2014 NATURE Summer Camp
BRIDGES
(The Abridged Version)

Description:

A bridge is a structure that provides passage over obstacles such as valleys, rough terrain, or bodies of water by spanning those obstacles with natural or manmade materials. They first began to be used in ancient times when the first modern civilizations started rising in Mesopotamia. From that point on, knowledge, engineering, and manufacture of new bridge building materials spread beyond their borders, enabling slow but steady adoption of bridges all across the world.

In the beginning bridges were very simple structures that were built from easily accessible natural resources – wooden logs, stone and dirt. Because of that, they had the ability to only span very close distances, and their structural integrity was not high because mortar was not yet invented and rain slowly but constantly dissolved the dirt fillings of the bridge. Revolution in bridge construction came in Ancient Rome, whose engineers found that grinded out volcanic rocks could serve as an excellent material for making mortar. This invention enabled them to build much sturdier, more powerful, and larger structures than any civilization before them. Seeing the power of roads and connections to distant lands, Roman architects soon spread across Europe, Africa, and Asia, building bridges and roads of very high quality.

One of the defining successes of Roman bridge architecture was their discovery of arches. By using this type of building, load forces of the bridge were conveyed to move along the curve of the arch, meeting with the ground where they were cancelled by supports on the end of the arch. Because of that, Romans were able to create bridges that were much lighter than before and were able to hold a load that was twice as heavy as the bridge itself. In construction of their numerous aqueducts, Roman architects even managed to create water carrying bridges with multiple arched tiers that reached incredible heights!

By using this new building technique, Romans had the ability to quickly produce cheap, light, and very powerful bridges from materials that could be found in the vicinity of the project. The only material that had to be imported from Italy was mortar dust, which was combined with water and inserted into the bridge structure.

After the fall of the Roman Empire, bridge building techniques in Europe and Asia stagnated until the 18th century (if we ignore introduction of the rope suspension bridges that were brought back to Europe from Central and South America) when a new age of science and engineering swept across the world. Architects of that time started using a new construction material – cast iron! Iron enabled creation of new bridge designs such as truss systems. Sadly, wrought iron did not have tensile strength to support heavy structures. This problem was fixed with the advent of steel and the ideas of famous French architect and engineer Gustave Eiffel.

Modern bridges are usually made with the combination of concrete, iron, and cables, and can be built from very small sizes to incredible lengths that span entire mountains, rough landscapes, lakes, and seas. Bridges are structures that need to be built to withstand incredible external forces and last for decades or centuries. Sadly many bridges have succumbed to their wounds and have taken many human lives with them.

In today's lesson, you will examine the forces that act on a bridge. You will learn that there are many factors used in describing a bridge. You will understand the differences between the different types of bridges. And, you will discover a variety of techniques that will help strengthen the bridges that you will build yourself!

Objectives:

- To learn about the different types of bridges
- To understand how loads affect bridges
- To discover the way forces act upon bridges
- To become familiar with good bridge design techniques
- To build a variety of types of bridges

Education Standards:

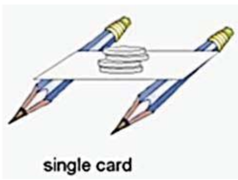
11-12.1.3 Explain how a system can be dynamic yet may remain in equilibrium (e.g., balance of forces, Le Chatelier's Principle, acid base systems)
11-12.1.4 Explain the relationship between form and function (e.g., atoms and ions, enzymes, aerodynamics)
11-12.2.5 Use technology and mathematics to improve investigations and communications
11-12.3.8 Identify the principles and relationships influencing forces and motion (e.g., gravitational force, vectors, velocity, friction)
11-12.6.2 Identify examples of how new technologies advance science

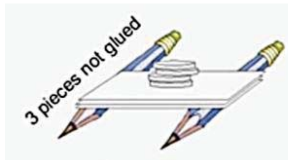
Schedule:

