#21610 Young's Double Slit Apparatus
A Design Technology Unit

About this unit:

What Students Do
Students begin by making a vehicle to meet the design requirement that it must roll down a ramp. Then they strengthen the wheel-axle connection by building hubs. They next minimize friction between the wheels and the vehicle frame to meet the design requirement that the vehicle must roll down a ramp and roll a certain distance on a level surface. Then students brace the vehicle frame to hold a specified load. To power their vehicles, students make a mount for a balloon and install it. They then test their balloon-powered vehicle against a design requirement that the vehicles, with the diameter of the inflated balloon controlled, move a certain distance. Students add several masses and observe the effect on the distance their powered vehicle moves. Finally, students review how their vehicle design has changed and progressed throughout the unit.

Grade Level: fifth grade through ninth grade

Total Time Required: about fifteen 45-minute class periods

Materials
Utilizing materials effectively is an important part of the engineering design process. *Vehicle Engineering* enables students to construct a vehicle out of remarkably simple materials—card stock, paper straws, dowels, and cardboard wheels. The body of the vehicle is the card stock, which is barely able to support its own weight. To build a vehicle that can carry a load, students must brace the card stock with pieces of paper straw. Likewise, the cardboard wheels slip right over the dowel axles, but the wheels are so thin that they do not remain perpendicular to the axle. To correct this problem, students build up a hub from short pieces of paper straw and a small cardboard wheel. Students design and build in cardboard and paper in the same way that an engineer designs and builds in steel.

Materials Management
In this unit, materials are provided in ample quantities. The kit contains materials for sixteen groups of two students, who can work together, share ideas, and learn from each other. There are enough materials so each group can, if necessary, build a *second* vehicle from scratch, so there is no need to worry about students "getting it right the first time." Just as with engineers and their models, students can start over if they recognize a mistake or have a new idea they want to try out. Also, the limitation of the materials to card stock, straws, dowels, and cardboard wheels simplifies materials management, since these basic materials are employed in nearly every activity and quickly become familiar to both students and teacher.

About the author
Ed Lee taught physics and physical science at various grade levels for twelve years. He worked in educational materials development at the National Sciences Resources Center, where he contributed to two of the units in the Science and Technology for Children (STC) curriculum, and also at the Capital Children's Museum. He has bachelors and masters degrees in physics.

The drawings in this book are by Margo Klass, Chairman of the Art Department at the Holton-Arms School, Bethesda, MD.

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Activity Summary

1. **Working with the Materials:** Students discuss how to make a vehicle with the materials in the kit. To become familiar with the kind of construction required, students practice gluing small pieces of paper straws to small pieces of copy paper. To prepare to cut out the card stock for the vehicle frame, students practice drawing full-size plans on paper and cutting the paper according to the plan.

2. **Roll-Out:** Students build and test a model vehicle to meet the design requirement that it roll down a ramp. The materials are card stock, paper straws, small dowels, and cardboard wheels, which the students glue together. They test their vehicle and modify it as needed to meet the requirement.

3. **Building Hubs:** Students discuss possible ways to improve the connection between the wheels and axles on their vehicles and then examine the hubs on a bicycle and a wagon. Students build up hubs by gluing small pieces of straw between two wheels to form a sandwich. Then they compare and contrast the wheel-axle connection with and without the hubs.

4. **Friction and Wheels:** To investigate the effect of wheels, students remove the vehicle's wheels and place the vehicle's body on the ramp. Students then raise one end of the ramp until the body just begins to *slide* downhill. For comparison, they reinstall the wheels, place the vehicle on the ramp, and raise one end until the vehicle just begins to *roll* downhill. Then they minimize friction to meet a design requirement on how far the vehicle rolls.

5. **Carrying a Load:** Students modify their vehicle to carry a load of two washers. A design requirement specifies the maximum amount the vehicle can flex when carrying this load. Students brace the vehicles by gluing paper straws to the cardboard frame and then test their vehicles to see if they meet the design requirement. Later, in Activity 9, students will add two washers to their vehicles to investigate how the load affects the distance the powered vehicle travels.

6. **Making 3-D Structures From Flat Materials:** Students discuss how to mount a balloon on their vehicle. To make a simple three-dimensional structure, they make a box from a sheet of paper, following an engineering process called *development.* They first draw a full-size plan on the sheet. Then they cut the paper, fold it to make it three-dimensional, and tape together pairs of sides to make the box. Students discuss how this kind of construction could be used to make a balloon mount.

7. **The Balloon Mount, in Paper:** Students discuss how they can adapt the box design from Activity 6 to make a mount for the balloon. They draw a full-size plan, and then they practice building the mount in paper. They cut out the paper according to their plan, fold it to make a 3-dimensional structure, and tape together pairs of sides to make the balloon mount.

8. **The Balloon Mount, in Card stock:** Having built a balloon mount in paper in Activity 7, students now build one in card stock and glue it in place on their vehicle. To stiffen the mount, they gently squeeze it to find out where it bends easily and then glue paper straw bracing at these places.

9. **Balloon Power and the Effect of a Load:** Students install the balloon and meet a design requirement that the powered vehicle go at least three meters. To insure that each group inflates the balloon the same amount, the class controls the diameter of the inflated balloon. Then students add different loads and observe the effect on the distance traveled.

10. **Reflecting on the Design Process:** With design and testing complete, students review the improvements they made to their vehicles during the unit.

Standards Addressed

Vehicle Engineering addresses the following National Science Education Content Standards, grades 5-8:

Evidence, model, and explanation
Change, constancy, and measurement
Form and function
Abilities necessary to do scientific inquiry
Abilities of technological design
Motion and forces

Concepts and Skills

Science and Engineering Concepts
motion
effect of vehicle mass
friction
meeting design requirements
bracing

Mathematics Concepts
angle
measurement
units

Science and Mathematics Skills
measuring distance
measuring angles
controlling variables
making predictions
interpreting results
organizing, analyzing, and presenting data

Engineering Skills
working from a plan
drawing a full-size plan
budgeting materials
testing and redesigning a model
interpreting dimensioned drawings
cutting and folding flat material to make a 3-dimensional object

Materials

Kit Materials

32	dowels, 3/16" x 6 ¾"
28	pieces card stock, 65 lb., 8 ½" x 11", red
28	pieces card stock, 65 lb., 8 ½" x 11", blue
130	small cardboard wheels, 3.8 cm (1 ½") diameter
130	large cardboard wheels, 6.4 cm (2 ½") diameter
32	fender washers, 2" *x* ½"
20	balloons, helium quality, 9"
16	glue cups (film canisters)
16	gluing sticks (rectangular wood sticks)
16	corrugated cardboard pieces, 12" x 15"
130	paper straws, 6 mm diameter
	3/8" punch
	roll of cellophane tape

Classroom materials for each group

white glue
protractor
scissors
ruler
meter stick
copy paper, 3 sheets
several books
white glue
unsharpened pencil
graph paper

Other classroom materials

pocket folder for each student (optional)
paper towels
old newspapers
container for scrap pieces of straw
masking tape

Other materials

bicycle (or bicycle wheel) and wagon
1 shoebox for each group (optional)

Budget

To be sure you have enough materials left as you move through the unit, it may help set aside batches of straws and card stock for certain activities. You can label each batch to identify it easily. Here are the number of straws and sheets of card stock required, by activity. Note that these numbers include enough to let sixteen groups each build two vehicles.

Activity 1:	*4 straws*	
Activity 2:	*22 straws*	*16 sheets card stock*
Activity 3:	*24 straws*	
Activity 5:	*32 straws*	
Activity 8:	*35 straws*	*40 sheets card stock*

Activity 1: Working with the Materials

Overview
Students discuss how to make a vehicle with the materials in the kit. To become familiar with the kind of construction required, students practice gluing small pieces of paper straws to small pieces of copy paper. To prepare to cut out the card stock for the vehicle frame, students practice drawing full-size plans on paper and cutting the paper according to the plan.

Time Required: one class period

Background
A *model* is a way to represent something large or complex. A model of the solar system enables students to visualize the paths of the planets. A model airplane tested in a wind tunnel yields important information for the design of aircraft without requiring a large investment in a full-size prototype. Although such physical models are still used today, most products are actually designed from computer-generated models.

Vocabulary
axle
dowel
model
vehicle
wheel

Materials
Kit materials for each group
- paper straw piece, 10 cm
- glue cup and gluing stick

Classroom materials for each group
- ruler
- scissors
- white glue
- old newspapers
- piece of paper towel
- small piece of copy paper, about 5 cm *x* 10 cm

Classroom materials for each student
- pocket folder (optional)

Other materials
- container for scrap pieces of straw
- shoebox (optional)

Preparation
Cover the students' work surfaces with old newspapers and set out a piece of paper towel for each group so students can wipe up any excess glue. If students ask for additional paper straws, try to encourage them to use leftover pieces of straw instead. You can create a recycling container for the straws, so students can use the discarded pieces. Note that there are enough straws, card stock, and wheels in the kit for many students to make a second vehicle, if necessary. See the note after the listing of kit materials on setting aside straws for later activities. Pour white glue into each group's glue cup to a depth of about half a centimeter.

If pocket folders are available, each student can use the folder to hold the records of the design work. If a shoebox is available for each group, students can use it to store the vehicle and leftover materials. If folders are available for each student, they can hold the students' records.

Group the students. Remember that there are enough materials for a class of 32 to work in pairs.

Procedure
1. Explain that in this unit, the students will be working like engineers. They will build *models* of vehicles that must meet requirements. Explain that a model is much smaller than a real vehicle, so that students can test their designs easily.

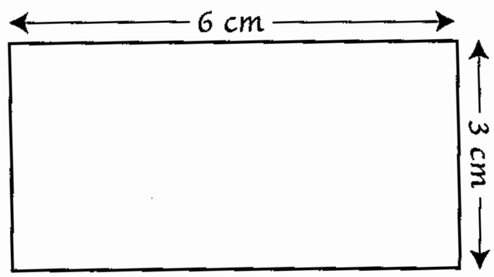
The holes in the cardboard wheels can open up if the wheels are pushed onto the axles roughly. To minimize wear-and-tear on these holes, show students the wheels but do not hand them out. In the next activity, students build a vehicle with the wheels.

2. Hold up the card stock, the dowels, the paper straws, and the cardboard wheels. Go over each material and give its name. Explain that you will hand them out in the next activity, when students will build their first *vehicle*. Explain that a vehicle can be a car, truck, ambulance, go-kart, or even a spacecraft. Discuss how students might build a vehicle from these materials.

3. Explain that for the rest of this activity, students will practice cutting out paper of the proper size and gluing pieces of straw to this paper. Hand out a small piece of copy paper, the straw piece, the scissors, ruler, glue pot, and glue stick.

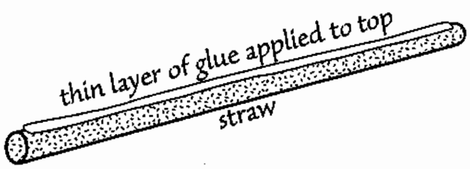
4. On the board draw a rectangle, with one side twice as long as the other. Label the sides 3 cm and 6 cm, as in Figure 1. Have students use the ruler to draw a 3 cm *x* 6 cm rectangle on their paper. You might suggest that they first trace the corner of a sheet of paper to make a right angle, measure off a 3 cm and 6 cm side along this corner, trace the corner at the end of one of these sides to make the next right angle, and continue around the rectangle in this way until it is complete. Have students cut out the rectangle.

Figure 1



5. Tell students that they will now glue short straw pieces onto a small rectangle of white paper. Explain that the gluing works best if they place a smooth layer of glue on the straw piece from one end to the other, as shown in Figure 2. Mention that there is no need to place any glue on the sheet of paper.

Figure 2



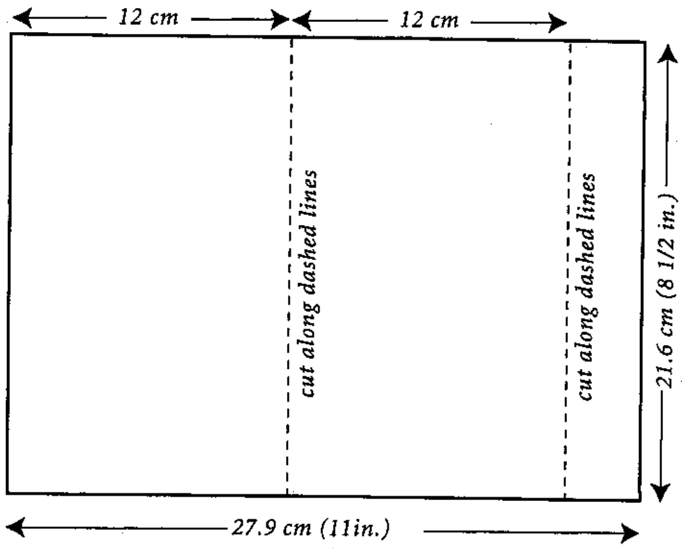
6. Have students cut the 10 cm straw piece into smaller pieces and glue these to the small paper rectangle.

