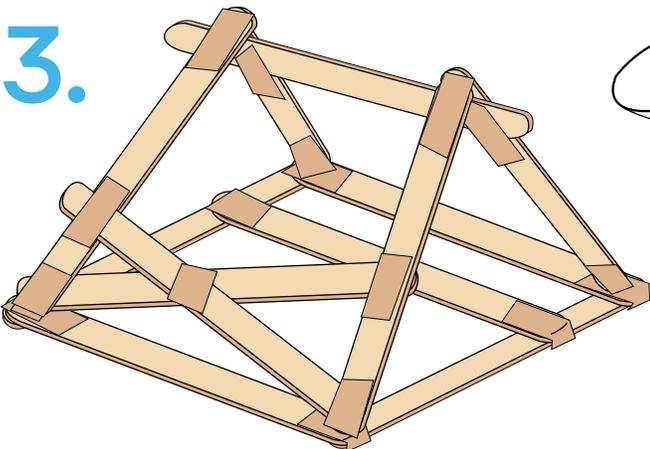
1.



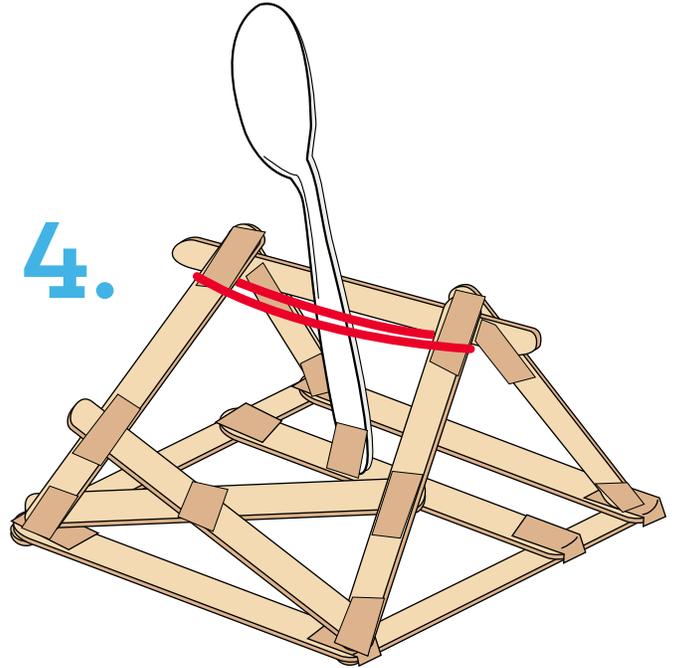
2.



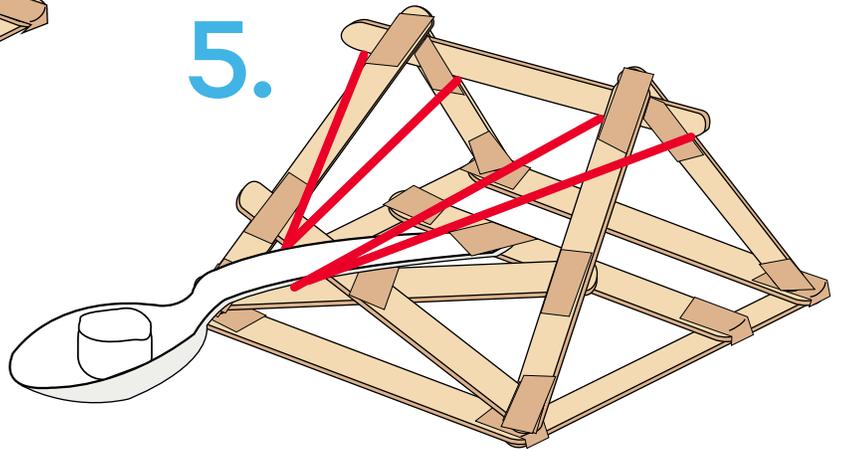
3.



4.



5.



Wind-up Racers

The Potential for Speed

Time

1–2 sessions

Before You Start

Collect and clean 24 empty soft drink cans. Punch a hole in the bottom of each can with a large nail or a screwdriver.

You Need This Stuff

Teacher Materials

- Tape measures or metersticks

Per Student

- 4 #32-size rubber bands
- Pencil or dowel
- Masking tape
- Metal washer
- 2 large paper clips
- 2 small paper clips
- Safety goggles
- Thread spool (large) or empty soft drink can
- Wooden or plastic bead (large)

Extra Materials for Modification

- Different sizes of rubber bands
- Sandpaper
- Variety of large and small washers

A toy car's winding mechanism adds energy to a spiral spring, which releases energy to gears that control speed and force.



What It's About

Students will construct and test a self-propelled wind-up racer to investigate how vehicles use potential and kinetic energy. After testing their racers, students will be challenged to improve them using the engineering design process.

What's the Question?

Does the number of turns on the rubber band influence the amount of energy stored? How does energy storage affect the racer's motion?

What to Do: Part 1

1. Ask students, *Do rubber bands have energy?* Distribute rubber bands and have students use them to investigate potential and kinetic energy. Ask, *What is the difference between these two kinds of energy?* If students are uncertain, demonstrate a rubber band's (1) potential energy by stretching it and (2) kinetic energy by shooting the stretched rubber band toward a target. Ask, *Where did the rubber band get its potential energy?* (From "muscle power," as you stretched the rubber band.) Have students repeat the exercise, taking great care not to shoot rubber bands at each other.

