Bridges

Synopsis

Each student builds the lightest-weight bridge he or she can that spans a 24-inch space between two supports. The bridge must be made from simple materials and must be able to support a standard brick (about five pounds). In the process, students formulate the basic engineering principles of bridge design.

Objectives

This exercise provides students with an opportunity to use model-building as a way to help understand the forces and phenomena at work in the world around them. This process skill is a component of the Science as Inquiry strand of the *NC Standard Course of Study for Middle School Science*: "Mastery of integrated process skills: formulating models." Likewise, this exercise meets the *NSES Content Standard A (Science as Inquiry)* for levels 5-8, "Abilities Necessary to do Scientific Inquiry: develop descriptions, explanations, predictions, and models using evidence."

Through follow-up discussions, specific curricular objectives can be addressed. Depending on the direction of these discussions, students can be expected to be able to do any of the following:

- describe gravity as a universal force that pulls everything toward the center of the earth;
- distinguish between tensile (stretching) and compressive (squashing) forces;
- analyze the relationships between form and function in man-made structures; and
- describe science and technology as human endeavors, influenced by the prevailing cultures and beliefs of the time.

Procedure

The exercise: Ask students to design and build a bridge that sits on two flat supports and spans the 24-inch space between them. The bridge must be able to support a standard brick (about 5 pounds). They may use any material derived from plant fiber (cellulose): paper, cardboard, wood, string, thread, cotton fabric or cotton in any form. Plastic is *not* allowed--no monofilament fishing line or plastic straws. Metal is *not* allowed--no coat hangers or steel rods. The bridge may *not* be attached to any other support. *No* glue or sticky tape is allowed, even within the bridge structure itself.

The test: A convenient test set-up is two concrete building blocks standing on their ends. This allows the bridge to sag or have other below-the-support structure. The blocks should be placed exactly 2 feet apart. Each student should place the brick on her own bridge.

Of those bridges that successfully span the 24 inches and support the brick, the one that *weighs the least* wins the gold star.

Suggestions and comments: We suggest that this be an exercise that students work on individually. In this way, they must work out all the details themselves, and they experience the entire construction process with their own hands. If students work in pairs, one person tends to do all the physical labor while the other does very little.

We assign this exercise for homework, and give students one week for the task. We stress that they should begin construction early. Some students undertake fairly complex structures. Bridges built at the last moment that are tested at home often fail (and break) when the brick is applied. Then there is precious little time to rebuild the bridge with appropriate modifications.

The above description includes many constraints that can be changed or eliminated according to taste. For example, the use of glue certainly makes this challenge more accessible to younger students. Plastic straws are cheap and easy to obtain in quantity. Teachers should feel free to modify these instructions as much or as little as they wish.

The lightest solution to the exercise we've ever seen was a 25-inch dowel rod about 1/8 inch in diameter to which thread was attached at both ends. The thread sagged in the middle below the dowel. The brick was balanced on the thread. The bridge itself weighed less than 10 grams!

Discussion and Extensions

As they test their bridges by placing a brick upon them, students will notice how the bridge deflects downward under the weight of the brick, probably causing some elements of the bridge to bend. A bent object is subjected to two types of forces at the same time: the material on the outside of the bend is being stretched, and the material on the inside of the bend is being compressed. It is easy to illustrate this with a large sponge on which grid lines have been drawn with a permanent marker, as shown in the illustration below.

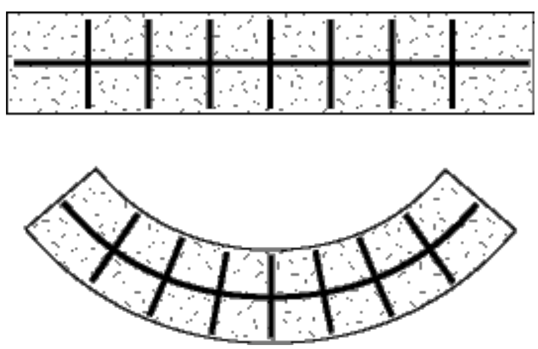

Figure 1. In the unbent sponge at the top, the grid lines are spaced equally along the top and bottom edges of the sponge. In the bent sponge, below, the grid lines are closer together along the top edge and farther apart along the bottom edge.