7. When students are finished gluing, have them put the small rectangle aside for use in a later activity (Activity 5). Ask them to share what they have learned about gluing the straws to the paper.

If your students are skilled at drawing parallel lines and measuring accurately, you can skip the rest of this activity. In that case, consider going over the bulleted items in Step 9 before students cut their rectangles from card stock.

8. Explain that they now will cut out a much larger rectangle for their model, and they will again practice by cutting copy paper. Copy Figure 3 onto the board. Hand out an 8 ½" x 11" sheet of copy paper to each group and say that they will cut the paper in two places, as shown in the drawing on the board.

Figure 3



9. Mention that the two lines in the drawing are separated by 12 cm. Discuss how to draw these lines. Here are some steps you can suggest to help students:

- Turn the sheet of paper so the short side is on the left.
- Make a mark 12 cm from the left side at the top of the sheet *and* at the bottom. Then connect these marks to draw the first dashed line (the one on the left).
- Then make marks 12 cm to the right of this line, again at both the top and bottom of the sheet.
- Connect the marks to draw the second dashed line.

10. When students have a correct drawing, they can cut out the two paper rectangles. Have students save these in case they want to build a vehicle of paper.

11. Have students wash out the glue cups and clean up. Tell them that they will use the skills they have learned in Activity 1 when they build their vehicle in Activity 2. After the glue has dried, have students put the small paper rectangles in their shoeboxes.

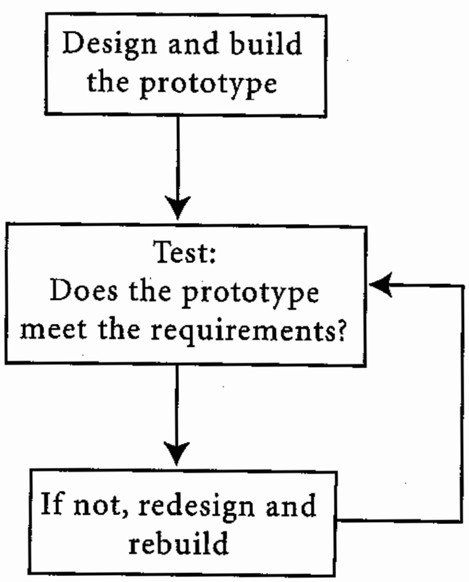
Activity 2: Roll-Out

Overview
Students build and test a model vehicle to meet the design requirement that it roll down a ramp. The materials are card stock, paper straws, small dowels, and cardboard wheels, which the students glue together. They test their vehicle and modify it as needed to meet the requirement.

Time Required: two class periods

Background
Engineering design is driven by requirements. For a process, like an assembly line, the requirements might be the ability to build a car in a certain length of time or with a certain maximum number of workers. For a product, like a car, the requirements might be gas mileage, top speed, or price. After the requirements are established, engineers design the car and build *models* and *prototypes*. A model is typically smaller than full-size and enables the engineers to test and make refinements easily and inexpensively. A prototype is a full-size, preliminary version of the product. Engineers perform tests to see if the models and prototypes meet the requirements. If not, the engineers modify the model or prototype as needed, as shown in Figure 1.

Figure 1



Scientists and engineers have different goals. Engineers create products or processes to meet human needs and use science in this work. For instance, an automotive engineer designs an engine based on the chemistry of gasoline and how it burns in air. On the other hand, scientists learn about the natural world by creating theories and performing experiments. For example, a physicist investigates how the arrangement of atoms in a crystal affects the properties of the crystal.

Vocabulary
requirement

Materials
Kit materials for each group

1	piece of card stock, 8 ½" x 11"
4	large cardboard wheels, 6.4 cm (2 1/2") diameter
2	dowels
1	paper straw piece, 10 ½" long
	glue cup and gluing stick
	corrugated cardboard piece, 12" x 15"

Classroom materials for each group

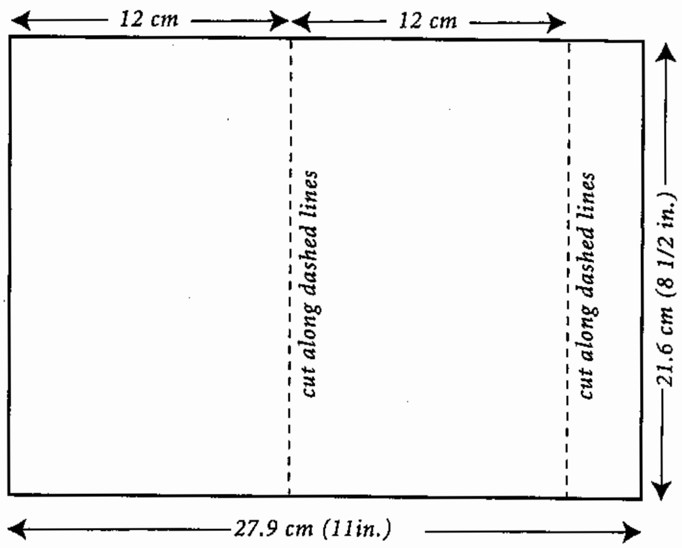
- ruler
- protractor
- scissors
- white glue
- old newspapers
- piece of paper towel
- several books
- masking tape strip about 8 cm long
- copy paper, one sheet

Other classroom materials

- container for scrap pieces of straw

Preparation
Cover the students' work surfaces with old newspapers and set out a piece of paper towel for each group so students can wipe up any excess glue. Fill the glue pots to a depth of about 1 cm. Cut the straws to a length of 10 ½", as indicated in the Materials section. Keep the leftover pieces, which may be needed if groups want to start over and make another vehicle. Cut a masking tape strip for each group. Draw Figure 2 on the board.

Figure 2



Procedure

1. Ask students to review what they learned in the first activity about drawing full-size plans and cutting out rectangles. Explain that the paper straws are important materials for their models, and that is why they practiced gluing the straws in place.

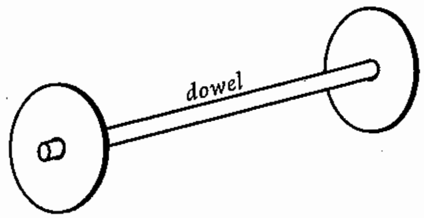
In Steps 2 and 3, students cut out rectangles from card stock.

2. Hand out the colored card stock, scissors, and rulers to each group. Give groups their choice of color. Explain that students will cut rectangles for their model from colored card stock, the same size rectangles as those they cut from paper in the first activity. Refer them to the drawing on the board, which is Figure 2 above.

3. Have the groups cut out the two rectangles of card stock according to the drawing on the board and place one rectangle in their shoebox.

4. Hand out the straw piece, glue cup and gluing stick, dowels, and wheels. Ask students how they can build a vehicle with these materials. You may want to bring out the possibility of pushing the wheels onto the dowels to make a *wheel* and *axle*, as shown in Figure 3. Also, you may want to push a dowel into a straw and ask students how the straw could support the axle.

Figure 3

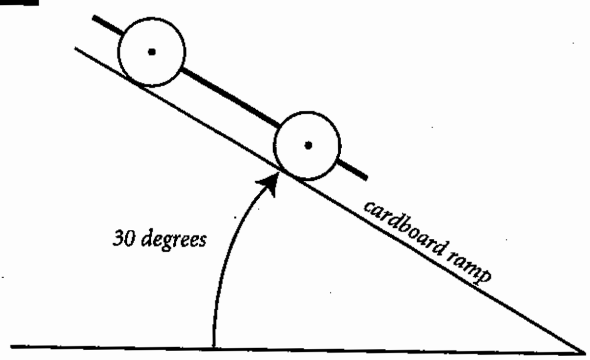


5. Next, tell students that engineers design to meet *requirements.* In this activity, the requirement is:

The model must roll down a ramp at a 30° angle to the table or the floor.

See Figure 4. Have the students write down the design requirement before beginning work.

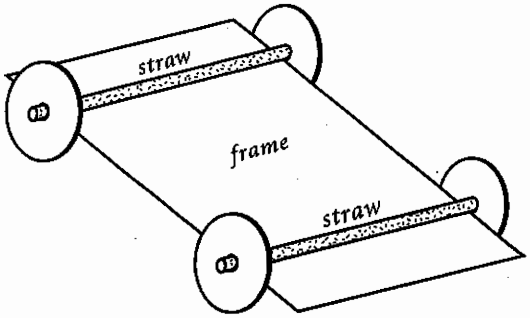
Figure 4



In Step 6, students build the vehicle.

6. Ask students to review what they learned in the first activity about gluing paper straws. Explain to students that while they are gluing, they must be sure remove the wheels and axles (to prevent gluing the wheel and axle to the straw). Have students make their vehicles, which will probably look like Figure 5.

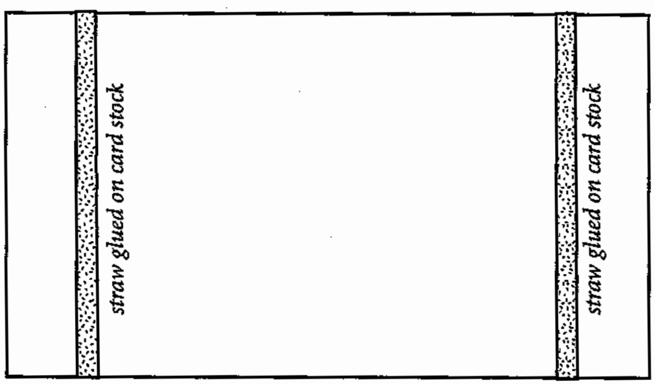
Figure 5



7. When the groups have finished gluing the straws in place, remove the glue. Ask them to return any scrap pieces of straw for use in a later activity.

8. While the glue dries, have students make a drawing of their vehicle and date the drawing. Suggest that they stand directly over the model and draw what they see. The result will be a drawing like Figure 6.

Figure 6



9. Hand out the protractors, the masking tape strips, and the cardboard for the ramps. Have students tape the bottom of the ramp in place so it will not slide. Then have students prop up one end of the ramp with books and, with the protractor, set the angle between the ramp and the floor to 30 degrees, as shown in Figure 4. Have them make a side-view drawing, again as in Figure 4, of the ramp.

10. When the glue is dry, ask each group to *gently* press the wheels onto the axles. Be sure students have no glue at this time. Have each group test its model by rolling it down the ramp. Also, have them record the test results and compare them with the design requirement.

There is enough material in the kit for each group to repeat the gluing of straw pieces to card stock, if necessary. In this case, students can use the second piece of card stock cut out in Step 3.

11. Discuss the results of the test. If any groups need to modify their vehicles to meet the design requirement, find a time for them to do that. Have students make a drawing of their vehicle and record the results of the test.

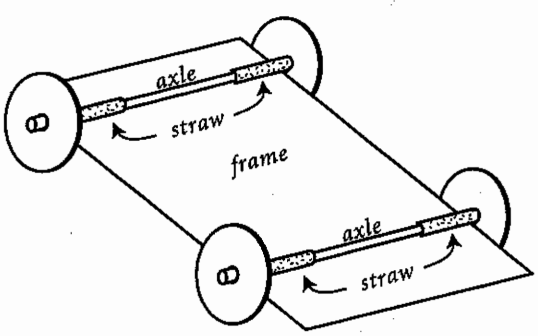
12. Have students clean up and wash out the glue cups.

13. Ask the students what parts of their models need improvement. Ask them to offer suggestions. (See Teaching Suggestions below.) Have the students record possible improvements for their group's model.

Teaching Suggestions

The main challenge in this activity is aligning the two straws that support the axles so these straws are parallel to each other and to the short end of the card stock. Encourage students to draw parallel lines on the card stock to show where to glue the straws. The vehicles built in this activity probably will look like the one shown in Figure 5. However, students may choose to support each axle with several short straw pieces instead of one long straw, as in Figure 7. This design is much more

Figure 7



difficult to build, since the short pieces must be lined up and the glue must be kept out of the inside of the straws, where it would rub on the axles.