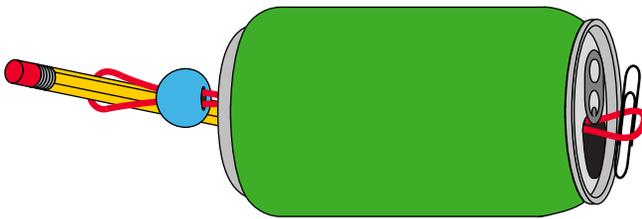
Note: All participants should wear safety goggles.

2. Challenge students to devise a way to improve their accuracy in shooting rubber bands at the target. Discuss how the amount of stretching (potential energy) affects the distance a rubber band travels (kinetic energy) when released. Ask, *Can the rubber band be stretched too far?*
3. Explain that students will be making cylinder racers propelled by rubber bands. Follow the instructions below to demonstrate how to make

a racer from a soft drink can and a large sewing spool. Then, have students construct their own racers.

How to Build a Wind-up Racer Using a Can

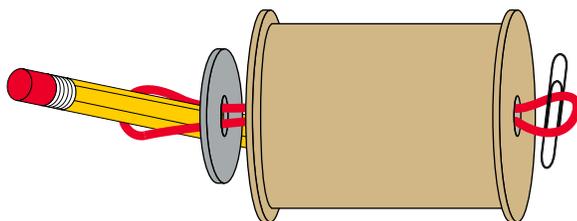
1. Bend a large paper clip into a long hook.
2. Loop one end of the rubber band around the pencil and push the other end of the rubber band through the bead (see illustration below).



3. Push the end of the rubber band through the hole in the can bottom. Using the paper clip hook, reach inside the top of the can and capture the loose end of the rubber band.
4. Making sure the bottom loop of the rubber band does not slip off the pencil, pull the top loop up through the mouth of the can. To secure the top of the rubber band, slip it through the small paper clip, and then tape the paper clip securely on top of the can. The racer is ready for testing.

How to Build a Wind-up Racer Using a Spool

1. Slip a rubber band through the center of a spool. Be sure one end of the rubber band is sticking out from either side of the spool.
2. Insert a paper clip through one loop of the rubber band. Use tape to secure the clip to the end of the spool.



3. Slip the other end of the rubber band through a washer. Then slide the pencil through the rubber band loop (see illustration above). The spool racer is ready for testing.

What to Do: Part 2

1. Designate a clear area of the floor for testing the racers.
2. Have students wind up their racers by turning their pencils 10–15 times. Ask, *What happens when you wind the rubber band?* (Adds potential energy to their racers. More turns means more potential energy.) Direct students to place their racers on the floor and release the pencils (to produce kinetic energy).

Note: If the racers do not travel in a straight line, have students adjust where the rubber band holds the pencil (move the rubber band from the middle of the pencil to one end, etc.).

3. After all students have tested their racers, Ask, *How could you improve the design of your racer to make it travel further?* As a prompt, ask, *Why are automobile tires made from rubber?* (Produces better friction with the road.) Follow by asking, *What could you do to increase friction and help your racer travel a greater distance?*
4. Have students redesign, rebuild and retest their racers. Remind them that it is important to control their tests by winding the rubber band the same amount each time. Using the same number of winds makes it possible to evaluate how well the changes work.
5. Clear the racing area once again. Mark a starting line on the floor and lay a tape measure to track distance. Have groups of four student competitors race “qualifying heats.” Then have the winner of each group race in a “final” to determine the Racer Champion!
6. Have students compare their racers and draw conclusions. Ask, *What made the best racer? Why?*

Extras

- Construct a ramp to test the racers’ climbing power. Alternately, test the racers’ steering by laying a narrow corridor of books on the floor to see if racers can travel from one end to the other without hitting the books.
- A video from The Children’s Museum of Houston shows how wind-up toys work and how to make a wind-up spool racer. To view the video, visit <http://vimeo.com/46440675/>.

6

Rocket Cars Off to the Races

Time

3 sessions to build, test and modify/retest

Before You Start

Construct a sample rocket car to demonstrate to students how to operate their vehicles.

Create a “racetrack” with a 10-meter strip of masking tape. Use a marker to indicate one-meter intervals on the course.

Obtain 24 Styrofoam™ trays (no sections).

Make 24 copies of the “Wheel Patterns” page on card stock for students to use as templates when cutting wheels from the Styrofoam™ tray.

Optional: Obtain 26 plastic drink covers (4 per student) to serve as wheels.

You Need This Stuff

Teacher Materials

- 10-meter strip of masking tape
- Meterstick

Per Student

- 2 coffee stirrers (axles)
- 2 non-bending straws (sleeves for axles)
- 2 round, 12.7 cm (5 in.) size balloons
- Flexible straw
- Masking tape
- Pair of scissors
- Sandpaper
- Sharp pencil
- Styrofoam™ tray (large, no sections)
- Copy of “Design Plan,” “Build a Rocket Racer,” and “Rocket Racer Data” pages
- Copy of the “Wheel Patterns” page on card stock

What It's About

All vehicles, whether designed for land, sea, air or space, are governed by the scientific principles stated in Isaac Newton's Laws of Motion. In brief, the laws are as follow.

First Law: An unbalanced force is required to cause an object to change its state of motion or rest. Once in motion, an object will continue moving in a straight line until acted upon by an unbalanced force. Imagine two people pushing on each other. If they are equally strong, neither will move because the opposing forces are balanced. If one person is stronger than the other, the forces are unbalanced and the weaker person will be pushed backward.

