Figure 1. Millau Bridge over the River Tarn

Design Activity - Construction Technology: Bridge Building

Class and Period___________ Date: ______________

List of students on design team:

_______________________ ___________________________
_______________________ ___________________________
_______________________ ___________________________

Materials Needed:

_______________________ ________________________
_______________________ ________________________
______________________ ________________________
_______________________ ________________________
_______________________ ________________________
_______________________ ________________________

State the Design Challenge:

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I. Clarify the Specifications and Constraints

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II. Research and Investigate – Completing Knowledge and Skill Builders

In order to better complete the design challenge, you need to first gather information to help you build a knowledge base.

Knowledge and Skill Builder 1: Cost of materials

The table below indicates the unit cost for the materials you might use in building your bridge. When designing a bridge, cost matters, as do strength and safety. As you build your knowledge base, determine the size and/or quantity of materials needed to build the bridge, and then figure the total cost of each.

Material	Size and/or Quantity	Unit Cost	Total Cost
Oak tag		$0.01/sq.ft	
Brass fasteners		$0.02 each	
Drywall screws		$0.02 each	
White glue		$0.10/oz.	
Wood glue		$0.30/oz.	
String		$0.01/ ft	
Craft sticks (basswood)	1/8” x 2” x 24”	$2.00 each	
Popsicle sticks		$0.02 each	
Wood sticks	1/8” x 1/8” x 24”	$0.30 each	
	¼” x ¼” x 24”	$0.70 each	
	½” x ½”x / 24”	$2.00 each	
	1” x 1” x 12”	$1.20 each	
	1 cm x 1 cm x 40 cm	$0.20 each	
Wood dowels	1/8” x 36”	$0.30 each	
	¼” x 36”	$0.60 each	

Knowledge and Skill Builder 2: Beam Bridges

While you are hiking, you come upon a tree that has fallen across a stream, and you walk across the tree to cross the stream. This is an example of a **beam bridge** where piers on both ends support the beam.

1. Let’s build beam bridges from oak tag and see how they can be made stronger. For your beam bridge, take two wooden blocks or bricks and stand them on end 12" apart. Take a piece of oak tag measuring 4 ½” x 16" and fold it in half, lengthwise. Lay it across the bricks. Now add weight to the bridge and measure the deflection for each increment of weight. Keep adding weight until the bridge buckles. See how much weight your bridge will hold before failing.

Weight (ounces or grams)	Deflection (bending) in inches

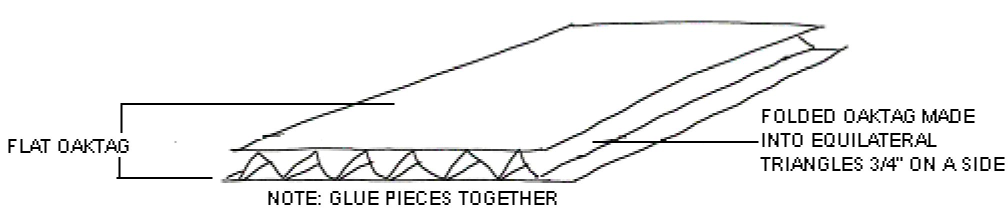
2. Determine the cost of this bridge based on the materials table. The cost is _______________.
3. Now figure out how cost effective the bridge is. The cost effectiveness is determined by how much weight the bridge will hold for a certain cost. We call that relationship the **figure of merit.** For example, if a model oak tag bridge holds 100 grams and costs 10 cents, the figure of merit is 100 grams/10 cents, or **10**. If the bridge could hold 200 grams for the same cost, the figure of merit is **20**. The figure of merit is a **ratio** between weight and cost. Calculate the figure of merit for your simple beam bridge.

Cost of Materials	Maximum Weight	Figure of Merit (Cost/Weight)

4. What do you conclude from the investigation of your simple beam bridge?
____
____
5. Do some research and find the figure of merit of a real bridge. How does it compare to your bridge? ____

   Why is there a difference? ____
6. Making the Beam Bridge Stronger

Now, investigate how to make the bridge stronger. Take three pieces of oak tag measuring 4 ½” x 16". Fold one piece into triangular ridges measuring ¾” (like a fan, as shown in the illustration) so that the total width of the ridged section is 4 ½”. Then glue the other two flat pieces of oak tag to it on the top and on the bottom. **NOTE:** Before you fold the triangles, let’s figure out how much oak tag we need to make a 4 ½” folded section.



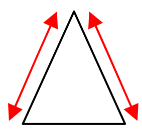
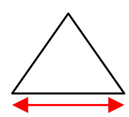
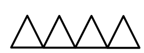
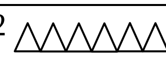
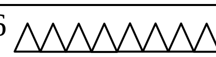
Remember, the folds form two sides of an equilateral triangle with each side measuring ¾”. Since the triangle is equilateral, the base width will also be ¾”. If the total width is 4 ½” you will need six triangles to fill the space (6 x ¾” = 4 ½”).