The straw must be glued along its entire length to the cardboard without any glue getting inside the straw. As discussed in Activity 1, the best gluing technique is to pick up glue on the end of the glue stick and wipe it along the straw to lay down a smooth, unbroken layer of glue. Then students simply press the straw into place. It is probably a good idea to draw a line to show where the straw will fasten to the card stock, since moving the straw once it has been glued in place will weaken the bond.

For materials management, set aside the straw pieces leftover when you cut the 10 ½" pieces. The leftover piece is 5 ¼", just the length needed to support one axle. If students need to start over, you can give them two of these leftover pieces, and they can use the second piece of card stock that they cut in Step 3.

In Step 14 above, when you ask the students what parts of their vehicles need improvement, they may well respond with a list of items that could be added, such as motor, steering, body, and so on. These indeed are part of most vehicles. But try to focus the discussion on how well the students' vehicles work as rolling platforms. In this sense, the most important improvements are probably to improve the connection of the wheels to the axles (Activity 3), to reduce friction (Activity 4), to brace the body (Activity 5), and to add power (Activities 7 through 9).

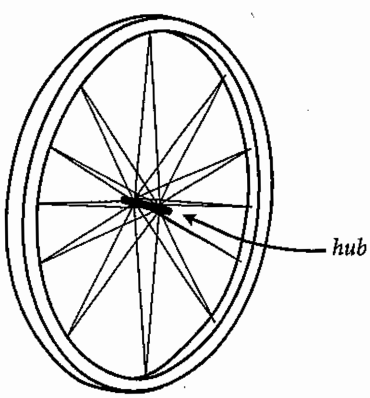
Activity 3: Building Hubs

Overview
Students discuss possible ways to improve the connection between the wheels and axles on their vehicles and then examine the hubs on a bicycle and a wagon. Students build up hubs by gluing small pieces of straw between two wheels to form a sandwich. Then they compare and contrast the wheel-axle connection with and without the hubs.

Time Required: one and a half class periods

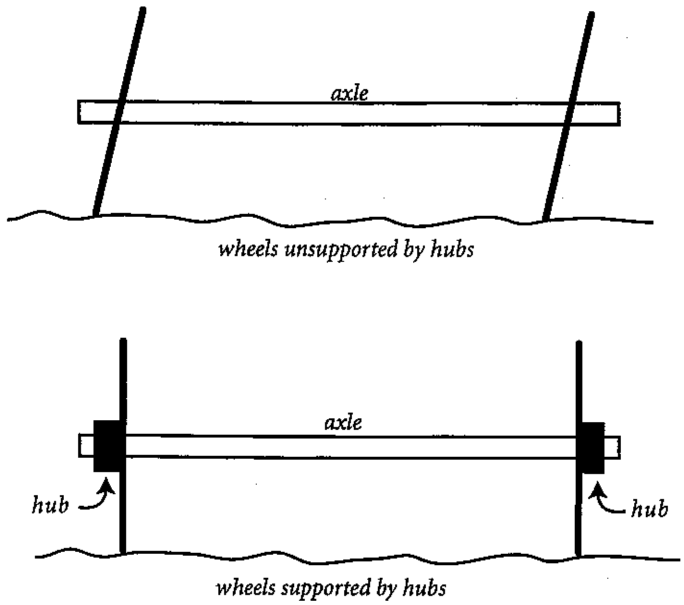
Background
One of the great challenges of designing a structure or machine is connecting one part to another. Often the connections weight as much as the separate parts themselves and are bulky and cumbersome as well. For the wheel and axle, the connection is called the *hub*. The hub must be strong, because the weight of the car and the force from the motor and brakes are applied to this connection. Figure 1 shows the hub of a bicycle wheel, which is typically about ten centimeters wide.

Figure 1



Since the axle supports the wheel everywhere inside the hub, the connection is very strong. Contrast the bicycle wheel with the thin cardboard wheels that students mounted on axles in Activity 2. The cardboard wheels have no hubs and easily twist so they are no longer perpendicular to the axles. Figure 2 shows wheels both with and without hubs.

Figure 2



Think of the wheel as a lever, with its pivot at the axle. If the wheel is thin and there is no hub, the wheel cannot resist a twisting force, and the wheel can be ripped right off the axle. The solution to this problem is to build a hub, shown in the lower drawing in Figure 2. See also Steps 2 through 4 of this activity.

Vocabulary
hub

Materials:
kit materials for each group

vehicle from Activity 2
paper straw piece, 12" long (can be several smaller pieces)
4 small cardboard wheels, 3.8 cm (1 ½") diameter
glue cup and gluing stick
corrugated cardboard piece, 12" x 15"

classroom materials for each group

ruler
scissors
white glue
old newspapers
piece of paper towel
unsharpened pencil

other materials

bicycle (or bicycle wheel) and wagon

Preparation

Cover the students' work surfaces with old newspapers and set out a piece of paper towel for each group so students can wipe up any excess glue. If possible, have the groups use scrap pieces of straw. Add glue to the glue cups to a depth of about 1 cm.

Procedure

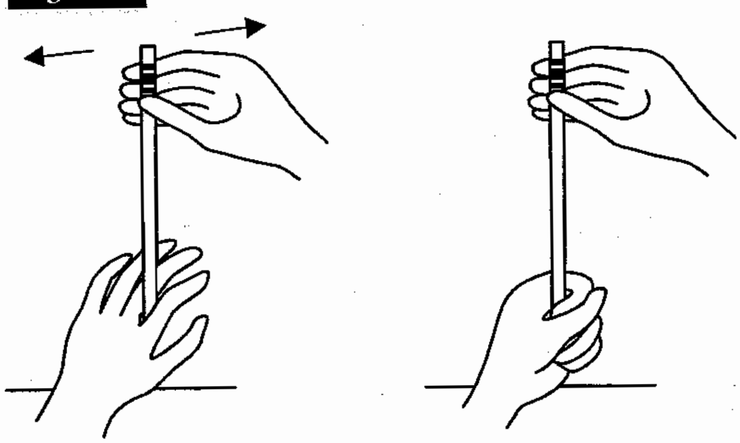
1. Hold up a wheel and axle. Ask the students if the connection between the axle and the wheel is strong or weak. Have students explain their answer. Explain that the word for the connection of the wheel and axle is *hub*.

With their hands and an unsharpened pencil, students make a model of the wheel, axle, and hub.

2. Hold up the wheel and axle the axle. Ask if moving (wiggling) the wheel could damage the wheel-axle connection (Yes).

3. Have students place one hand flat on the table and place an *unsharpened* pencil between two fingers, as shown in Figure 3. Ask them to wiggle the top of the pencil back and forth (move that end from side to side) with one hand and to try to stop the pencil from wiggling with the other hand. Ask what happens. (It is impossible to stop the pencil from wiggling.)

Figure 3



the hand is flat on the table

the fist gripping the pencil is a model of how the hub holds the wheel and axle together

4. Now have students make a *fist* on the table. Have them stick the pencil into their fist, all the way down to the table, and try to wiggle the pencil, as also shown in Figure 3. Ask if the fist can prevent the pencil from wiggling (yes). Explain that the fist is like the hub of a wheel and the pencil is like the axle.

Since the fist grips the pencil much farther up from the pivot (where the pencil touches the table) than does the flat hand, the fist has a bigger lever arm than does the flat hand and can prevent the pencil from moving.

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5. Show students the wagon and bicycle wheels. Ask how the design of the wagon and bicycle prevents the wheels from being twisted off.

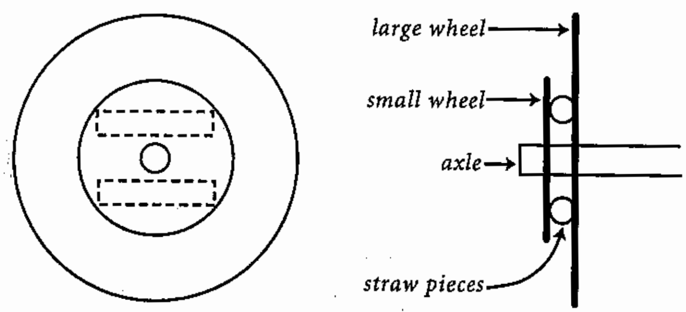
6. Discuss how students could build something similar on their models. (They can make the connection between the wheel and axle thicker. See Figure 4 below.)

7. Hand out the materials. Have the students *gently* remove the wheels from their vehicles and separate the wheels from the axles.

Students discuss how to build hubs.

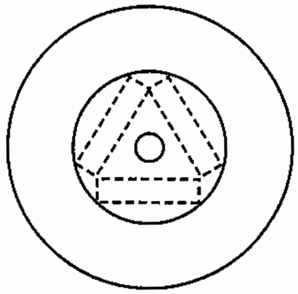
8. Discuss how students could use the small wheels and straw pieces to build a hub. Explain that they can sandwich the straws between the large and small wheel, so the middle of the wheel becomes thicker, and glue the whole sandwich together. One possible arrangement is shown in Figure 4.

Figure 4



Students can certainly use three small straw pieces, arranged in a triangle, instead of two parallel pieces, as shown in Figure 5.

Figure 5

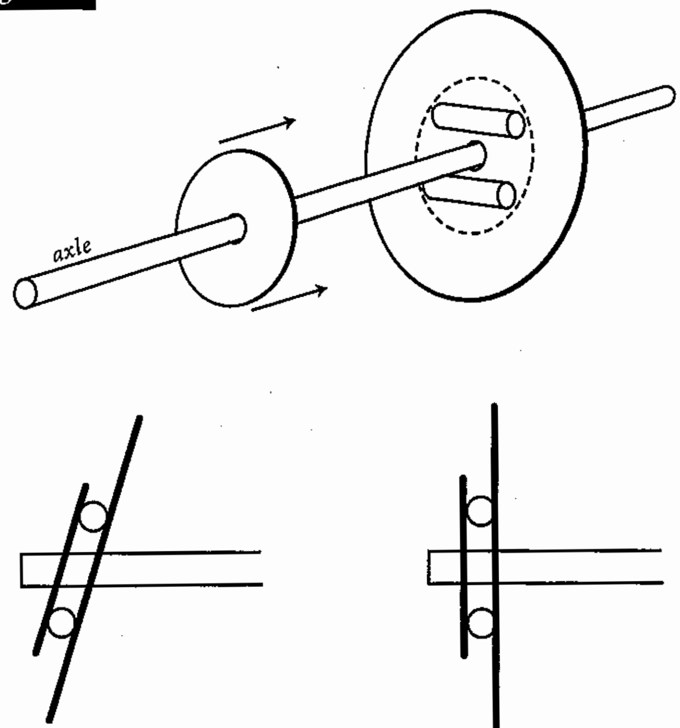


9. Suggest that as a first step, they lay the small wheel over the large wheel and trace the outline of the small wheel. Add that the trace is a circle, and all straw pieces can lie inside this circle, as in Figures 4 and 5.

Students build one compete hub first. Then they build the remaining three.

10. Suggest that students make one *complete* hub first, to be sure that they can make one that will work. Add that the holes in the large and small wheel must line up. Discuss how they can do this. (First glue the straw pieces to one wheel. Then push that wheel onto an axle. When they are ready to glue the sandwich together, they can push the other wheel on the axle, as shown in Figure 6. They also must make sure that both wheels are perpendicular to the axle, as also shown in Figure 6. Also, they must be sure to get no glue on the axle.)

Figure 6



11. Have students make the other three hubs. When they are finished, have them clean up and wash out the glue cups.

12. After the glue has dried, ask the students how the hub has changed the way the wheel and axle connection works. (The hub holds the wheel so it is perpendicular to the axle.). Have the students begin a description of vehicle improvements and include the results of this activity.

13. Hand out the cardboard ramps. Ask students to compare the inside of their hubs with the inside of the corrugated cardboard ramp (Both are thick, but mostly air inside; both have walls inside; both are strong).

Teaching Notes
As mentioned above, suggest that students complete one hub before making the rest (to conserve materials if something goes wrong). Suggest that they take care not to get glue on the axle.

Extension
Ask students to identify a vehicle with hubs and make a labeled drawing of the axle, hub, and wheel.

Activity 4: Friction and Wheels

Overview
To investigate the effect of wheels, students remove the vehicle's wheels and place the vehicle's body on the ramp. Students then raise one end of the ramp until the body just begins to *slide* downhill. For comparison, they reinstall the wheels, place the vehicle on the ramp, and raise one end until the vehicle just begins to *roll* downhill. Then they minimize friction to meet a design requirement on how far the vehicle rolls.