Second Law: An object's acceleration is directly proportional to the force exerted on it and inversely proportional to its mass. In other words, the less mass an object has, the more that object will accelerate when it is acted upon by an unbalanced



On May 23, 1928, Fritz von Opel (known as “Rocket Fritz”) drove the OPEL RAK2 at 238km/h. The car was powered by 24 powder rockets (ignited by a foot pedal), and had wings to compensate for uplift, which kept the car on the ground.

force. Acceleration also can be increased if the force is increased ($f=ma$).

Third Law: Every action is accompanied by an equal and opposite reaction. When force is applied to an object, the object exerts an equal opposing force. Consider what happens when someone fires a shotgun. The pellets fly out of the barrel and the shooter is pushed back by a strong “kick.”



Shown above is the fully electric Formula Student car developed and built by 60 students at Eindhoven University of Technology, The Netherlands. The annual engineering competition is run by the Institution of Mechanical Engineers, UK.

Rockets are an excellent example of the Laws of Motion at work. This activity demonstrates all three laws. Students construct and test a lightweight “rocket” car propelled by the action/reaction force of air escaping from an inflated balloon. The escaping air exerts an unbalanced force on the car, shifting it from a state of rest to a state of motion. The force of the balloon squeezing on air inside accelerates the car when the air is released. Because the car’s mass is very low, it impedes the acceleration minimally. If the car were heavier, it would accelerate more slowly. Finally, the balloon’s wall exerts an action force on the air, causing it to shoot out the nozzle. This creates an equal and opposite reaction force that propels the car. When the balloon’s air runs out, there is no more force to push the car, which coasts until friction brings it to a stop.

What’s the Question?

How can a balloon propel a race car?

What to Do

1. Announce to your class that this is the day of the big rocket car race. Each student will design and build a rocket car, and race his/her car on the track in the hall. Show your students a sample race car. Explain that this is only one possible design, and that their cars could look very different.
2. Demonstrate how the car works. Inflate the balloon by blowing through the straw. Pinch the straw and set the car on the floor. Release the straw and away the car goes!
3. Distribute the student sheets. Have students brainstorm design ideas as a group. Then have each student plan a car and draw pictures of what he/she wants his/her car to look like on the “Design Plan” sheet. Finally, have students begin construction on their cars.
4. Give each student a large Styrofoam™ tray, explaining that the car and its wheels must be made from the tray. Show students how to cut the pieces for their designs. If you are not using scissors, demonstrate the pencil trick: outline the pieces by punching the Styrofoam™ with a sharp pencil tip. When the outlines are completely punched, break out the pieces. Smooth the rough edges by rubbing them against a hard surface. It is especially important to smooth the edges of the wheels. Have students use sandpaper to refine the edges. (Optional: Obtain plastic drink covers from a restaurant to use as wheels.)
5. Show students how to create sleeves for the axles by cutting the non-bending straws. The sleeves should be shorter than the coffee stirrers.
6. When students have drawn and cut out all their car pieces, show them how to create wheel sets. Press one end of a coffee stirrer (axle) through the center of a wheel. Extend the end of the stirrer about a centimeter through the other side, and hold it in place with a small piece of masking tape. Slip a non-bending piece of straw over the stirrer. Then attach the other wheel to the opposite end of the stirrer. The

wheels should turn freely when you hold the axle by the straight straw covering the stirrer. Repeat this process for the second pair of wheels.

7. When both wheel sets are complete, mount them on the bottom of the car platform. Use masking tape to hold them in place. Make sure the wheels are not pressed against the platform and that they turn freely.
8. Pre-inflate the balloon once to make it easier to re-inflate when the car is finished. Insert the short end of a flexible straw into the balloon nozzle. Use masking tape to attach the balloon securely to the straw. Squeeze the tape around the straw to seal any leaks.
9. Mount the straw and balloon to the upper surface of the car's platform with masking tape. Be sure the long end of the straw extends off the back of the platform.
10. Have students test their cars, and explain that they may not perform as well as expected. Allow time for students to make needed design improvements before the "official" race. Mention that wheels that are not round, don't turn freely, or not mounted straight will affect speed and direction.

11. When all rocket cars are ready, organize races on the track in the hallway. For each trial, have two entrants inflate their balloons and hold their cars just behind the starting line. After a short countdown, have students release their straws. The fastest, straightest-running car wins!

Wrapping Up

1. Conduct a post-race talk show, during which racers explain their accomplishments. What worked? What didn't? How did they solve problems? What's the best rocket racer design?
2. Ask students how they would redesign their rocket cars to improve performance.
3. Lead a class discussion about the impact of friction on the performance of students' rocket cars. Ask, *What are some possible sources of friction?* (Wheels not round or rubbing on the frame, rough "track" surfaces, balloon touching the floor or front wheels, etc.)

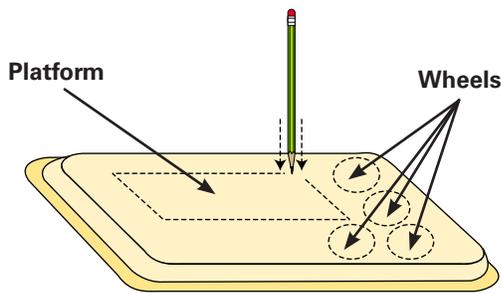
Extra

Have students design their ultimate rocket race cars. ■

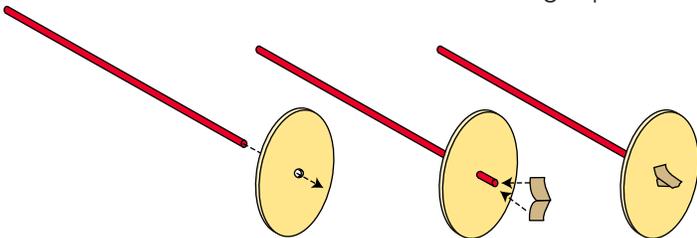
Build a Rocket Racer

Read the instructions below and refer to the illustrations to build a rocket racer. Keep in mind that your racer does not have to look exactly like this one. *Try different numbers of wheels and different shapes for the racer's frame!*

