Science Unit: *Structures*
Lesson 7: *Structures and Loads*

School Year:	2011/2012
Developed for:	Sexsmith Elementary School, Vancouver School District
Developed by:	Ingrid Sulston (scientist); Mari Matsuo and Carole Murray (teachers)
Grade level:	Presented to grades K-3; appropriate for grades K – 7 with age appropriate modifications
Duration of lesson:	1 hour and 20 minutes
Notes:	The younger students only did the bridge activity (activity 2). The shapes activity (activity 1) is technically challenging for younger students. Another variety of bridge building suitable for grades 3 and up is in Lessons 4 and 5, Building Bridges, in the Structures science unit, Scientist in Residence Program. http://scientistinresidence.ca/science-lesson-plans/structures/

Objectives

1. Become familiar with local bridges, and that their overall shape and the shapes they are made up of are important for their strength.
2. Experience how different shapes have different abilities to support a load.
3. Explore different bridge shapes and their the ability to support a load.
4. See how a graph with more data (such as a class graph) can show patterns in the data that is not revealed with fewer data points.

Background Information

The Lower Mainland has an excellent array of bridges to aid with the study of bridges and structures, as do many cities. Bridges are open structures, showing the basic shapes that they are all made up of. Examples of different bridge types demonstrate how each location demands a different design in order to build the strongest structure.

Vocabulary

<u>Structure:</u> a supporting framework that is built to hold a load or enclose a space

<u>Beam bridge:</u> the simplest kind of bridge, with a bridge deck supported by the bridge piers

<u>Truss bridge:</u> a beam bridge with an additional framework added above or below, that is made up of triangles

<u>Arch bridge:</u> a bridge with an arch that distributes the load

Materials

- sheets of letter-sized paper, about 8 per student pair (to make the shapes, activity 1)
- masking tape
- pennies, 50-100 per student pair, or other small weights
- worksheets

- flat strong cardboard, about 15cm X 20cm, one per student pair. I made them from cereal boxes.
- small container per student pair e.g. disposable ketchup cup
- quarter sized sheets of letter paper (to make the bridges, activity 2)
- bridge supports, one pair for each student pair. We used shallow tubs filled with sand, with a masking tape strip between the bases holding them 10cm apart. Piles of heavy books can also be used. The distance between any bridge supports must be adjusted so that when making an arch bridge, the top of the arch rests just under the flat bridge deck.

In the Classroom

Introductory Discussion

- Introduce students to man made structures by showing them images of familiar bridges. (I used a bridge near to the school, and a bridge crossed on a recent field trip: Oak Street Bridge and Port Mann Bridge.)
- Explain that with their science experiments they will explore how the shapes within the bridges, and the overall shapes of the bridges are carefully designed to make them as strong as possible with as little material as possible.

Brief description of science experiment/activity.

- Make different shapes from paper and tape, then test their relative abilities to hold a load.
- Make different kinds of bridges from paper, then test their relative abilities to hold a load.

Processes of science that the students will focus on: precise manipulation of materials, estimation, counting, recording, graphing, concluding.

Science Activity/Experiment

(1) <u>Experiment Title</u>: How strong are different shapes?

<u>Purpose of Experiment</u>: To determine the relative abilities of simple shapes to hold weight.

Please note that this activity was only done with a grade 2/3 class, and is not recommended for any younger: making the paper edges align precisely is hard. With the uneven taping unavoidable with younger students, you will not just be comparing each shape's ability to hold a load - other factors will come into play, such as whether there is a doubling of material at a corner, or whether the shape is the same size along its length. I would recommend this activity for grades 3 and up, or adapt it for younger students.

<u>Methods and Instructions:</u>
Set-up prior to experiment: none
Students work in pairs.

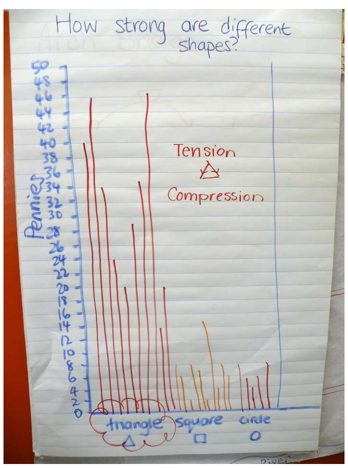
1. Briefly show the students a bridge photo again (or other man-made structure). Point out the shapes made by the steel girders (e.g. triangles in the Burrard Street Bridge, diamonds and rectangles in the Port Mann Bridge). Explain that the shapes are made during construction to make the structure as strong as possible. Tell the students they will be testing different shapes for their strength.
2. Show the students how to make a triangle and a square from a sheet of paper and tape, how to lay a platform between two identical shapes, and add a load to the platform. Do not reveal what will happen.