Time Required: two class periods

Background
Friction is the force that opposes motion. It occurs whenever one substance rubs against another. Both substances can be solids, like two steel parts turning in an auto engine. One can be a solid and one a liquid, like a submarine moving through water. One can be a solid and the other a gas, like a parachute falling through air. For a parachutist, air friction is a good thing, since it provides the force that slows the parachutist's descent. In fact, friction is helpful to everyone. We cannot walk unless we have enough friction between our shoes and the floor. We cannot drive unless there is enough friction between the tires and the road to push the car ahead, and we cannot stop the car without the friction in the brake pads. Without friction we couldn't even hold a pencil.

Nevertheless, friction slows motion and wastes energy. A race car is slowed by air friction, a sled is slowed by friction between its runners and the snow, and an automobile is slowed by friction between its moving parts. In fact, reducing friction is the purpose of the wheel. Imagine dragging a heavy object over the ground. The whole surface of the object is in contact with the ground, so there is substantial friction. Contrast that with loading the object on a wagon. Now as the wagon moves, the wheels and axles turn. Friction is confined to the much smaller surface where the outside of the axle turns in its housing. There is much less friction between two smooth pieces of metal than between the underside of the object and the ground. Moreover, the metal can be lubricated, which reduces friction even more.

A vehicle's axles ride in cylindrical housings called *bushings*. The bushings are fastened to the *frame*. For the students' vehicles, the paper straws are the bushings, and the frame is the card stock and the straws glued to it. If the wheels should rub against the frame, the friction can bring the vehicle's motion to a halt. Since the wheel pivots on the axle, this rubbing acts like a lever, and the further the rubbing is from the axle, the greater its twisting, or torque, on the wheel and axle and the greater the slowing of the vehicle. To minimize the effect of this kind of friction, the wheels are mounted so they cannot touch the frame, as shown in Figure 1.

Figure 1

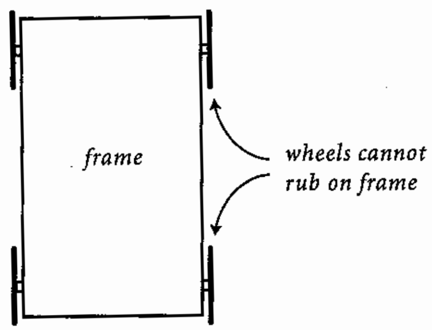
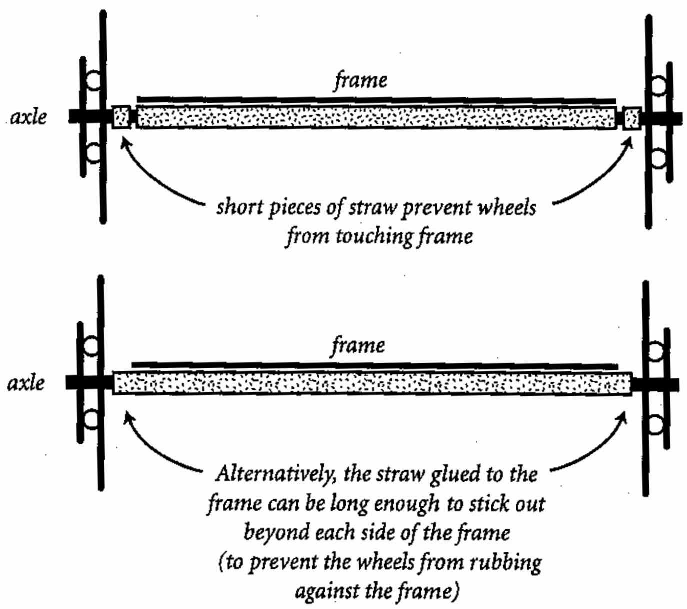


Figure 2 shows two different designs that prevent the wheels from rubbing on the frame.

Figure 2



Of the two designs above, the one shown in the lower drawing has a disadvantage, because the exposed ends of the long straw are easily bent and add substantial friction if they rub against the axle. In the other design, where short straw pieces shim the wheels away from the frame, any such wear-and-tear takes place on the short straw pieces, which are easily replaced.

Vocabulary
friction

Materials
Kit materials for each group:
vehicles from Activity 3
cardboard ramp

Classroom materials for each group:
protractor
masking tape strip, 10 cm

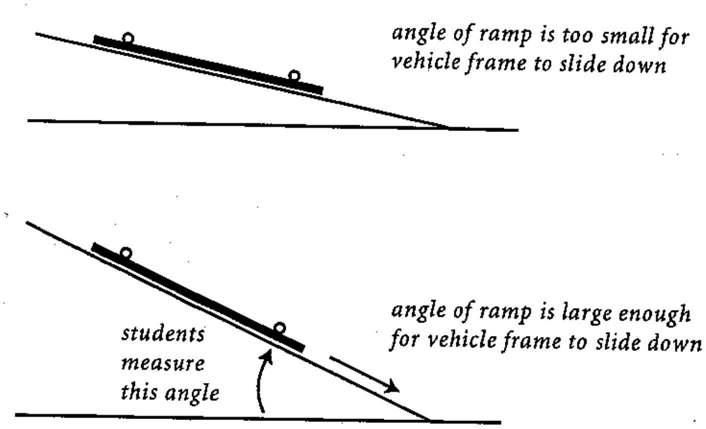
Preparation
Cut the 10 cm masking tape strips.

Procedure
1. Ask students to tell what they know about friction.

2. Have students place their fingertips on the cardboard ramp and slide their hand back and forth, without pressing down. Explain that they have experienced the force of friction, which occurs whenever one moving object touches another. Add that friction slows down the moving object.

3. Give each group its cardboard ramp, protractor, and masking tape strip. Have students carefully remove the wheels from their vehicle. Explain that the card stock and straw bracing is called the *frame*. Have students lay the ramps flat on the floor or tabletop and tape the bottom in place so the ramp will not slide. Explain that they will place their frames (without the wheels) on the ramp. They will then tilt one end of the ramp up until the model *just* begins to slide downhill, as shown in Figure 3. They will then measure the angle between the ramp and the floor.

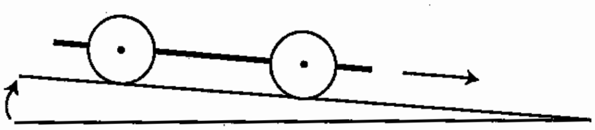
Figure 3



4. Have students make the measurement described in Step 3 and record the results. (To make the frame begin to slide, the ramp must be tilted to an angle of about 25°.) Discuss what happened.

5. Have students make and record a prediction for performing the same experiment but with the wheels in place, as shown in Figure 4. Then have students carefully reinstall the wheels and make the measurements described in Step 3, but with wheels on the vehicle. Be sure they record the results.

Figure 4



angle of ramp is large enough for vehicle with wheels to roll down

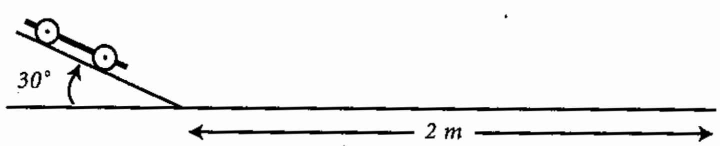
6. Have students compare and contrast the results with and without wheels. (With wheels, the ramp must be tilted to an angle of only about 3°—quite an improvement!) What can they conclude? (Wheels provide a remarkable reduction in friction.)

For the rest of the activity, students need to set up their ramps on an uncarpeted floor.

7. Explain that students will test their vehicles to meet a design requirement related to friction. The design requirement is the following, which is also shown in Figure 5:

The vehicle must roll down a ramp tilted at 30 degrees and then roll at least 2 meters across the floor.

Figure 5

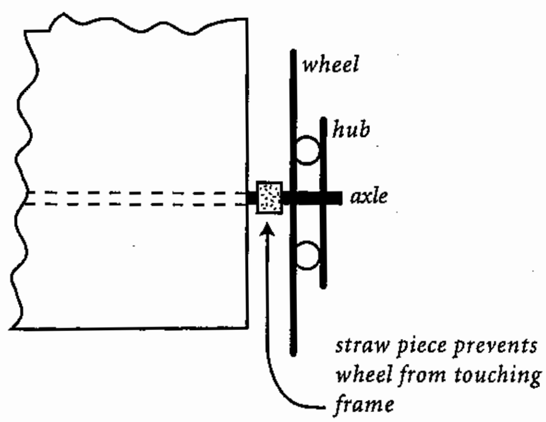


At this point, some vehicle may roll further than others, depending on whether or not the wheels can rub against the frame. With the wheels shimmed out as shown in Figure 6, all vehicles should easily meet the design requirement.

8. Have students hold the vehicle in their hands and spin the wheels by twisting the axles. (In a well-made vehicle, the wheels will spin for several seconds.) Ask students to think about where parts of the vehicle rub together as the vehicle rolls. Help students recognize that the wheels may rub against the side of the frame. Ask students how they could prevent this rubbing (by keeping the wheel out away from the frame).

9. Ask students how they could keep the wheels out away from the frame (by adding short pieces of straw on the axle between the frame and the wheels). Have students add these pieces if necessary, which need be only about one-half centimeter long, as shown in Figure 6.

Figure 6



If students already built their vehicles with the straws sticking out just beyond the edge of the frame, as in the second drawing in Figure 2, then they have no need to add these short straw pieces. However, if the ends of the straws stick out like this, they are easily damaged. Since the short pieces are easily replaced, the optimal design is to bring the straw bushings out flush with the edge of the frame, as shown in the upper drawing in Figure 2.

10. Have students test their vehicles to meet the design requirement and redesign and retest as needed. Ask students to record the changes they have made to their vehicles and the results of the tests they have performed.

11. Have students discuss friction and how they minimized it in their vehicles to meet the design requirement.

2. Ask students to prepare a written or oral presentation on the invention of the wheel and axle. Suggest they do library research to learn about where, when, and how it was invented. Encourage them to use their imaginations to show how and why this discovery would change everyday life.

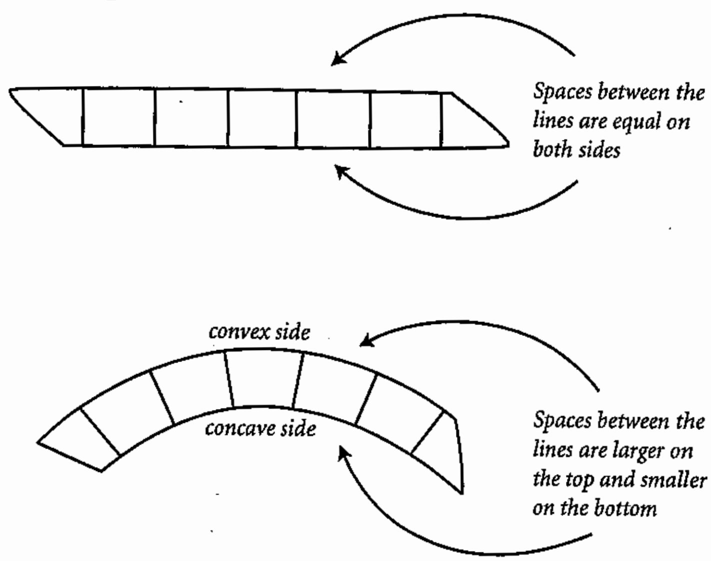
Activity 5: Carrying a Load

Overview
Students modify their vehicle to carry a load of two washers. A design requirement specifies the maximum amount the vehicle can flex when carrying this load. Students brace the vehicles by gluing paper straws to the cardboard frame and then test their vehicles to see if they meet the design requirement. Later, in Activity 9, students will add two washers to their vehicles to investigate how the load affects the distance the powered vehicle travels.

Time Required: one to one and a half class periods

Background
Your students may have noticed that the frame is much stiffer around the straw bearings, and if additional straw pieces are glued in place, the whole frame can be made even stronger. These straws are beams. When a horizontal beam bends, the upper half elongates and the lower half shortens. You can easily demonstrate this with a rubber eraser by drawing lines, about 1 cm apart, perpendicular to the large sides, as shown in Figure 1. If you flex the eraser, you will see that

Figure 1



the distance between the lines increases on the convex side (the top, here) and decreases on the concave side (the bottom, here), as also shown in Figure 1. This observation shows that the convex side of the eraser has stretched, the convex side has contracted, and there is no change in the length down the center.