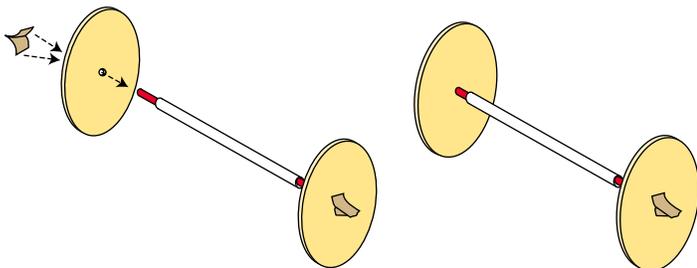
1. Use a sharp pencil and wheel templates to punch out wheel patterns on the Styrofoam™ tray. Punch out a pattern for the racer's platform. Break the pieces out of the tray. Use sandpaper to make sure the wheels are smooth and round.



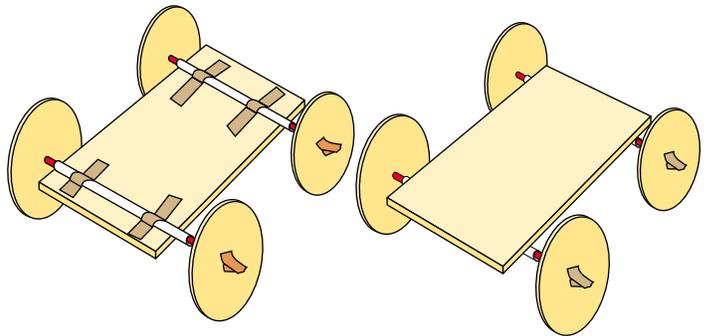
2. Cut two non-bending straws so that they are a bit shorter than a coffee stirrer.
3. Use a coffee stirrer (axle) to punch a hole in the center of one wheel, then punch another hole in a second wheel. Push the tip of the axle just a little bit through the wheel. Secure the axle to the outside of the first wheel with masking tape.



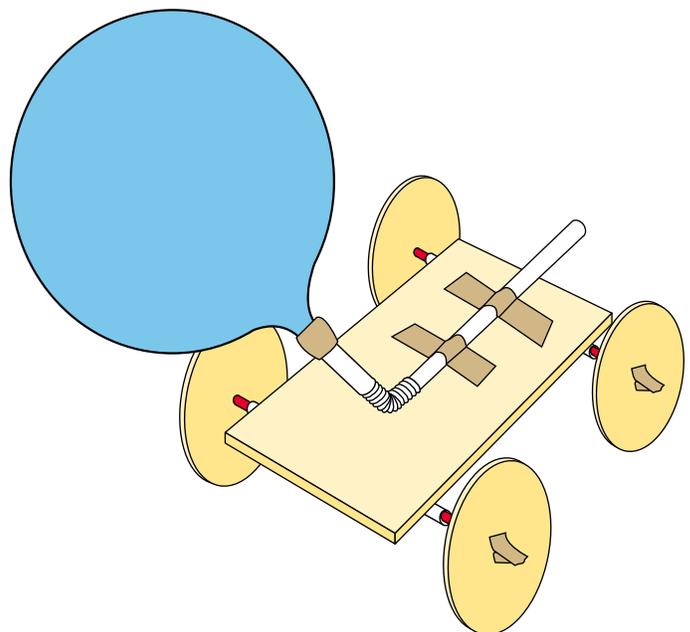
4. Slip a shortened straw (sleeve) over the axle. Attach a second wheel to the other end of the axle. This is one wheel assembly. *Tip:* Leave a bit of room on the inside of the wheels so that you can see the axle inside of the sleeve.



5. Repeat the steps above to create at least one more wheel assembly.
6. Tape the sleeves of both wheel assemblies to the racer's frame.