Since you need six triangles, and each triangle will be made from two folds measuring ¾” each, you will need 6 x 2 x ¾” or 9 inches of oak tag to make the 4 ½” folded section. The length of the folded section requires paper that equals twice its length (2 x 4 ½”).

So: how much paper would you need to make a 9 inch folded section using ¾” folds? ________?

How about to make a 12 inch folded section _________?

7. Here is a table that shows how the number of triangles and the number of folds determines the length of the paper needed. The table is started for you. *Please fill in all the blanks.*

Number of Triangles	Length of Each Fold (each leg of the triangle) 	Length of the Folded Section 	Number of Folds	Length of Paper Needed
1	¾”	¾”	2 	1 ½”
2	¾”	1 ½”	4 	3 “
3	¾”		6 	
4	¾”		8 	
5	¾”			
6	¾”	4 ½”	12 	9”
7	¾”			
8	¾”		16 	12”

8. Can you figure out a *mathematical formula* to figure out the length of the paper you’d need for any folded section length? The formula would be: Paper length needed = ______________

In designing and building bridges, engineers apply mathematical formulas. If they apply the formulas correctly, the bridge will stand up under load.

9. Would your formula change if the triangle folds are a different length than ¾”? Yes__ No__

Explain your answer. ____

____.

10. Now construct the bridge. Perform the same experiment as before to test its strength.

Weight (ounces or grams)	**Deflection (bending) in inches**

11. Determine the cost of this bridge based on the materials table. The cost is _______________.

Now determine the figure of merit for your improved beam bridge.

Cost of Materials	**Maximum Weight**	**Figure of Merit (Cost/Weight)**

12. What do you conclude from this investigation of the two beam bridges?
____
____

13. For a given span, increase the depth of a beam of given shape and see what happens to the deflection and strength. What is your prediction, and what actually happens?

My prediction is that: ____
____

What actually happened is that: ____
____

Knowledge and Skill Builder 3: Arch Bridges

We tend to think of an **arch** as curved, but it does not have to be. The simplest arch is two pieces of solid material joined together in the middle, like a nutcracker or a pair of pliers.

1. Connect two Popsicle sticks and hang a weight from the middle, as shown in the illustration below.

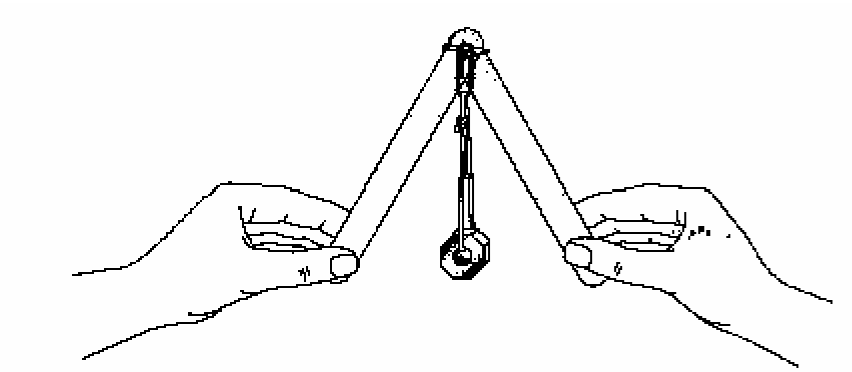


Figure 3. Popsicle Sticks. Please redraw.
Caption: Notice that the weight *compresses*, or pushes *down and out* on the handles.

Bridges may be supported using simple arches, such as shown in the illustration below.

Figure 4. Arch bridge. Please redraw.

2. Now create an oak tag beam with a folded section between the top and bottom (as in Knowledge and Skill Builder 1), and support it between the jaws of a vise, two brick or blocks of wood. Now, create a simple arch support for the bridge using wooden centimeter sticks to support the middle, anchoring them to the brick or wood sidewall. See Figure 5.

Figure 5. Model arch bridge. Caption: This model bridge is supported at each end and in the center. The center support is a simple arch.

3. Perform the same experiment as before to test its strength.

Weight (ounces or grams)	Deflection (bending) in inches

4. Determine the cost of this bridge based on the materials table. The cost is ________________.

5. Now determine the figure of merit for the arch bridge.

Cost of Materials	Maximum Weight	Figure of Merit (Cost/Weight)

6. What do you conclude from this investigation of this bridge?

____

____

____

Figure 6. Covington Ohio stone arch bridge.