Now consider the straw as a beam. The only material in the straw is far from the center, out where the stretching and contraction are greatest. The paper material resists these changes, especially stretching, and in fact a 10 cm paper straw can support about 1000 times its own weight.

Vocabulary
brace, bracing

Materials
Kit materials for each group
vehicle from Activity 4
1 paper straw
2 washers
glue cup and gluing stick
small paper rectangle from Activity 1
small piece of copy paper (for paper tent)

Classroom materials for each group
white glue
scissors
ruler
old newspapers
piece of paper towel

Preparation
Cover the students' work surfaces with old newspapers and set out a piece of paper towel for each group so students can wipe up any excess glue. Students made the small paper rectangle in Activity 1 to practice gluing straws to paper. This piece is recycled here to save time and materials, but students can make another if they have lost the original. Pour glue into each group's glue cup to a depth of about one centimeter.

Procedure
1. Ask students for examples of vehicles carry a load. (All vehicles carry loads.)

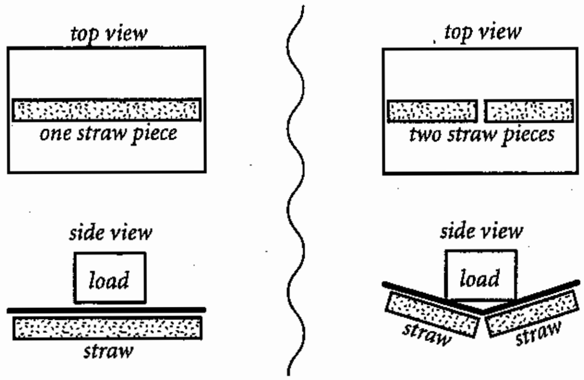
2. Ask how the straws glued to the vehicle's frame affect the stiffness of the frame. (Where the straws were glued, the frame became stiffer.) Ask how they might stiffen the whole frame in the same way (by gluing straw pieces in other places). You can add that the straws are *bracing* and that the straws *brace* the frame.

In the next step, students practice bracing the small rectangle of copy paper.

3. Explain that for practice, students will first brace a 3 cm *x* 6 cm piece of paper. You can add that engineers make small samples of a construction to try out a new material or a new way to fasten the parts together. Have each group find the small rectangle, with two straws glued to it, made in Activity 1. Ask students to gently bend this construction to see where it most needs bracing. Then have them cut a few small straw pieces and glue them in place to brace this small construction.

4. Discuss the results. How could students tell if the construction became stiffer? (It seems to bend much less than before. You can add that it would of course be better to find a way to *measure* the stiffness.) Ask students to compare and contrast the effectiveness of bracing with one long piece and bracing with two shorter pieces end-to-end, as shown in Figure 2. (Bracing with one long piece is far more effective, since the construction can bend where the short pieces meet.)

Figure 2



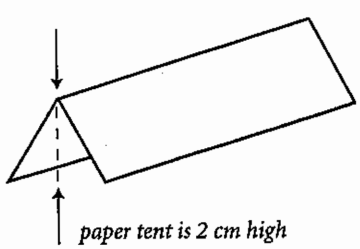
5. Getting back to the students' vehicles, explain that students will brace them to carry a load of two washers. Add that the materials for bracing are a paper straw and glue. On the board, write the requirement:

- *The vehicle must be able support a load of 2 washers.*
- *When loaded, the vehicle must clear the ground by at least 2 cm.*

Have students copy the requirement.

6. Suggest that students build a 2 cm-high paper stand, so they can easily evaluate their vehicle by rolling it over the stand. One possible design for the stand is a paper tent, as shown in Figure 3.

Figure 3

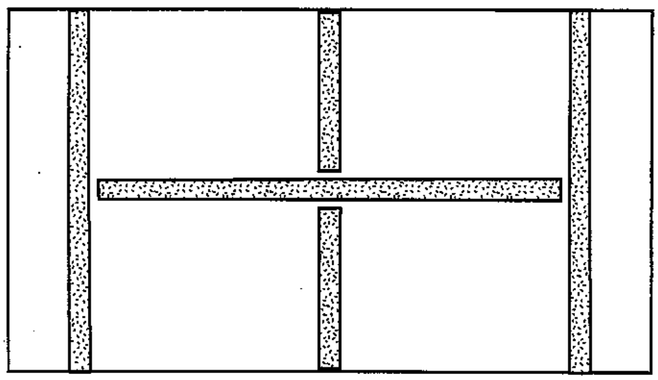


7. Hand out the rest of the materials and ask each group to get its vehicle. Have each group place two washers in the middle of the vehicle frame. Discuss what happens. (The middle of the vehicle sags to the ground.)

In Steps 8 and 9, if students put the bracing on the same side of the frame as the straws that hold the axles, then the other side, which will become the top, will remain flat. That will facilitate the installation of the balloon mount in Activity 8.

8. Ask students to gently remove the wheels and axles, so they will not be accidentally glued to the paper straws. Have students place their vehicle frames on the table with the straw pieces facing up. Have students brace the frame just as they braced the small construction in the beginning of the activity. For an example of bracing, see Figure 4.

Figure 4



9. While the glue is drying, have students record how their vehicle was braced and also make a drawing of their vehicle's frame. Suggest that they make a top or bottom view, which is what they see when they look right down on the frame, like the view shown in Figure 4.

10. Have students discuss how they braced their vehicles.

11. When the glue is dry, ask each group to test its vehicle by adding the load of two washers and observing if the vehicle can pass over the 2 cm stand. Have students record the results.

12. Discuss examples of objects that have bracing (corrugated roofs, corrugated cardboard, and the sides of railroad cars, for example).

13. Have students clean up and wash out the glue cups.

Teaching Suggestions

The straws are so strong that many different bracing designs are possible. Remember that the bracing goes on the same side of the frame as the straws that support the axles, so all straw pieces are on one side and the other side is flat.

If a wheel on a vehicle begins to slide back and forth on the axle (and the wheel may even fall off) because the hole for the axle has enlarged, suggest that students hold the wheel in place by applying one or more small pieces of tape where the end of the axle comes through the outside of the wheel.

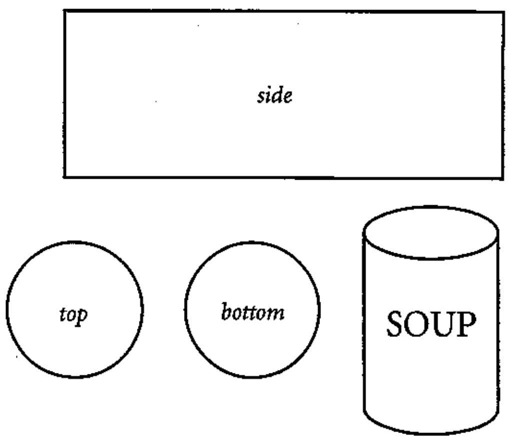
Activity 6: Making 3-D Structures from Flat Materials

Overview
Students discuss how to mount a balloon on their vehicle. To make a simple three-dimensional structure, they make a box from a sheet of paper, following an engineering process called *development.* They first draw a full-size plan on the sheet. Then they cut the paper, fold it to make it three-dimensional, and tape together pairs of sides to make the box. Students discuss how this kind of construction could be used to make a balloon mount.

Time Required: one class period

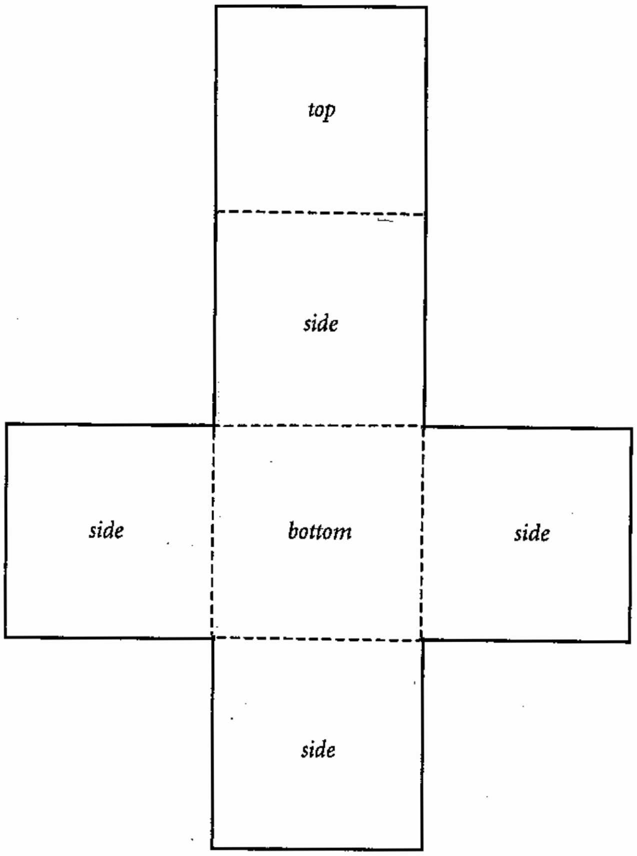
Background
Many objects are fabricated from flat material. The ubiquitous tin can is made from three pieces of metal, two circles and one rectangle, as shown in Figure 1. The rectangle is rolled into a cylinder and the top and bottom are attached.

Figure 1



A different kind of construction is shown in Figure 2, the plan for a cube. Here the cut material is folded along the dashed lines and pairs of sides are fastened together.

Figure 2



Pull open the drawers of a filing cabinet and you will see how the steel sheet has been bent to form the body and drawers. Plans for such objects are relatively easy to draw, since the plans and the materials are flat. Sometimes plans can be full-size, facilitating visualization of the finished product. In this activity students draw a full-size plan on paper, cut out the paper, fold it, and then fasten it together to make a box.

Materials

For each group

- copy paper, one sheet
- cellophane tape strip, 12 cm
- ruler
- scissors

For the class

- 2 copy paper boxes, one opened up into a flat sheet of cardboard
- meter stick

Preparation
Find two copy paper boxes. (Tops are optional). Gently pull apart the ends of one of the boxes, and flatten the cardboard. No glue is used in this activity, so there is no need to cover tables with newspaper. Also, have some extra copy paper on hand for students who need to start over.

Procedure

1. Hold up a vehicle. Ask how to attach the balloon. (This is a difficult question; some students may say "Use tape," which indeed will work, but the balloon would have to be taped in place each time it was blown up. Explain that a better approach would be to add a construction to the vehicle to support the balloon.)

2. Explain that to learn how to build a construction from the card stock, students will first examine a cardboard box. Show students the copy paper box and ask them to try to figure out how it is made.

3. Now show students the box that has been opened up into a flat piece of cardboard. Have some students refold it and show the class. Discuss how the box was made. (The cardboard was cut, folded, and the ends glued together.)

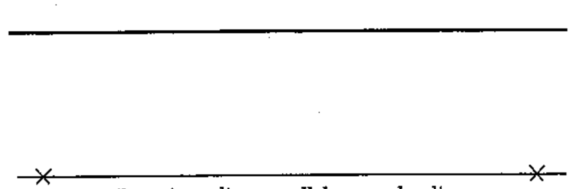
4. Point out that a flat sheet of cardboard is two-dimensional (with both width and length), whereas a box is three-dimensional (with length, width, and depth). Ask students how they could build a box from a piece of paper.

5. Hand out the copy paper and the copy of the Box Plan blackline master. Sketch the drawing from the blackline master on the board and go over the length of each side. Explain that the plan is not full-size, but students will draw a full-size plan on a sheet of copy paper and then cut out the paper according to the plan.

6. Point out that students will fold the paper along the dashed lines on the plan. Discuss which sides will be taped together.

7. To help students draw the full-size plan, show them how to construct parallel lines. Draw a straight line on the board. Ask students how to draw another line parallel to the first line and separated from it by 50 cm. Explain that the best way is to make marks at a distance of 50 cm near each end of the line and then place a ruler over the marks to connect them with a straight line, as shown in Figure 3.