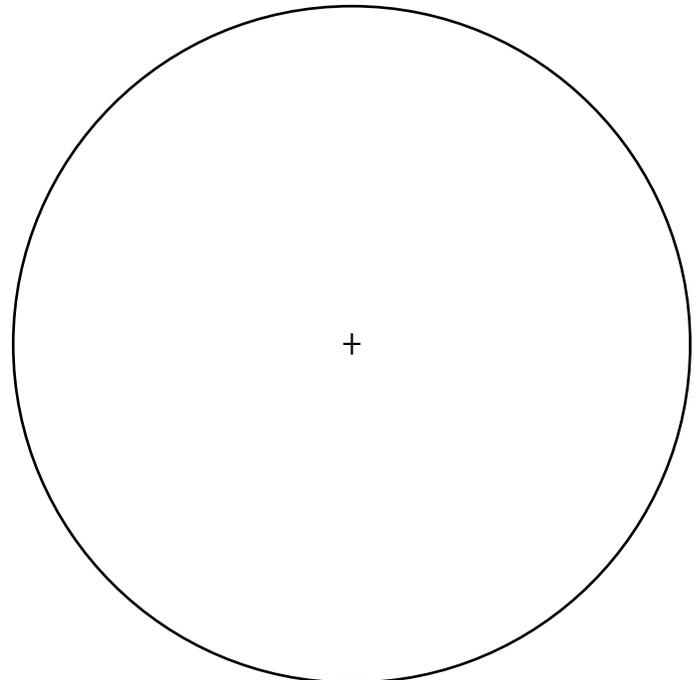
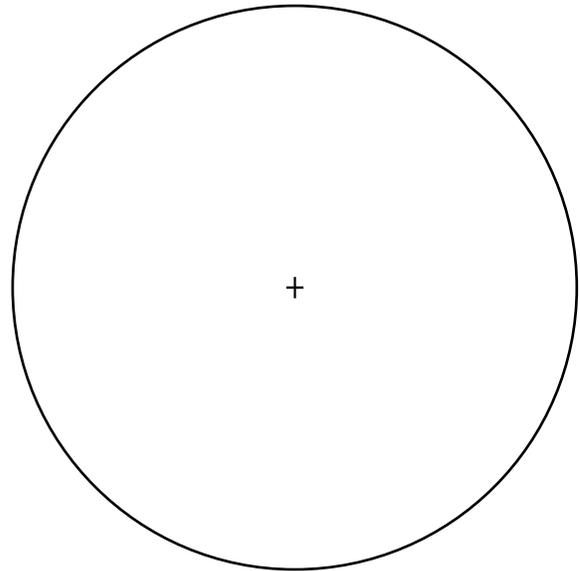
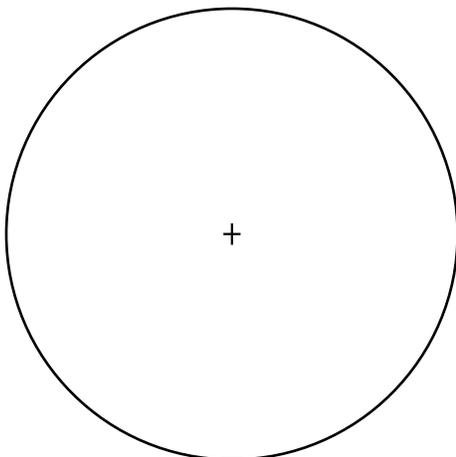
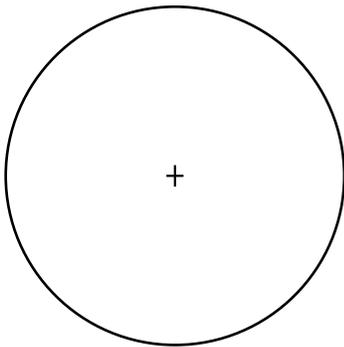
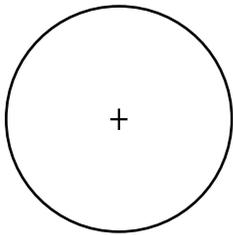


7. To complete the race car, insert the shorter part of a flexible straw into the end of a round balloon. Secure it with tape. Bend the straw and tape its longer end to the racer's platform.



Wheel Patterns

1. Select the wheel size for your rocket racer. Cut out the shape you wish to use as a template for your wheels. *You may use more than four wheels for your racer, as well as different shaped-wheels.*
2. Notice the “+” in the center of each pattern. This is where you should use a coffee stirrer to punch a hole in the Styrofoam™ wheel. (See instructions and illustrations on the “Build a Rocket Racer” sheet.)

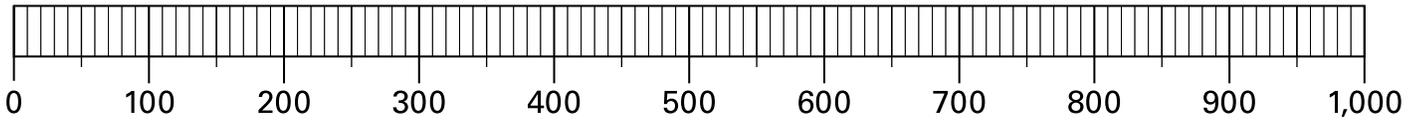


Rocket Racer Data

Name _____

For each trial, color in the graph to show how many centimeters your rocket racer traveled. Then answer the questions below on the back of this sheet or on a separate sheet of paper.

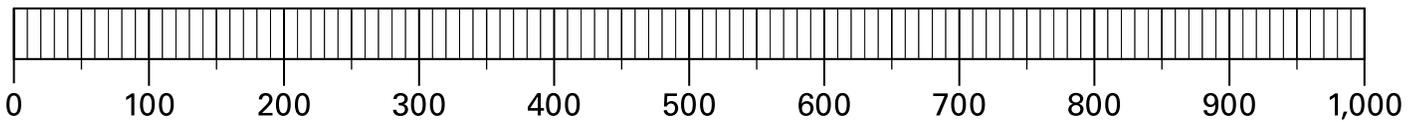
TRIAL 1: Initial Design



1. How did your rocket racer run (straight, curved, circles, stuck, etc.)?
2. Did your racer perform as well as you hoped? Explain why or why not.

TRIAL 2: Modifications 1

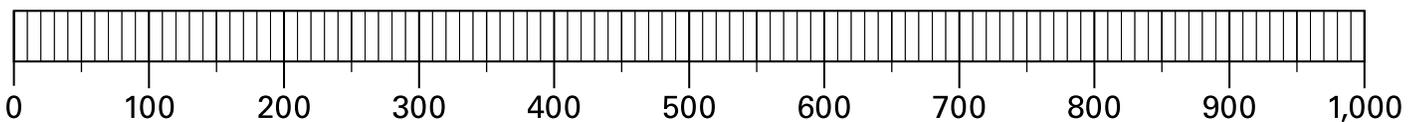
1. How did you improve your rocket racer?
2. Predict how far your modified racer will run. _____ cm.



3. How did your modified rocket racer run (straight, curved, circles, stuck, etc.)?
4. Did your improvements work? Explain why or why not.