Caption: Modern arches used for bridges are commonly constructed using either steel or steel-reinforced concrete. Some much older arch structures used stone or bricks as the construction material. When these masonry arches are properly shaped (not all arches are semicircles), large compression forces (which exist in all arches) squeeze the stone or bricks together, making the arch strong. All bridge arches have side thrusts at the supports. In the photo, the thrusts are resisted by the stone abutments.

Knowledge and Skill Builder 4: Suspension Bridges

Simplified model of a suspension bridge.

1. Suspension bridges are supported by steel cables, which may extend more than 5,000 feet between their supports. The longest bridges in the world are suspension bridges. Let's begin by exploring how a cable supports weight. For our model, the steel cable will be replaced by a piece of string. Take a piece of string measuring about 2' long and tie a knot in the middle, attaching to it a paper clip connected to a metal nut. See Figure 7.

Half of the weight is supported by your left hand, half by your right hand. The string is in *tension* (you can feel it pulling on your hands). Now, try to straighten the string. Does it require more effort? Yes____ No____. Does the tension in the string increase? Yes____ No____. Explain why? ____

____

2. Now add more weights to the string at equal distances from the center. If you add six more weights, the string will resemble the illustration in Figure 8.

Figure 8. The load is suspended from the string

In the illustration, the hands represent the towers and the load is *suspended* from the string.

Just as you supported your weights with a string, engineers use cables to support a roadway made from steel and concrete.

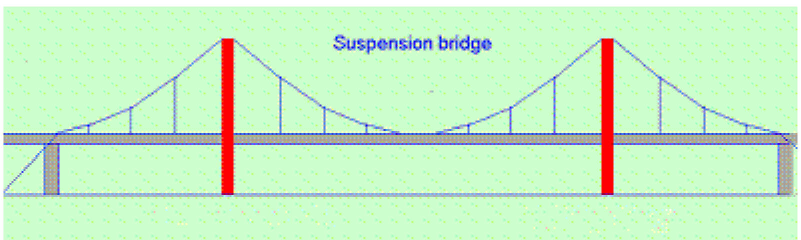


Diagram of a suspension bridge.

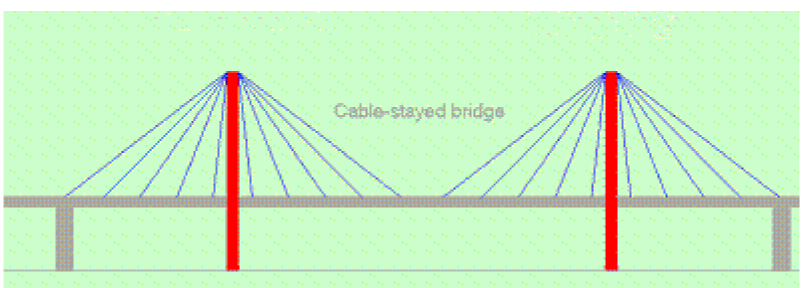


Diagram of a cable-stayed bridge.

This is a diagram of a suspension bridge. In a suspension bridge, the deck hangs from the suspending cables that are strung along the entire length of the bridge and the load is transmitted to the towers and to the anchorages at the ends. A variation of the suspension bridge is called a **cable-stayed** bridge. Like a suspension bridge, the cable-stayed bridge has two towers and a suspended deck; but the deck of the cable-stayed bridge is in compression as it is pulled towards the towers. In cable-stayed bridges the cables are strung from the towers: The towers bear the load. Suspension bridges can span over 3000 feet. Cable stayed bridges are used for spans between 350 and 1500 feet. In both diagrams, the towers are in compression and the cables are in tension.

Figure 11 is of a cable-stayed bridge over the River Tarn, in southern France. Each of its sections spans 350 meters and its columns range in height from 75 meters to 235 meters - higher than the Eiffel Tower - with the masts rising a further 90 meters above the road deck.

Cable-stayed bridge over the River Tarn.

Figure 11. Simple cable-stayed bridge. Obtain photo from M. Hacker

3. *Now for some fun.* Create a simple cable-stayed bridge by using string and wooden strips provided by your instructor to construct the cables, and the towers. You can clamp the bottoms of the towers into vises on either end of a bench.

Make the roadbed from the same oak tag beam with a folded section between the top and bottom as you have used in the previous KSBs. Draw a sketch in the space below to illustrate your cable-stayed bridge.