Figure 3

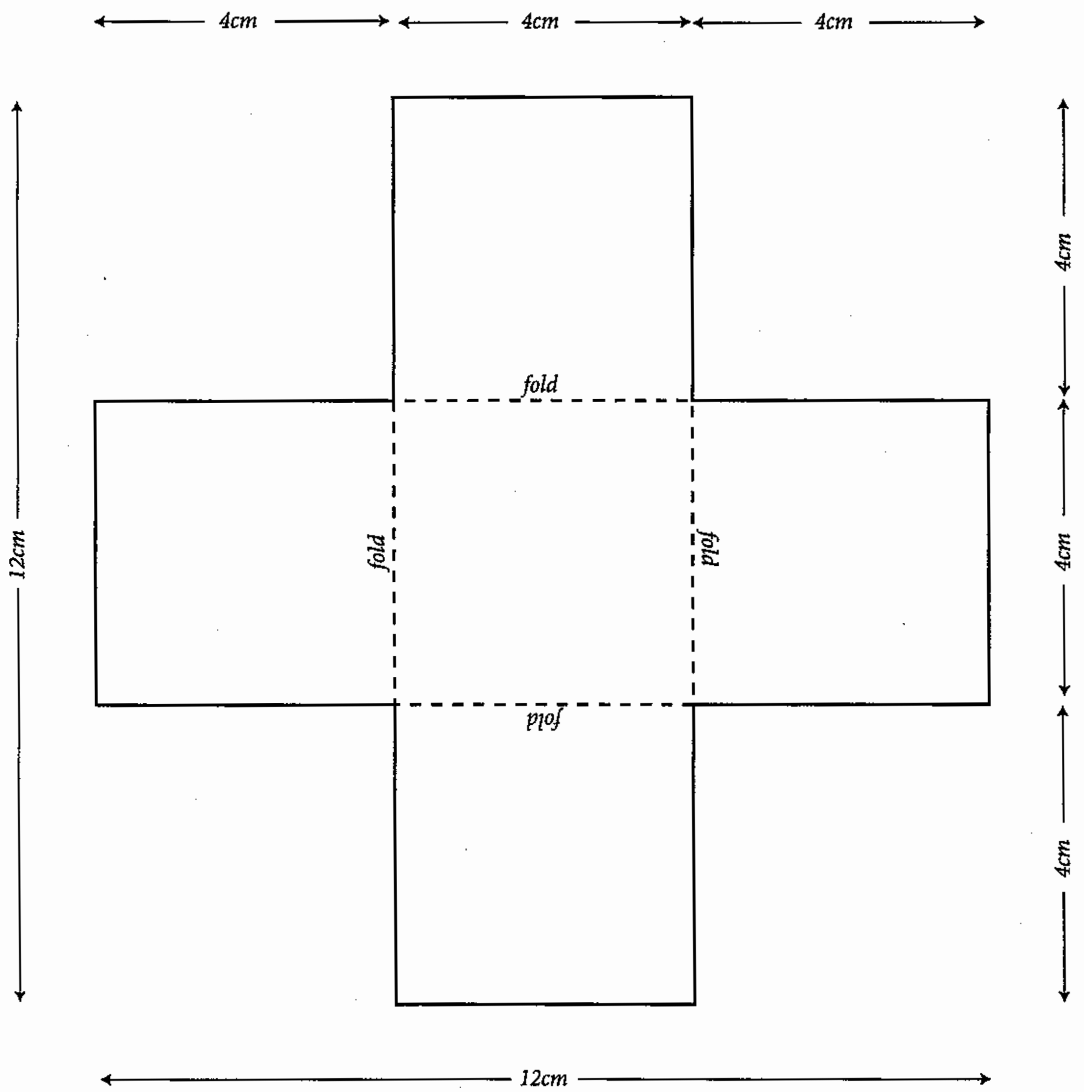


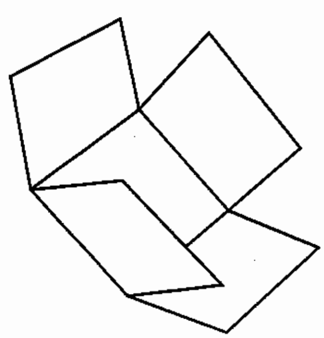
Drawing a line parallel to another line

8. Have students draw the full-size plan on the sheet of copy paper. When each group has drawn a correct plan, give that group scissors and tape so students can cut out the paper and tape the box together. To help students visualize the box, point out the two drawings at the bottom of the blackline master.

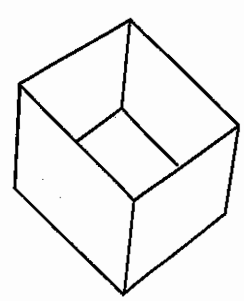
9. Collect the materials and have each group keep its paper box. Ask students to look around for other objects, besides the cardboard box, that are formed by folding flat material (for example, filing cabinets, heating ducts, metal cases for electrical equipment, metal picture frames, downspouts, lockers)

10. Ask students how cutting and folding flat material, as they did in this activity, might be used to mount a balloon on their vehicles.





paper cut and folded



paper folded and taped into a box

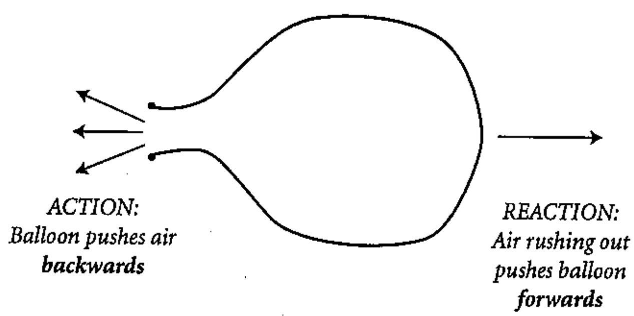
Activity 7: The Balloon Mount, in Paper

Overview
Students discuss action-reaction forces and how a balloon can power their vehicles. They adapt the box design from Activity 6 to make a mount for the balloon by drawing a full-size plan and then, for practice, build the mount in paper. They cut out the paper according to their plan, fold it to make a 3-dimensional structure, and tape together pairs of sides to make the balloon mount. With this experience, in the next activity students make the mount with card stock and fasten it to their model.

Time Required: two class periods

Background
As you blow up a balloon and let it go, the balloon leaves your hand and moves. Since the balloon starts at rest and them moves, some force acts on it. That force comes from the gas that rushes out. As you inflate the balloon, its material stretches and creates an inward force that balances the outward push of the gas inside. When you release the balloon, the stretched material pushes the gas back out, as shown in Figure 1.

Figure 1



According to Newton's third law, the principle of action-reaction, the gas that rushes out exerts an equal but opposite force on the balloon, which pushes it in the opposite direction. This is the same kind of force that pushes a canoe backwards if someone steps forward off the bow (the front).

As you can imagine, the force from the balloon on the air inside is small, so the reaction force on the model vehicle is small too. Newton's second law, $F = ma$, describes how an object with a mass m accelerates (changes speed) when it feels a force. Rewriting the equation as $a = F/m$ shows that this acceleration increases as the mass of the vehicle decreases. That's why the vehicles in this unit are ideal for balloon power, since their mass is so small. And in the real world, that's why race cars must be designed with as small a mass as possible, to produce the greatest acceleration from the force of the engine.

Materials

Kit materials for each group

constructed box from Activity 6
1 piece copy paper (8 ½" x 11")
copy of blackline master Balloon Mount Plan
copy of blackline master Full Size Balloon Mount (optional)
cellophane tape strip, 30 cm

Classroom materials for each group

scissors
ruler

Kit material for the class

1 hole punch
scrap piece of card stock

Preparation

Decide how much help your students will need to construct the balloon mount. If they need to work from a plan, make a copy for each group of the blackline master Balloon Mount Plan, found at the end of this activity. (The directions in this activity are for students using this plan.) If they need to trace a full-size outline of the plan, copy for each group the blackline master Full Size Balloon Mount.

Procedure

The next two steps introduce action-reaction forces.

1. Ask what pushes a rocket through the air. (The gases shooting out the back of the engine push the rocket forward; see Background.)

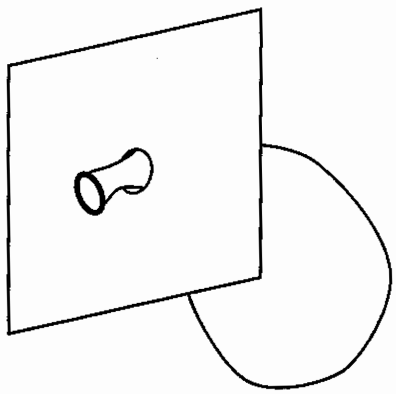
2. Blow up a balloon and hold it so everyone can see. Ask students to predict what will happen if you let it go, and then show what happens. Ask how a rocket is similar to a balloon. (Gases rush out the back of both. These gases push the balloon or rocket ahead.)

The next three steps introduce the challenge of fastening the balloon to the vehicle.

3. Hold up a vehicle and a piece of card stock. Point out that the opening of the balloon has a thick rim of rubber. Suggest that the rim could fit into a hole in a hole in a piece of card stock, which would hold the neck of the balloon in place.

4. Hold up the scrap piece of card stock, the hole punch, and the balloon. Punch a hole in the card stock. Push the balloon neck through the hole in the card stock, as shown in Figure 2. Ask students if this way of fastening the balloon in place could be used to make a balloon mount. (The piece of card stock holding the balloon can be mounted on the vehicle. This piece of card stock must be part of a three-dimensional structure, since it must hold the neck of the balloon above the frame.)

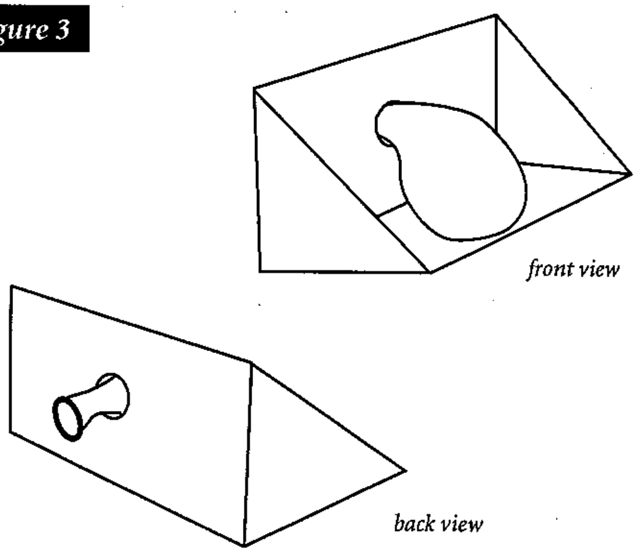
Figure 2



For the rest of this activity, students build a balloon mount with copy paper. In the next activity, they will build an identical mount in card stock and then brace it with paper straws.

5. Ask students to review how they made the box in Activity 6 by bending and folding paper. Explain that they will follow the same procedure to make the mount, as shown in Figure 3, and that they first will practice by making the mount with paper.

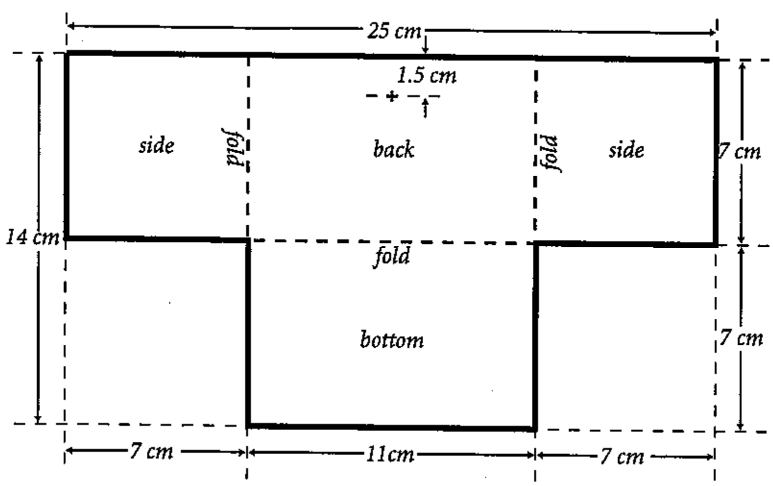
Figure 3



If your students can do it, challenge them to make their own design for the balloon mount. If your students need a ready-made plan, give each group a copy of the blackline master Balloon Mount Plan and lead them through Steps 6 through 9 below. If your students need a full-size drawing, give each group a copy of the blackline master Full Size Balloon Mount and have them cut it out and fold and tape it together.

6. Give each group a copy of the blackline master Balloon Mount Plan, which is shown below as Figure 4. Also give a sheet of copy paper to each group.