TRIAL 3: Modifications 2

1. How did you improve your rocket racer?
2. Predict how far your modified racer will run. _____ cm.



3. How did your modified rocket racer run (straight, curved, circles, stuck, etc.)?
4. Did your improvements work? Explain why or why not.

Roller Coasters

Getting Loopy

Time

1–2 sessions

Before You Start

Download and install the trial version of NoLimits Roller Coaster Simulation (Mac/PC) software, which features five roller coaster rides. (Use of the free trial version is limited to 15 days.)

<http://www.nolimitscoaster.com/download.php>

You will need nine 6-ft lengths of foam pipe insulation (for 3/4-in. diameter pipes). Pipe insulation comes with a slit running along its length. Use the slit as a guide for cutting the tube in half lengthwise. Alternately, have the tubes pre-cut at the hardware store.

You Need This Stuff

Teacher Materials

- 9 6-ft lengths of foam pipe insulation (for 3/4-in. diameter pipes)
- Computer with projector and Internet access
- Software: NoLimits Roller Coaster Simulation
- Videos: Roller Coasters, and World's Second Greatest Paper Roller Coaster/Marble Run
- Web page: Paper Roller Coaster

Per Group of Students

- 3 pre-cut, 6-ft lengths of foam pipe insulation (see “Before You Start,” above)
- Marbles
- Masking tape
- Pair of scissors

Per Student

- 2 sheets of color copy paper (8.5-in. x 11-in.)
- Copy of “An Engineer’s Approach” page (p. vi)

What It’s About

Mechanical engineers design and improve machinery and systems upon which we depend. One special kind of mechanical engineer designs roller coasters for amusement parks. Students may have ridden roller coasters, or seen them in movies and on the Internet. A roller coaster propels riders through exhilarating drops, turns, twists and loops that simulate the movements of an aerobatic plane.

All roller coasters go through an extensive design and testing process. To provide the most exciting, yet safe, ride possible, an engineer must have an excellent understanding of force, gravity, motion, momentum, and potential and kinetic energy.

The basic roller coaster shape (a series of progressively smaller hills) has been used since the roller coaster was created in the 1400s. Early modern-style roller coasters were built with wood



Dragon Khan is a steel roller coaster in Catalonia, Spain. The train cars can be seen inverted on the highest loop of the coaster.



Texas Giant wooden roller coaster at Six Flags Texas.

supports and steel rails. But wooden roller coasters, which tend to feature hills and steep turns, can make for a rough ride. In 1959, Disneyland unveiled the first all-steel roller coaster, the Matterhorn Bobsled. Steel generally provides a smoother ride and allows more extreme maneuvers. That's why most roller coasters today use steel supports and tracks. Of course, loops, turns and gravity-defying spirals now are standard elements of roller coaster design.

What's the Question?

What makes a good roller coaster design?

What to Do: Part 1

1. Ask the class, *Have you ever ridden a roller coaster? Why do you think they're so much fun?* Lead students to think about how these rides safely simulate dangerous—but exciting—drops and turns.
2. Have each student draw a roller coaster on which he or she would like to ride. Then show the “ride of their life” coaster demonstrations

from the NoLimits Roller Coaster Simulation software.

<http://www.nolimitscoaster.com/download.php>

3. Have students rate each of the five rides. Ask, *What makes a great roller coaster ride?* Discuss their responses.
4. Ask, *Who do you think builds roller coasters?* Show the video, *Roller Coasters*, which introduces Chris Gray, a mechanical engineer and roller coaster designer. He discusses why he became an engineer and what his work is really like.

http://www.youtube.com/watch?v=H_Xo9i9O-cXk

5. After watching the video, have students share what they learned about this engineer and his work.
6. Have students to think about the types of questions roller coaster designers must address when they begin a new project. Ask, *How much space do you have to build? How long should the ride last? What should the roller coaster do? How can you ensure its safety? How much fun can it be?*

What to Do: Part 2

1. Divide the class into teams of four. Explain that they will work as mechanical engineers to design their own roller coasters. Students will build their roller coasters from foam insulation tubing, and will use marbles as the roller coaster cars.
2. Show students a sample section of foam half tube. Encourage them to investigate the tubing and ask questions about how it might work for a mini roller coaster.
3. Provide each team with three 6-foot lengths of pipe insulation  tubing, cut in half lengthwise. *Not to scale.*
4. Like all engineers, the students will work within defined parameters. For this design, they may

use furniture or classroom structures for support. Their roller coaster “car” must have a starting and ending point, must pass through at least one loop, and must complete the entire track without falling off.

5. Have students follow the engineering design process to create a roller coaster from the tubing and masking tape, using marbles as roller coaster cars.
6. After all teams seem to have produced successful roller coasters (or after a given period of time), have students rotate around the room to view the different designs. Ask them to identify similarities and differences in the roller coaster designs, and any original ideas they observed. Lead a class discussion about what worked—and didn’t work—in their roller coasters.
7. Have teams use what they have learned to improve their designs, and then make longer roller coasters. If possible, create a video of each team’s roller coaster.

What to Do: Part 3

1. Challenge students to create more complex roller coasters using copy paper, sentence strips, scissors and tape. Information and animations on the Paper Roller Coaster web page explains the best method for creating a basic paper roller coaster. Review their information before starting, and use the site’s resources, as needed.