4. Perform the same experiment as before to test the strength of the cable-stayed suspension bridge.

Weight (ounces or grams)	Deflection (bending) in inches

5. Determine the cost of this bridge based on the materials table. The cost is ________________.

6. Now determine the figure of merit for the cable-stayed bridge.

Cost of Materials	Maximum Weight	Figure of Merit (Cost/Weight)

7. What do you conclude from this investigation of this bridge?
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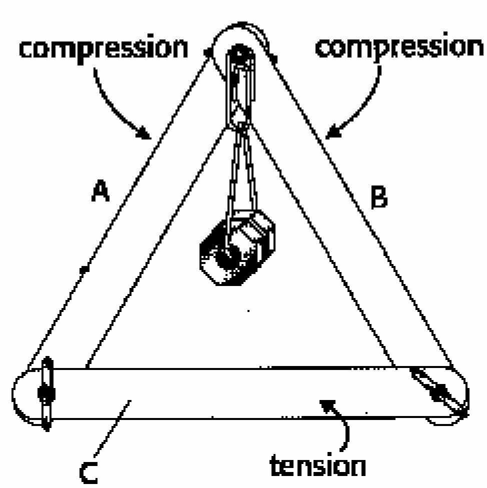
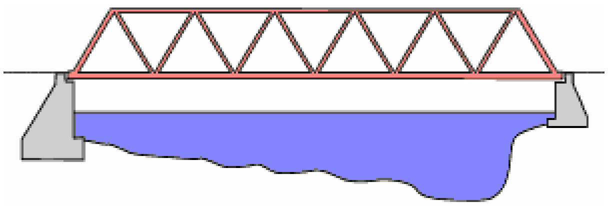
Knowledge and Skill Builder 5: Truss Bridges

1. A truss bridge uses the strength of a triangle for its support. Take three craft sticks and punch holes in the ends. Join the craft sticks together in a triangle using brass fasteners. It should resemble the following illustration. If a weight is hung as shown, then two of the sticks are under compression and the third in under tension. Think about how the force of the weight is pushing down sticks A and B and how stick C, which joins them, is being pulled in tension.



Simple Truss.

2. Truss bridges are used for shorter spans than suspension bridges, normally between 100-1300 feet. The truss members are made of steel. Rivets or high strength bolts are used to fasten the members together. Use craft sticks to create several trusses of your own.



Schematic of truss bridge.

3. Now - here's a problem:

Suppose you want to make a truss bridge that spans a length of 120 feet and we want to use trusses that are made from equilateral triangles that are 20 feet on each side. How many triangles will be needed? The answer, of course, is six, since the base of each triangle is 20 feet and we need to span 120 feet (dividing 120 by 20 = 6). That was pretty easy.

However – how many **truss members** are needed for the truss? Look at the diagram above. Notice that the six apexes of the triangles are connected by five horizontal members. Therefore:

Six triangles each have three members so, the total = 18 members

Six triangle apexes require five horizontal members = 5 members

Total number of members = 23 members (count them).

Here's how you can use mathematics to determine the number of truss members needed for a truss built from any number of triangles.

You will see that for each triangle, an extra member is needed at the top. EXCEPT that for the last triangle, no extra member is needed. In the picture above, you will notice that we need 4 members for each triangle, but only three members for the last triangle. We need 4 members for each triangle (or 4 x 6) minus one for the last triangle where we need only three so: (4 x 6) -1 = 23 members.

How about a truss where we wanted 10 triangles? How many members would there be? Following the same logic, we would need 4 members for each triangle except for the last triangle. We therefore, would need (4 x 10) – 1 = 39.

Using the same pattern, fill in the following table:

Number of Triangles	Number of Members
6	23
10	39
15	
20	
25	

4. Now, can you write a formula that will tell us the number of members for truss with a particular number of triangles?

____

III. Generate Alternative Designs

Describe two of your possible solutions to the design challenge that you wrote on Page 1. Remember to consider the specifications and constraints. In your description of your possible solutions, indicate what you consider to be each solution's strengths and weaknesses. Include such considerations as material cost, results from experimentation, and ease of construction.

Describe Solution 1:

Describe Solution 2:

IV. Choose and Justify the Optimal Solution

Choose your preferred solution. Explain how your solution meets the specifications and constraints.

____
____
____

Why is this better alternative?

____
____
____

What trade-offs, if any, did you make in selecting this alternative?

____
____
____

V. Develop a Prototype

Construct your bridge. Sketch your final design, or include a photo or technical drawing of your prototype.

VI. Test and Evaluate

Did your design meet the initial specifications and constraints? ___________________________

Indicate the tests you conducted and the experiments you performed to verify this.

____

____

____.

Did you include any additional specifications? ____

____.

Describe the testing procedure, and explain how the design meets these specifications.

____

____.

VII. Redesign the Solution

What problems did you encounter which caused you to have to redesign your solution?

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____

Did you change your original design concept? _________________ Why? _________________

____.

If you had to redesign your model, what changes would you recommend in your new design? Explain your reasoning.

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VIII. Communicate Your Achievements

Describe the plan you will use to present your solution to your class, and include any handouts or overhead transparencies you will use. (You may include PowerPoint slides.)

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