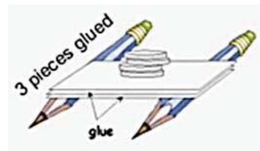
9:00 – 9:30	Cultural Connection
9:30 – 10:00	Teacher Demo & Activity #1 (Paper Beam Bridge)
10:00 – 10:25	PowerPoint – Main Concepts
10:25 – 10:30	Activity #2 (Paper Bridge Pier)
10:30– 11:00	Activity #3 (Toothpick Truss Bridge)
11:00 – 11:45	Activity #4 (Sugar Cube Arch Bridge)
11:45 – 12:00	Activity #5 (Human Cable-Stayed Bridge)
12:00 – 12:45	LUNCH
12:45 – 1:15	Activity #6 (Straw Suspension Bridge)
1:15 – 2:45	Activity #7 (Pasta Bridge Contest)
2:45 – 3:00	Session Wrap-up

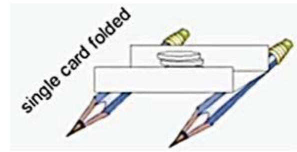
OPENING QUESTION FROM POWERPOINT

Which bridge design will support the most weight? (Circle your guess)









Activity #1: Paper Beam Bridge

In this activity, you will use one sheet of paper to create a bridge that will span across two supports (books work well) that are 8 inches apart. You want your bridge to be able to support as much weight as possible.

Materials

- 8½” x 11” printer paper (enough to experiment with and one for your final bridge)
- 2 books (or similar objects for support that are about an inch high)
- pennies (or other items for weight)

Rules

1. All competitors must use the same kind of paper.
2. Bridge supports should be placed 8 inches apart.
3. Your bridge must have a span that is flat and wide enough for a penny to sit on (to emulate a road). This span must remain flat across the entire length of the 11 inches. This span is not required to be parallel to the 11 inch side, nor must it be straight.
4. Only the zone between the supports should be loaded with pennies.
5. Stacks of pennies should be a maximum of ten coins high until the entire surface of the bridge is covered. After that, coin stacks can be any height.

In the two boxes below, draw a top view and a cross-sectional view of your bridge.

Top view

Cross-section

How many pennies (A) did your bridge hold? ______ (B) did the winner’s bridge hold? ______

<u>Activity #2:</u> Paper Bridge Pier

In this activity, you will determine which geometric shape is the best for a bridge's pier.

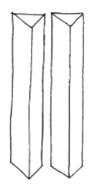
Materials

- 3 sheets of 9" x 12" construction paper
- tape
- paperback books (or similar items to be used as weights)

Procedure:
Make three different paper bridge piers, according to the guidelines below. Stand each pier on end and gradually add one book at a time until the pier collapses. Make sure that the books are balanced. Record your results in the spaces provided.

<u>Square</u>: Fold the paper in half (lengthwise). Open up the paper and fold each side of the same sheet into the center fold. Open up the paper and tape it into a square column.

<u>Triangle</u>: Fold the paper into three equal parts (lengthwise), like a letter, except lengthwise. Open up the paper and tape it into a triangular column.



<u>Cylinder</u>: Roll the paper (lengthwise) into a cylinder with the ends slightly overlapping and tape together.

Record the maximum number of books each pier held before it collapsed.

Shape of Pier	**Maximum Number of Books**
SQUARE	
TRIANGLE	
CYLINDER	

<u>Activity #3:</u> Toothpick Truss Bridge

In this activity you will build a truss bridge and test its strength. It will be compared to different styles of truss bridges built by other students in the group.

Materials

- toothpicks
- miniature marshmallows
- common truss types sheet

Procedure:
Your instructor will assign a truss type for you and your partner each to build. Build it exactly like the diagram, and make sure your partner's is made to the exact same specifications. When each of you have completed your truss, use toothpicks to join them together on both the top and the bottom, so you will in essence have a "through" truss bridge (without a travel surface). Your instructor will set up a place for you to test the strength of your bridge. Record your truss style and the maximum load it handled.