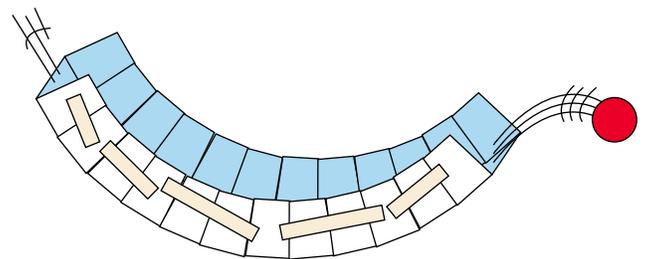
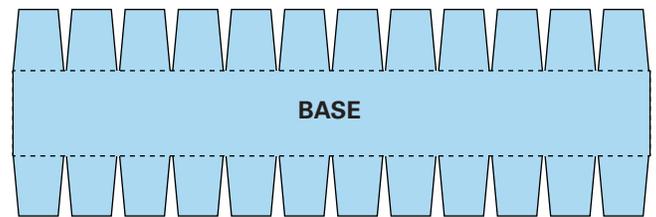
<http://www.mrwaynesclass.com/ProjectCoaster/Lab/index.html>

2. It may be helpful to view the YouTube video, World’s Second Greatest Paper Roller Coaster/ Marble Run. Discuss the video, with specific emphasis on how the roller coasters achieved various tricks.

<http://www.youtube.com/watch?v=CSdtMdj7k68>

3. Demonstrate how to create a track by folding the edges of a sentence strip up on both sides, leaving about an inch in the center.
4. Fold a second sentence strip the same way. Make cuts in the outside sections to form

trapezoids. Do not cut the center section (the base). Demonstrate the flexibility of the strips, showing how they can be bent up or down to create hills and valleys. Explain or demonstrate that several pieces of tape, placed on the cut sides of the track, can help to keep the desired shape of a curve.



5. To create supports for the roller coaster, roll 8.5-in. x 11-in. pieces of paper lengthwise into 11-in. tubes that are 1-in. in diameter. Tape the ends of each tube securely. The number of supports needed will depend on the design. Students can use tape to attach the roller coaster tracks to the support legs. If desired, build taller support columns by taping two tubes together. Shorter columns can be made by cutting them to a desired length.
6. Have students use a copy of “An Engineer’s Approach” page (p. vi), to brainstorm and build their roller coasters.
7. Allow students to present their roller coasters to the class.

Wrapping Up

Have teams self-evaluate their roller coasters. Ask students, *Did the marble remain on the track and travel all the way to the end? Were there any unanticipated challenges? Any problems that teams could not solve? How fast did the marble roll? Is the ride safe?*

8

Kinetic Art Sculptures in Motion

Time

1–2 sessions

Before You Start

Gather a variety of recycled materials (see list below).

You Need This Stuff

Teacher Materials

- Computer with projector and Internet access
- Online videos of kinetic artists and sculptures (select 1 or more from 7 videos)

Per Class

- Crepe or tissue paper strips
- Electric fan
- Metal washers
- Nails, straight pins, or other devices to serve as pivot points
- Recycled materials (e.g., cardboard, cans, cups, etc.)
- Skewers
- String
- Tape

Per Student Group

- 10-cm x 10-cm sheet of paper (up to 15-cm x 15-cm square)
- Colored markers, crayons or decorative stickers
- Pair of scissors
- Pencil with full eraser
- Ruler
- Straight pin
- Copy of “Make a Kinetic Pinwheel” page

What It's About

On blustery days, we commonly hear people use the phrase, “Look at the wind.” Have you ever wondered what it actually means? When air is moving, we feel wind, but of course, we don't actually “see” it. Instead, we observe the movement it causes in the objects around us. Flags wave, leaves rustle, and if the wind is very strong, rain may even fall sideways. In this investigation, students will create and study unique sculptures that move in interesting ways when acted upon by the force of the wind.



“Tyne Anew” by Mark di Suvero combines artistic design with engineering skills. Three huge tripod-style legs support a top piece that twists, dips and moves with the wind.

What's the Question?

How does a kinetic sculpture work?

What to Do

1. Begin the activity by asking students, *Do you know what a kinetic sculpture is?* (It's a special kind of sculpture that moves.)
2. To increase students' comfort with, and understanding of kinetic sculptures, have them

start by making a mini-sculpture (a pinwheel), using the “Make a Kinetic Pinwheel” page as a guide. Instruct students to hold their pinwheels in front of the fan, or take them outside to observe their movement in the wind.

- Project one or more of the videos below (see “Viewing YouTube Videos,” right).
 - Anthony Howe’s Otherworldly Kinetic Sculptures (The Creators Project)**
http://www.youtube.com/watch?v=RshSaF_juGs
 - Kinetic Sculptor Puts Cyber Dreams in Motion (The Creators Project; subtitled)**
<http://www.youtube.com/watch?v=FoM8U-oMuvl8>
 - Reuben Margolin (MAKE: television)**
<http://www.youtube.com/watch?v=dehXio-MIKgO>
 - Reuben Heyday Margolin: Waves**
<http://www.reubenmargolin.com>
 - Theo Jansen: Strandbeest Evolution**
<http://www.youtube.com/watch?v=MYGJ9jrb-pvg>
 - Theo Jansen’s Strandbeests (BBC One)**
<http://www.youtube.com/watch?v=HSKyHm-jyrkA>
 - Time-Lapse: Mark Di Suvero Installation**
<http://www.sfmoma.org/explore/multimedia/videos/563>
- Show students the materials available for them to design and build their own kinetic sculptures. Encourage teams to collaborate on the design. Recommend that they draw their planned sculptures on a sheet of paper, label the parts, indicate sizes of parts, etc.
- Have teams gather materials and create their kinetics sculptures.
- Let teams present their sculptures to the class and explain what they want their sculptures to do when the wind is blowing. After each presentation, ask the rest of the class, *Do you think it*

Viewing YouTube Videos

To download and view YouTube videos, install the **KeepVid Video Downloader (free web application)**, or play the video immediately at www.keepvid.com.