3. Students make two identical triangles and two identical squares by folding a letter sized sheet of paper and taping it closed with pieces of masking tape. If there is time, they can also make two of another shape that they choose (e.g. circle, pentagon). This requires some skill to accurately assess where to make the folds, and to tape the edges together so that there is no overlap. If the students are unable to do this accurately, the teacher should do it for them.
4. Students test the strength of each shape by laying a cardboard platform between two of the same shape, adding a small container to the centre of the bridge, then adding pennies to the container until the shape starts to collapse or distort.

   In the adjacent photo, the square shapes are already collapsing with just a few pennies, whereas the triangle shapes can hold more pennies before they distort. [This is the experiment done before the pennies were constrained by containers.]

5. Students record the number of pennies added to a shape before it distorts or collapses. (See the first worksheet after this lesson).
6. As a class, add all results to a class graph, with number of pennies up the side of the graph and the shapes along the bottom, and find out which shape is the strongest. It is expected that the triangle would be the strongest.

   Our results showed a triangle being able to hold between 14 and 46 pennies, a square being able to hold between 2 and 15 pennies, and a circle being able to hold between 4 and 8 pennies:



This graph is a good opportunity to show students that sometimes data is a little messy, and one might need a lot of data points before seeing a pattern emerging.

From one group's results, it might not have been clear which shape was the strongest, but when everyone's results are graphed together, a pattern emerges: the triangle is clearly stronger than the other shapes. There is not enough data here to determine if the square or circle is stronger.

7. Explain why the triangle is the strongest shape: the sides of a triangle are a fixed length, so as a force is applied the angles of the triangle cannot change, so maintaining the triangle's shape. A triangle will fail when either the sides buckle (as probably happened in this experiment), or when the joints break apart. When a load pushes down on the triangle, the two top sides are under compression as the force from above pushes down on them. The bottom side is under tension as the ends are pulled apart. (So in construction the bottom side that only experiences tension can be made of a lighter material than the upper two sides that must be more rigid to stand up to compressive forces). (Ref 1) In the case of the square, the angles can change even when the length of the sides stays the same - it is easily pushed into a diamond shape.

(2) Experiment Title: Testing bridges

Purpose of Experiment: To determine the relative abilities of different styles of bridges to hold weight.

Methods and Instructions:
Set-up prior to experiment: none
Students work in pairs.

1. Show students photos of local bridges, and name the type of bridge in each case. I used Oak Street bridge and a log bridge as examples of a beam bridge, Second Narrows and Burrard Bridges as examples of truss bridges, Port Mann Bridge as an example of an arch bridge. See ref 2 and 3 for types of bridges.
2. Show students how to construct their own bridge types from the quarter sheets of letter sized paper. Each bridge uses two sheets of paper so that they all use the same amount of material. For each bridge type, show the students the photo of a real bridge of the same type.

A beam bridge is simply two sheets of paper on top of each other, spanning the bridge supports:

A truss bridge is a kind of beam bridge. It is made by creasing one sheet of paper into an accordion,

then laying the second sheet of paper over the accordion:

An arch bridge is made by curving one sheet of paper between the two bridge supports, then laying the second sheet of paper over the arch so that it rests on the top of the arch and the bridge supports:

3. Show the students how to add weights to their bridges to test their strength: add the small container to the centre of the bridge, then add pennies one by one until the bridge starts to collapse.
4. Students work in pairs to build each kind of bridge, and record how many pennies each kind can hold on their worksheet (see the second worksheet following this lesson for older students and the third worksheet for younger students).
5. The class comes together to add their results to a class graph. Expected results: a beam bridge is the weakest bridge under these conditions and the truss the strongest. (Our class found that the beam bridge held between 2 and 7 pennies, the arch bridge held between 4 and 26 pennies, and the truss bridge held between 19 and 130 pennies).
6. Discuss why the truss bridge is the strongest: point out the triangles in the truss bridge, and that this is the strongest shape to include in man-made structures. (Refer back to the previous activity).

   Ask the students why the arch bridge is stronger than the beam bridge. They will often have an understanding of why the arch helps hold up the bridge deck, even if it is not explained in technical terms. Technically, the forces on the bridge deck are distributed down the arches of the bridge, so that no point holds all the weight and the bridge can hold more before failing.

7. Look at the local bridge photos again. These bridges are of all different kinds: beam, truss and arch. Why are they not all truss bridges, as we found this to be the strongest in our experiment?