Some materials and shapes are better equipped to handle the stretching, or tension, that occurs during bending, and some are better equipped to handle the compression. For example, thin rods are very light in weight and can handle tension just fine. String, rope, and wire are extreme examples of long, thin rods; they are used quite successfully in suspension bridges. Long, thin rods, however, do not work well in compression. If you push on the two ends of such a rod, it bends and then kinks if it is made of metal, or it bends, kinks, and breaks if it is made of wood or plastic. Wire, rope and string, of course, are absolutely useless for resisting compression.

Stone and concrete, however, work very well in compression; it's pretty hard to crush them. Most of the world's oldest bridges that are still standing are made of stones arranged in great arches. By arranging the stones in an arch shape, the bridge is always under compression due to the weight of the stones themselves. Stone and concrete can, however, be pulled apart, so they are less than ideal for handling tension. Nowadays when structural engineers use concrete in bridges (or buildings), they generally embed some sort of mesh or grid of metal rods or wires within the concrete to give it more tensile strength.

Wood works reasonably well in both tension and compression. Trees sometimes have to withstand strong winds and so are subject to bending, yet they seldom break along their trunks. In very strong winds, trees generally get uprooted before they snap. The problem with wood is that it is very biodegradable, so wooden bridges tend to be comparatively short-lived.

After students have had an opportunity to experiment with their own bridges, you can then present examples of modern bridges on down through antiquity. (Don't forget suspension bridges made of natural materials by aboriginal peoples all over the world.) You can ask students to research different types of bridges, and compare their relative advantages and disadvantages. A good place for students to get started is the website http://www.pbs.org/wgbh/nova/bridge/build.html. Although it is meant to complement the 1997 Nova television program *Super Bridge*, which chronicles the design and construction of a 4,260-foot bridge across the Mississippi River in Alton, Illinois, the website can stand alone as an excellent resource for students. It is not necessary to watch the program to appreciate the information and interactive program contained in the website.

Middle school students love disaster stories, and there have been some notable bridge failures in recent history, especially the Tacoma Narrows suspension bridge. In fact, most of what is now known about bridge building is the result of bridges that collapsed -- not unlike the way the students just figured out for themselves how to make a successful bridge. The Nova website mentioned above includes film clips of the Tacoma Narrows bridge as its span oscillates and then crashes into Puget Sound below. Some very readable information about the bridge design and its failure can be found in Henry Petroski's book, *Engineers of Dreams*.

Virtually every major city in the world is built on the banks of a river, and why this is so would be a good subject for class discussion. While there were certainly historical advantages for being on a river, most modern cities now face major traffic problems because of that very fact. Moving hundreds of thousands of people across a river each day as they commute to and from work is a major headache for traffic planners! When students quite reasonably ask, "Why don't they just build more bridges?", you can challenge them to find out how much it costs to build one.

There are many inspiring books on bridges from around the world that give insights into the cultures and societies that built them. See, for example, the stunning photography in *Bridges* by Graeme and David Outerbridge (1989, Harry N. Abrams). Also, the book *Structures -- or Why Things Don't Fall Down*, by J.E. Gordon (1978, Plenum) is a delightful paperback that we highly recommend as background reading for this and other exercises about structures.

Instructions for Students

The exercise: Design and build a bridge that sits on two flat supports (concrete blocks standing on end) and spans the 24-inch space between them. The bridge must be able to support a standard brick (about 5 pounds). You may use any material derived from plant fiber (cellulose): paper, cardboard, wood, string, thread, cotton fabric or cotton in any form. Plastic is *not* allowed--no monofilament fishing line or plastic straws. Metal is *not* allowed--no coat hangers or steel rods. The bridge may *not* be attached to any other support. *No* glue or sticky tape is allowed, even within the bridge structure itself.

You have a week to design and construct your bridge. Don't put off your construction till the last minute. When you test it at home, it may break and then you'll have to start your construction again. Structural failure is okay; it is unlikely that lives will be lost in this particular case. But leave yourself time to rebuild your bridge with modifications before the due date.

Of those bridges that successfully span the 24 inches and support the brick, the one that *weighs the least* wins the gold star.

The test: When you come to class, we will have set up two concrete building blocks standing on their ends. The blocks will be placed exactly 24 inches apart. You will set up your bridge yourself, and then you will place the brick yourself. But we will all partake in the thrill of your victory or the agony of your defeat!

Revised: February 12, 2001