- On YouTube, highlight the url of the page on which the desired video is loaded.
- Open keepvid.com and paste the url in the box at the top.
- Click either “Download” or “Play Now.”
- If you are downloading the file, KeepVid will ask you to choose the format in which you want to save the video, and where to save it on your computer.

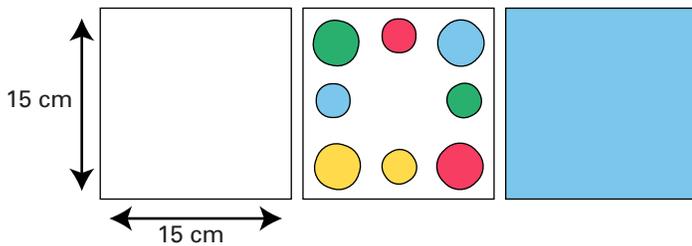
will do what the team says it is designed to do? Can you suggest improvements?

- Use the fan to test each team’s sculpture. Begin each test with the sculpture located a specified distance from the fan. Gradually, move the sculptures incrementally closer to the fan. Ask, *Do the parts move as expected? Is the sculpture stable? If not, does it need a wider or heavier base? Is it top-heavy?*
- Discuss the videos with the class. Make sure students understand that movement is imperative for their sculptures, but that aesthetics also should be considered. Ask, *Why is this important?*
- Have students brainstorm ways to improve their original designs. Students may suggest adding or removing weight, changing shapes, using other types of materials, etc.
- You may want student teams to design new or improved kinetic pinwheels, perhaps with even more moving parts. Again, students should draw diagrams and label the parts. They also should consider how each new design element might improve the sculpture’s motion.
- Have teams select materials from those offered, build and test their new sculptures, and adjust as necessary.
- Finally, have each team explain how it planned, built and tested its sculpture, and provide a brief summary of outcomes. ■

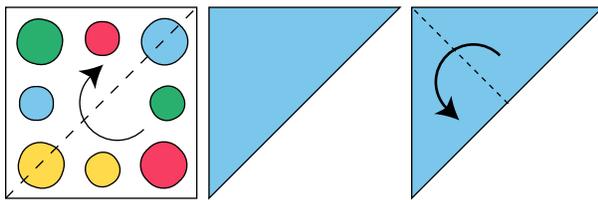
Make a Kinetic Pinwheel

Read the instructions below and refer to the illustrations to build a kinetic pinwheel sculpture. Keep in mind that your sculpture does not have to look exactly like this one.

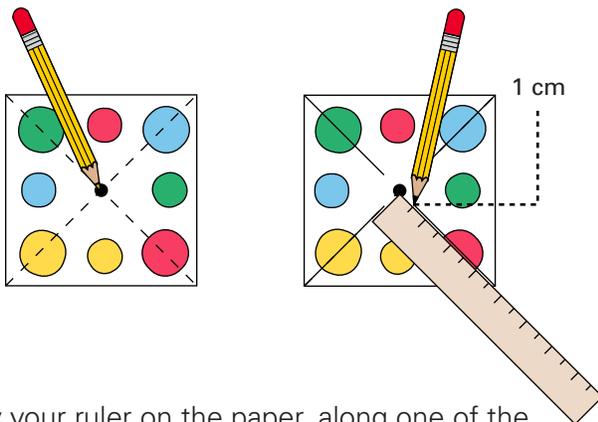
1. Start with a 15-cm square piece of paper. Decorate both sides of the sheet of paper.



2. Fold the square in half to make a triangle. Then fold the triangle in half, to make a smaller triangle.

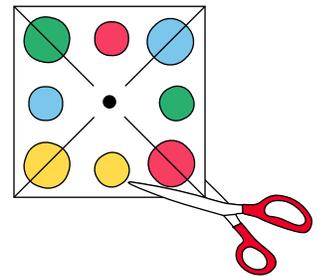


3. Unfold the paper. Use your pencil to put a dot in the center of the square, where the four fold lines meet.

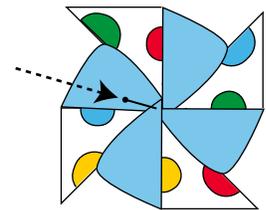
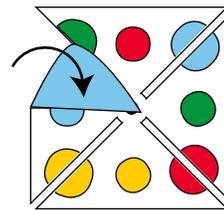


4. Lay your ruler on the paper, along one of the folds. The top of the ruler should be on the center dot. Starting 1 cm below the dot, draw a line to the corner of the paper. Repeat this step to draw a line to each remaining corner.

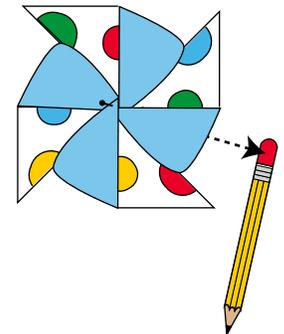
5. Cut along the lines you have drawn. Be sure to stop cutting before you reach the center dot at the end of each line.



6. Fold every other point in toward the center. The points should reach a little beyond the dot.
7. With four points folded down over the center, push a straight pin through all four points and the center dot.



8. Push the pin into—but not all the way through—the eraser on your pencil.



9. Smooth out the creased edges a little, to open and puff out the pinwheel.

Consider this. *What kind of power makes the wheel go around? What real-life machines work the same way?*