Figure 4

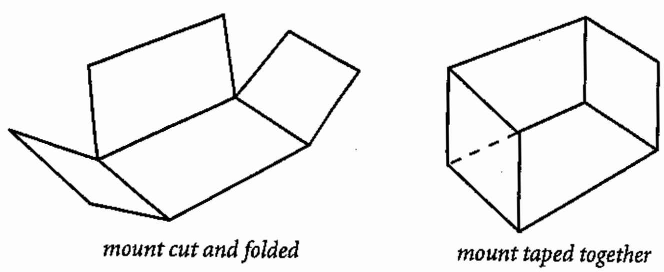


7. If necessary, draw the plan on the board and go over the length of each side with the students. Point out the small cross, which is the location of the hole for the balloon neck.

8. Ask students to review how they drew the plan in Activity 6. (They made marks at a certain distance near each end of the line and then placed a ruler over the marks to connect them with a straight line.)

9. Have students make a *full-size* drawing of the balloon mount on the piece of copy paper. Hand out scissors and the cellophane tape strip to each group. Have students cut out the plan and fold along the dashed lines, so the mount looks like the drawing on the left in Figure 5.

Figure 5

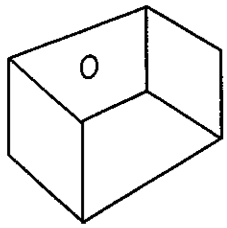


10. Have students tape the mount together so it looks like the drawing on the right in Figure 5.

In the next step, students practice punching a hole in the mount for the balloon neck.

11. When all groups have assembled the mounts, ask what else must be done (punching a hole for the neck of the balloon, as shown in Figure 6). Have the punch available so each group can use it when ready.

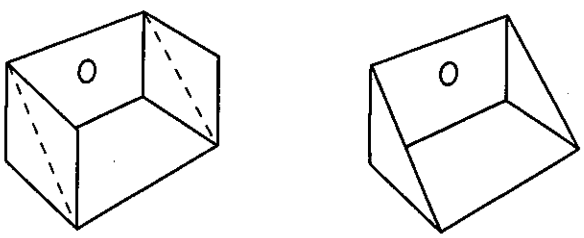
Figure 6



For safety, and to simplify the bracing to be applied in the next activity, students cut off the corners of the sides of the balloon mount. If students designed their own mounts, and there are exposed corners like the ones in Figure 6, have students cut those corners off.

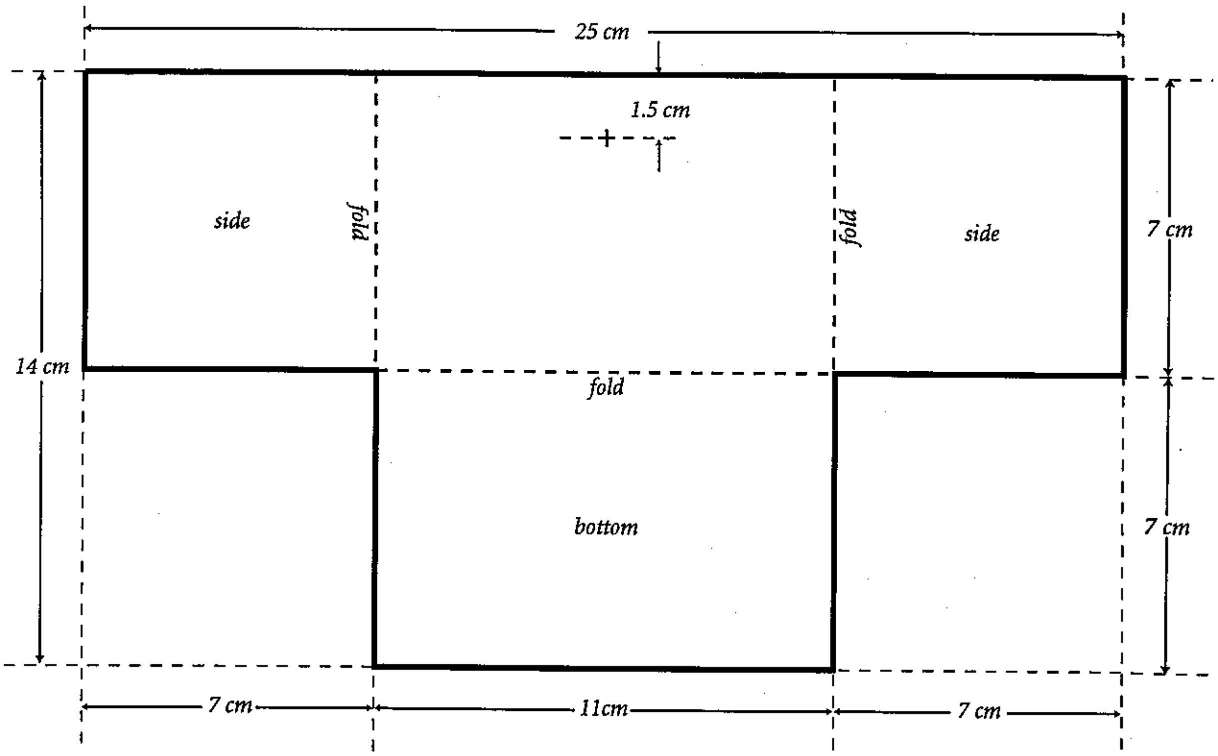
12. Explain that for safety, students must cut the corners off the sides of the balloon mount, as shown in Figure 7 below. Have them draw a line on each side to show where the cut will be. Check the line before they cut.

Figure 7

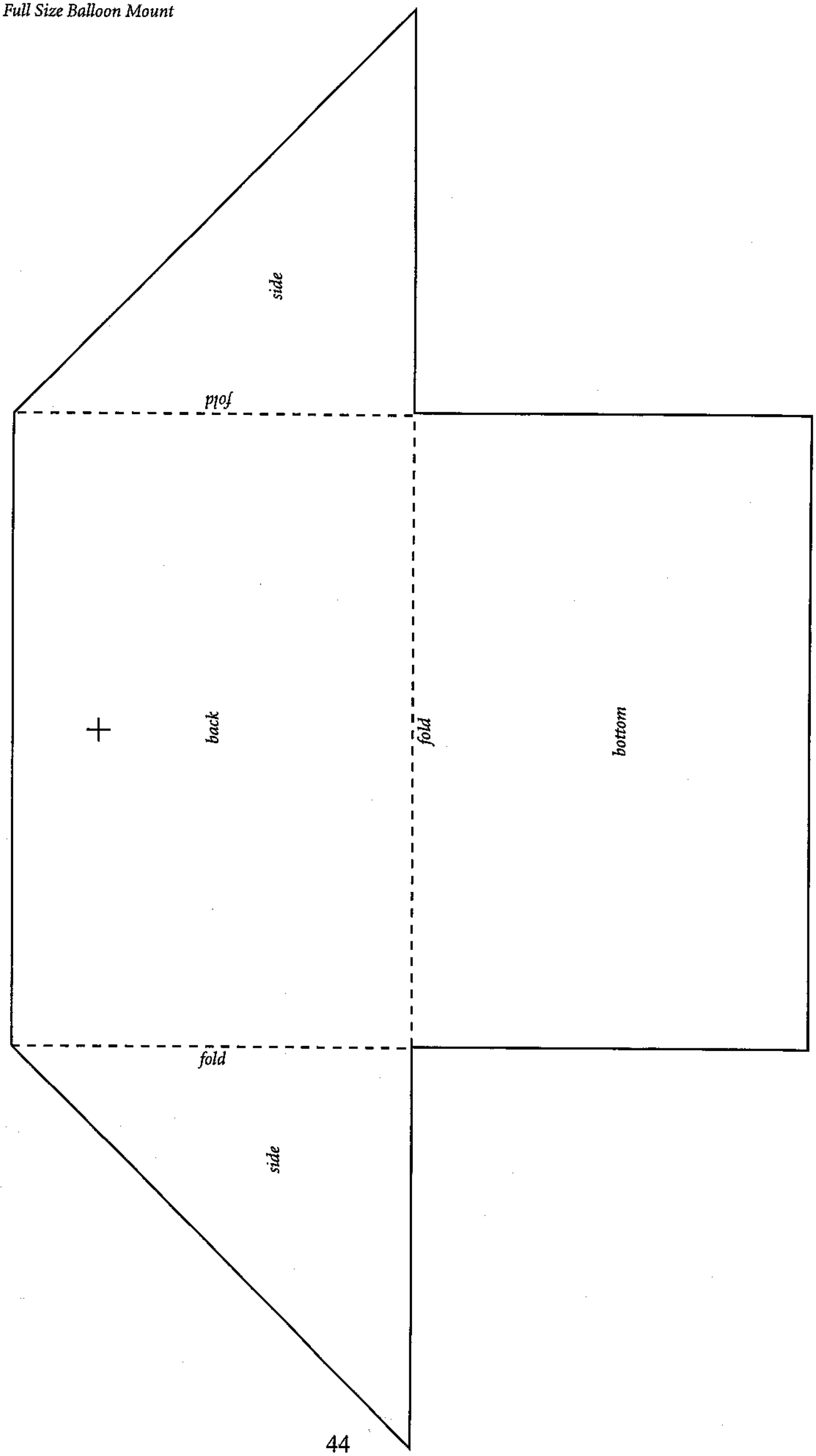


cut along dashed lines

13. Explain that in the next activity students will build an identical mount with the colored card stock, so each group should save its mount and its copy of Balloon Mount Plan.



25 cm
1.5 cm
side
fold
fold
side
7 cm
14 cm
fold
bottom
7 cm
7 cm
11cm
7 cm


side
fold
back
fold
bottom
fold
side

Activity 8: The Balloon Mount, in Card Stock

Overview
Having built a balloon mount in paper in Activity 7, students now build one in card stock and glue it in place on their vehicle. To stiffen the mount, they gently squeeze it to find out where it bends easily and then glue paper straw bracing at these places.

Time Required: one and a half class periods

Background
In this activity students must brace the balloon mount. First they gently flex it to see where it bends most easily—an example how a model provides a quick, inexpensive guide to effective design. Imagine building a full-size steel prototype, trying to flex that, and then adding steel bracing.

Materials
Kit materials for each group

1 piece card stock (8 ½" x 11")
copy of blackline master Balloon Mount Plan from Activity 7
copy of blackine master Full Size Balloon Mount from Activity 7 (optional)
constructed paper balloon mount from Activity 7
vehicle from Activity 5
glue cup and gluing stick
1 paper straw

Classroom materials for each group

scissors
ruler
old newspapers
piece of paper towel
white glue

Kit material for the class

1 hole punch

Preparation
Cover the students' work surfaces with old newspapers and set out a piece of paper towel for each group so students can wipe up any excess glue. If groups are using the Full Size Balloon Mount, make an additional copy of the blackline master for each group so students can cut out the plan and then trace it onto card stock. Add glue to each group's glue cup to a depth of about 1.5 cm.

Procedure
1. Have students review how they made the paper balloon mount in Activity 1.

2. Have students pick up their mounts. Explain that in this activity they will build the same mount in card stock, the same material they used for the frame of their vehicle. Ask if each group has its copy of Balloon Mount Plan, and give a replacement copy to any group that needs it.

If groups are working with Full Size Balloon Mount from Activity 7, be sure each group has a copy of that blackline master.

3. Hand out the materials and have students go to work building the mount.

4. When students are finished, including punching the hole for the balloon neck, have them make a drawing of their mount.

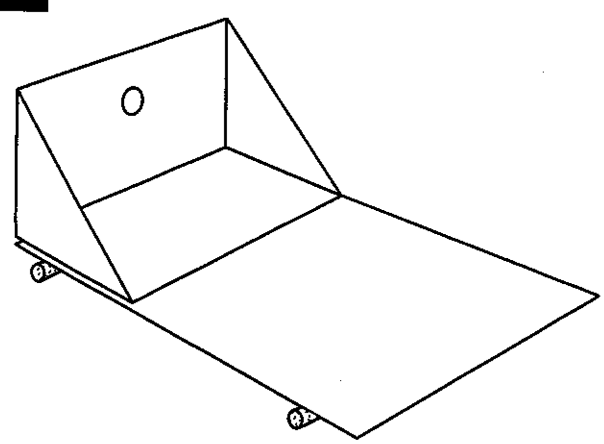
For safety, and to simplify the bracing, students cut the corners off the mount.

5. Remind students of how they cut the corners off the mounts they made in the last activity. Have students draw lines on their mounts to show where they will cut (just as they drew lines on the paper mounts in Activity 7). Have them cut off the corners.

Students glue the mounts to their vehicles.