Your truss style: ___________________________ Maximum load: ______________________

<u>Activity #4:</u> Sugar Cube Arch Bridge

In this activity, your group will create a double arch bridge that resembles the type that the ancient Romans once built. You will discover that the strength of the arch is its ability to dissipate the compression forces throughout the structure, giving it the ability to handle significant weight.

Materials
- sugar cubes
- Styrofoam cups
- powdered sugar
- water
- plastic spoons
- plastic knives
- knife or razor

Procedure:
1. Slice one cup in half (longitudinally) and lay it on a piece of paper (to make cleanup easier).
2. Fill another cup about ¼ full of powdered sugar and add about a spoonful of water.
3. Use the spoon to stir the mixture.
4. Continue to add powdered sugar and stir it until you get at least a half cup full. The consistency should be as thick as possible because it will not only be used to paste the sugar cubes together, but also to fill in the spaces (like mortar).
5. Use the large end of the cup as a form to build your sugar cube arch around.
6. Use the plastic knife to spread the "mortar" onto the sugar cubes
7. Use a knife or razor to trim a sugar cube for the keystone (and any other cubes that are absolutely necessary – try to use whole cubes wherever possible).
8. Build two arches right next to each other, and build the unit 4 cubes high. (See pictures on PowerPoint slide for assistance.)
9. Build two of these double arches, and "mortar" them together side-by-side.
10. Let the unit dry for at least an hour.
11. When reasonably dry, test the unit for sturdiness but don't destroy it. That is one <u>sweet</u> bridge!

<u>Activity #5:</u> Human Cable-Stayed Bridge

In this activity, the student will model a cable-stayed bridge with a person and some rope.

Materials

- rope (two pieces – one about 5 ft. and the other about 6 ft.)
- two weights that can be held with arms extended (e.g. gallon of water, books)

Procedure:

1. Have one person stand up and hold his/her arms out horizontally at each side. Imagine that your arms are a bridge, and your head is a tower in the middle. In this position, your muscles are holding up your arms. Have the person hold a weight in each hand.
2. Take a piece of rope (about five feet long), and have a partner tie each end of the rope to each of your elbows. Then lay the middle of the rope on top of your head. The rope acts as a cable-stayed and holds your elbows up.
3. Have your partner tie a second piece of rope (about six feet long) to each wrist. Lay the second rope over your head. You now have two cable-stayeds.

Where do you feel a pushing force, or compression? ____________________________________

Was this cable-stayed bridge the fan type or the harp type? ______________________________

<u>Activity #6:</u> Straw Suspension Bridge

In this activity, you will see how a suspension bridge is much more desirable than a beam bridge when spanning a longer distance.

Materials:

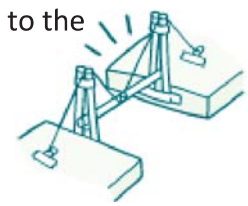
- 7 straws
- masking tape
- twine
- scissors
- 4 paper clips
- Styrofoam cup
- ruler
- pennies (for weight)

Procedure:

1. Cut two short pieces of straw, each 3 centimeters (about 1.25 in.) long. For each tower, tape two straws on either side of a short piece of straw, as shown. Tape the long straws together at the top, too.

2. Tape one tower to the edge of a desk or chair. Tape the second tower to a second desk or chair of the same height. Position the towers 17 cm (about 7 in.) apart.