   There are many factors in building a bridge, including the length of the span, the material the banks are made from and where piers can be built, and the cost of the materials. For each location the engineers determined the best bridge type.

References

1. Caney, Steven. 2006. Steven Caney's Ultimate Building Book. pp. 168-171. Running Press Kids.
2. Caney, Steven. 2006. Steven Caney's Ultimate Building Book. pp. 177-194. Running Press Kids.
3. <http://scienceprep.org/bridges.htm> An image of bridge types, from a Mike Edlin's website of science class information. Accessed May 28, 2012.

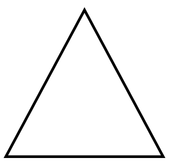
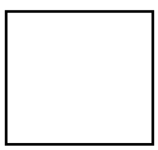
Extension of Lesson Plan

1. Looking at natural structures such as tree shapes, or animal body designs, to look for common shapes and patterns that make these structures strong.

Testing shapes

How many pennies can each shape hold before collapsing?

1. Make each shape from one piece of paper and masking tape.
2. Add a platform between two shapes of the same kind.
3. Add pennies one by one to a pot in the centre of the platform.
4. Count the pennies in the pot when the shapes collape.

Shape	Number of pennies	Rank
Triangle 		
Square 		

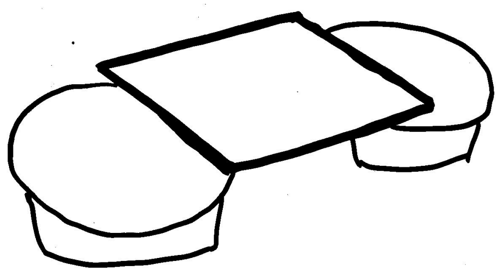
Testing bridges

How many pennies can each kind of bridge hold before collapsing?

1. Make each bridge from 2 pieces of paper.
2. Add pennies one by one to a pot in the centre of the bridge.
3. Count the pennies in the pot when the bridge collapes.

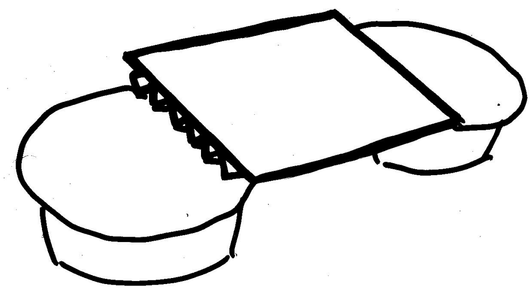
The **beam bridge** can hold

___________ pennies



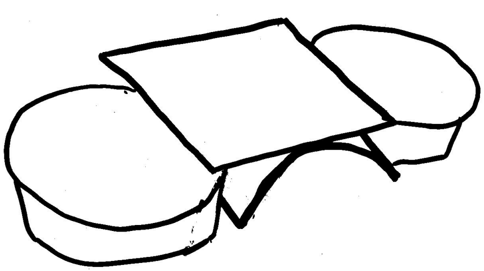
The **truss bridge** can hold

___________ pennies



The **arch bridge** can hold

___________ pennies

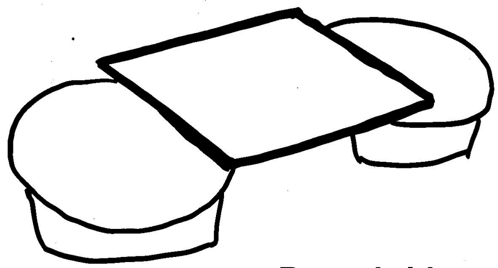


Design another bridge.

How many pennies can it

hold? ___________

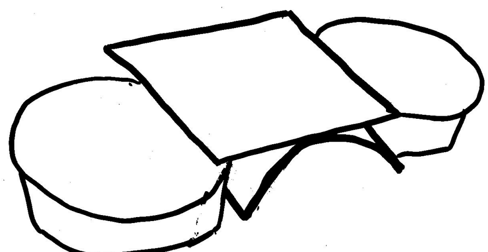
Bridges



Beam bridge

How many pennies?

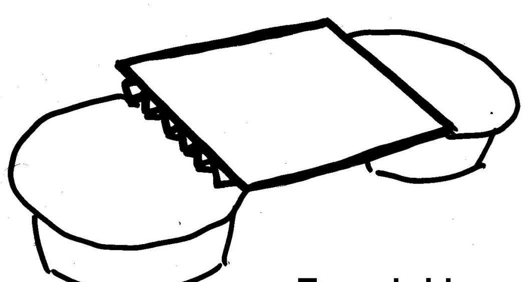
____



Arch bridge

How many pennies?

____



Truss bridge

How many pennies?

____