6. Hand out the vehicles so students can glue the mounts in place. One location for the mount is shown in Figure 1. Remind them to apply the glue to one surface only and in a smooth, thin layer. While the glue is drying, have them make a drawing of the vehicle.

Figure 1

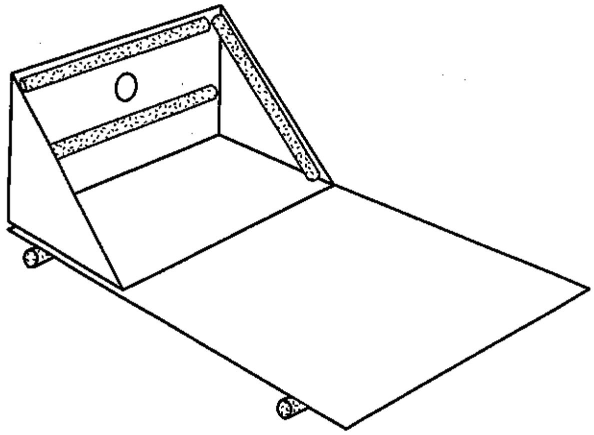


Students brace the mount by gluing paper straws in place. Since the vehicle frame is already braced, there is no need for students to add bracing to the bottom of the balloon mount.

7. Remind students of how they stiffened the frames of their vehicles in Activity 5. As students if they can think of a way to make their mounts stiffer (gluing pieces of straws to the mount to brace it). If necessary, also remind students of how they gently squeezed their frame to see where to add bracing.

8. Hand out one paper straw to each group. Have students squeeze their mounts, decide where to add paper straw bracing, and glue the bracing in place. One possible bracing plan is shown in Figure 2.

Figure 2



9. While the glue dries, have students make one or more drawings of their bracing. They may want to show a view from the side and also a view from the front.

10. Explain that in the next activity they will fit the balloon into the card stock mount and make their vehicle self-propelled.

Teaching Suggestions
In a class discussion of reaction forces, you may encounter the common misconception that the gas in the rocket is "pushing against the air." To help students overcome this misconception, you can point out that the rocket works perfectly well in outer space, where there is no atmosphere.

Activity 9: Balloon Power and the Effect of a Load

Overview
Students install the balloon and meet a design requirement that the powered vehicle go at least three meters. To insure that each group inflates the balloon the same amount, the class controls the diameter of the inflated balloon. Then students add different loads and observe the effect on the distance traveled.

Time Required: one to one and a half class periods

Background
The movement of a grocery cart is probably the best everyday example of the effect of mass on acceleration, as shown in Figure 1. The loaded cart, which has a large mass, is difficult to get moving and also difficult to stop, so it has a strong tendency to maintain its state of motion. This tendency is called inertia, and the greater the load, the greater the inertia. It takes a large force to start the loaded cart moving from rest. And once moving, a large force is required to stop it.

Figure 1

unloaded grocery cart requires only a small force to start and stop

loaded grocery cart requires a large force to start and stop

How objects change their motion when forces are applied is described by Newton's laws. The first states that in the absence of a net force, an object maintains its state of motion. The second describes how motion changes when a force is applied, through the famous equation F = ma, which can also be written a = F/m. This equation shows that the acceleration of an object when a force is applied is inversely proportional to the mass of the object. A large mass has a small acceleration, and vice versa, provided the force is kept constant. Keeping a variable constant is also called *controlling* that variable. For the balloon-powered vehicle, the force applied changes as the air rushes out of the balloon, so this force depends on time. At any time, this force depends on how much the balloon is inflated, so to find the effect of the vehicle's mass, the force variable must be *controlled* by inflating the balloon the same amount for each trial. When the vehicle is unloaded, its mass is the least, so its acceleration will be the greatest. The unloaded vehicle will reach a greater top speed and will go a greater distance than the vehicle carrying a load.

The difference between weight and mass is an important concept but need not enter the discussion of the results of this experiment. Mass expresses how much matter there is in an object. The mass of an object is the same anywhere, regardless of the force of gravity. The astronauts' masses did not change when they went to the moon. It is mass that enters into Newton's second law, so this law applies equally well on the moon. On the other hand, weight expresses the force of gravity. The astronauts' weights did change when they went to the moon, because the moon has much less gravity than Earth. The important relation is that mass and weight are proportional, so doubling the mass also doubles the weight.

Vocabulary
controlled variable

Materials
kit materials for each group

	vehicle from Activity 8
	balloon
2	washers
	graph paper (one sheet per student)

classroom materials for each group
meter stick

Preparation
You will need a hard-surfaced, uncarpeted area of about one meter by five meters for this activity, so you may have to move out into the hall.

Procedure
1. Ask students how far they expect their vehicle to move under balloon power. Explain that each group must designate one student to blow up the balloon (so germs won't be passed back and forth).

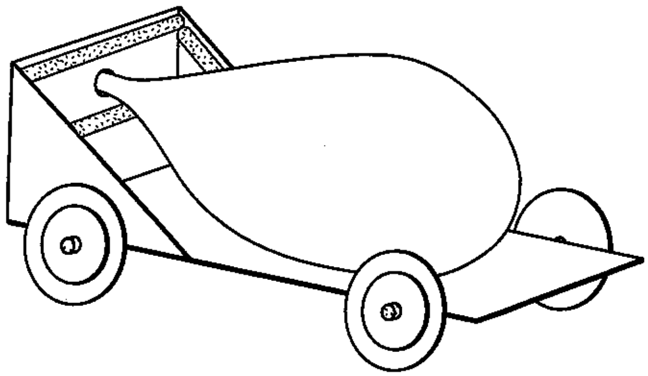
2. Write on the board the design requirement for the balloon-powered vehicle:

The model must move at least three meters under balloon power.

Have the students record the requirement.

3. Have each group pick up its vehicle and one balloon and then test their vehicles under power. With the balloon installed, the vehicle will look like the one in Figure 2.

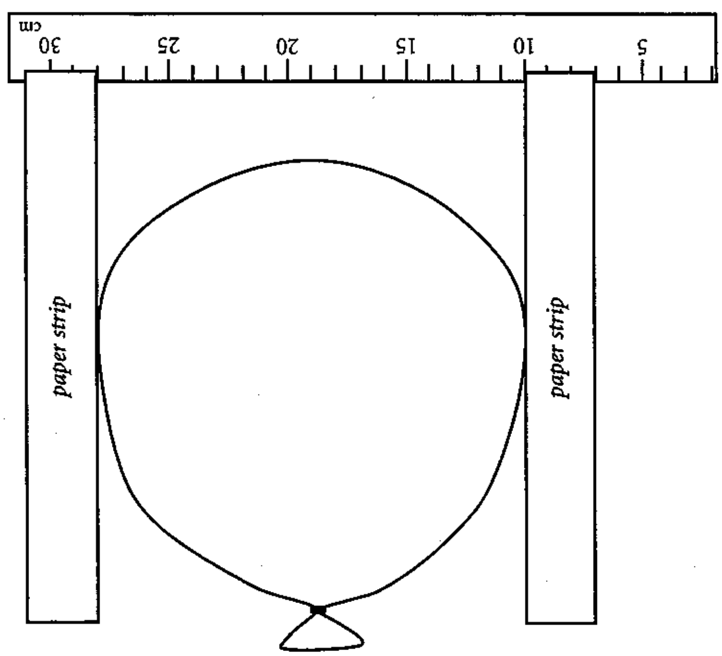
Figure 2



Step 4 refers to the balloon "diameter" even though the balloon is not a sphere.

4. When all groups have performed the test, discuss the results. Ask if the test is the same for each group (not necessarily, since some groups may have blown up the balloon more than others). Ask students to agree on a balloon diameter, as shown in Figure 3. A good diameter is 18 cm (about 7"). Discuss how students can measure this diameter. Suggest that one way is to cut two strips of paper and hang the strips from a ruler so the distance between the inner sides of the strips is 18 cm, as shown in Figure 3.

Figure 3



5. Have students repeat the test in Step 3 using the agreed-on balloon diameter and ask them to record the distance that their vehicle moves. Explain that they are controlling the variable of the balloon diameter so the test will be the same for all groups. Suggest that students make two or three trials and take the average of the distances traveled.

6. Remind students that in Activity 5 they added bracing so the vehicle would support a load of two washers. Ask students to predict what would happen to the distance their vehicle travels if they add a load of *one* washer. (The distance the vehicle travels will decrease. Let them wait until they have done the experiment to find out what will happen.)

7. Hand out the washers so students can measure the distance the loaded vehicle moves with balloon power. Have them use the agreed-on balloon diameter. Explain that this process is called *controlling* a variable (the force), so that any change in the result (the distance traveled) is due to the variable being investigated (the number of washers). Have them record their results. See Sample Data below.

8. Discuss what happens. Ask how the load affects the performance of real vehicles. (Heavy cars accelerate less than light cars, if their engines are the same size. For this reason, racing cars are built with a minimum of materials. Larger cars and trucks require larger engines.)

9. Ask students to write down a prediction for how far the vehicle will go with a load of *two* washers. Have them perform the experiment and record the results in a table. (See Sample Data.)

10. Discuss what happens. (As the load increases, the distance traveled decreases.) Ask students to make a general statement to summarize their results.

11. Have students draw a graph of distance traveled vs. load. Ask students what would happen if they add more than two washers. (The vehicle would go a shorter distance as the number of washers increases.)

12. Ask about the everyday example of pushing a grocery cart. What happens when they push an empty cart? (The cart requires only a small force to start and stop.) What happens when the cart is full? (The cart requires a large force to start or stop.) How is this related to their experiment with the different loads? (The vehicle speeds up the most, and goes the furthest, when it is unloaded.)

Teaching Suggestions

Measuring the diameter of the balloon is an interesting challenge in itself. Students can line up one end of a ruler with one side of the balloon and then move their eyes parallel to the ruler so they can line up the other side of the balloon in the same way. However, it is not easy to find the line of sight that is perpendicular to the balloon. The method suggested in Step 4 is probably the most reliable.

Sample Data

Number of washers	Distance traveled (cm)	Average distance traveled (cm)
0	373	371
0	368	
1	213	214
1	215	
2	152	156
2	160	

Activity 10: Reflecting on the Design Process

Overview
Students review the improvements they made to their vehicles in the course of the unit.

Time Required: one-half class period

Background
Here are the important improvements that the students made:

1. (Activity 3) To keep the wheels from tilting or wobbling, build hubs with straw pieces and small wheels.

2. (Activity 4) To minimize friction, prevent the wheels from rubbing on the frame, either by adding short pieces of straw to hold the wheels out or by extending the straw bearings out beyond the frame.

3. (Activity 5) To meet the requirement that the vehicle carry a load, add bracing by gluing paper straws to the frame.

4. (Activities 6 through 8) To hold the balloon neck, make a structure by bending or folding cardboard and then brace the structure by gluing paper straws in place.

Materials
vehicles
students' records of their work

Procedure
1. Explain to the students that they will now write a summary of the improvements they made to their vehicles. Ask them to give the effect of each improvement. Encourage them to make specific references to activities and results of experiments.

2. If you wish, collect the students' written work to use as an assessment.

3. Have the students discuss their improvements. Ask them how they tested their vehicles to see if their changes made their vehicles better.

Extensions
1. Have the students make a body for their vehicles out of colored paper or cellophane (or any other materials they wish to include). They can select a type of vehicle (such as sport-utility vehicle, ambulance, pick-up truck, race car) to make. Students can write an advertisement that promotes the engineering features of their vehicle.

2. Challenge students to make a vehicle frame from paper straws and copy paper (instead of card stock).

Assessments

1. Examine each student's description of vehicle improvements from Activity 10 to assess how well that student has synthesized the work of the unit. (See Background section for a list of changes to the vehicle.) Also, you can get a sense from the class discussion how well the class as a whole has understood the design concepts.

2. Give each student a copy of the blackline master Plan, a sheet of copy paper, and an 8 cm strip of cellophane tape. Tell students that they are to build what the plan shows (a tray). Decide how much help to give students by reviewing past activities, giving help with reading the plan, and making suggestions as students work.

Resources

1. Linx® System (a series of wooden construction sets available from The Science Source, Waldoboro, ME).

2. National Science Resources Center. *Motion and Design*. Burlington, NC: Carolina Biological Supply Company, 1997.

3. Salvadori, M. *Why Buildings Stand Up: The Strength of Architecture*. New York: Norton, 1990.

4. Zubrowski, B. *Wheels at Work: Building and Experimenting with Models of Machines*. New York: Morrow, 1986.