3. Place another straw between the towers so its ends rest on the short pieces. This straw is the bridge deck. Now you have a simple beam bridge.
4. Make a load tester by unbending a large paper clip into a V-shape. Poke the ends of the paper clip into opposite sides of a Styrofoam cup, near the rim. Use a second paper clip to hang the load tester over the bridge deck. Record how many pennies the paper cup can hold before the bridge fails.
5. Now change the beam bridge into a suspension bridge. Tie the center of a 100-cm (about 4 ft.) cable around the middle of a new straw. Place the straw between the towers. Pass each end of the cable over a tower and down the other side.
6. To anchor the bridge, wrap each end of the cable around a paper clip. Slide the paper clips away from the tower until the cable pulls tight. Then tape the paper clips firmly to the desks. Test it again.



How many pennies did your beam bridge hold? __________

How many pennies did your suspension bridge hold? __________

Which parts of the loaded suspension bridge are in compression? ________________________

Which parts of the loaded suspension bridge are in tension? ____________________________

<u>Activity #7:</u> Pasta Bridge Contest

Now that you have been exposed to a variety of types of bridges, and have discovered the forces that act upon these bridges, it is your turn to demonstrate what you have learned. You will build a bridge out of pasta (uncooked) and try to make it stronger than anybody else's. There are, however, some guidelines you will need to follow. To mimic a real-world situation, you will not have an unlimited amount of supplies. You will have to stay within budget to complete your bridge. Good luck!

Materials

- 1-inch bundle of spaghetti
- ½ cup rigatoni
- ½ cup bow pasta
- 2 sheets lasagna noodles
- 1 spool of thread
- 1 glue gun
- 3 glue sticks
- 50 points

Each group will receive samples of each type of pasta, a glue gun, glue stick, and spool of thread. Before you build a bridge out of pasta, you should spend time familiarizing yourselves with the building materials. You will have about 15 minutes to explore the properties of the different kinds of pasta and become comfortable with the glue guns. Note, for example, pasta snaps easily along its length, but standing vertically, it can support a lot more weight. Recall what you already know about bridges. Think about ways to combine the materials to construct piers, a reinforced beam, and arch, truss, and suspension structures. Do not build a complete bridge, but rather experiment with the materials. Consider how your final bridge will be constructed. Draw a sketch of the bridge you will build.

Sketch of your bridge	

Procedure:

You are going to build your bridge in one hour using a limited amount of materials, which you will need to use economically. You can build any type of bridge you wish. It must contain an appropriate travel surface and you must meet the following criteria.

Bridge Building Criteria:

- Use only the materials provided
- Completed within one hour
- Clear a span of 11 inches (the length of a standard piece of paper)
- Support as much weight as possible
- Be attractive

In addition, each group must adhere to a point system. Each group begins with 50 points with which to purchase additional materials from the instructor. Once a group's total number of points runs out, it must make do with the materials it has.

Price List:

- 1-inch bundle of spaghetti = 10 points
- 1 glue stick = 10 points
- 1 spool of thread = 25 points
- 1/2 cup rigatoni = 5 points
- 1/2 cup bows = 5 points
- 1 sheet lasagna = 5 points

Once the bridges have been completed, place them over a span of 11 inches created by the ends of two tables, or two piles of books, and test how much load they can support. The winner is the bridge that can support the most weight. (Other prizes may be awarded for categories such as The Most Beautiful Bridge, or The Most Innovative Design, or Least Expensive Bridge.)

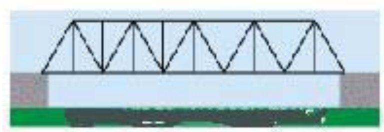
How much weight did your bridge hold? ____

How much weight did the winning bridge hold? ____

WRAP-UP QUIZ

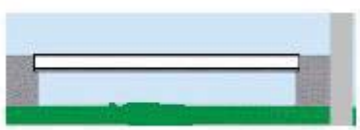
Label the bridges below, according to their type.

a) ______________________



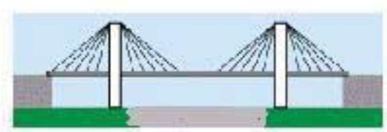
b) ______________________

c) ______________________



d) ______________________

e) ______________________



d) ______________________