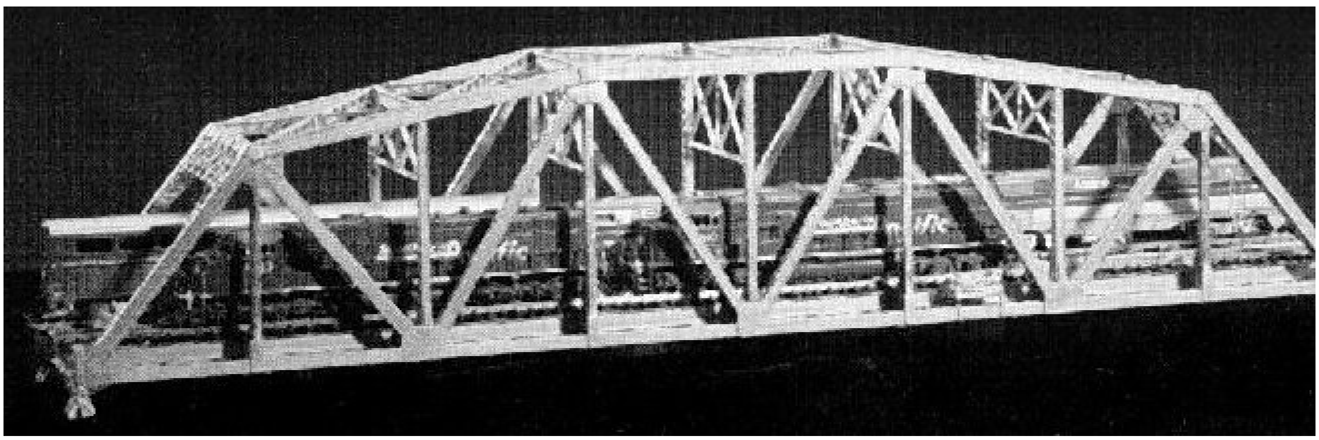
So, you've been given a project to design and construct a bridge that will hold the most weight for a given span. Now you are probably wondering where to start. What type of bridge is the strongest? (We get that question frequently from kids.) That question doesn't really have an answer. There are too many variables involved for the question to be meaningful. For example, what are your material constraints? Certainly, it would not be of much use to you were I to tell you that stone arches were the strongest, while you were instructed to build your bridge out of toothpicks.

The idea of "constraints" is an important one. The teacher did not tell you that you must build your bridge out of toothpicks (or popsicle sticks, balsa wood, or maybe even spaghetti) for no reason. Certainly one reason was so that it would be easier to compare your bridge with that of your fellow students. But the main reason that you were given the rules that you were was to "constrain" you just like bridge engineers everywhere. Before a bridge project begins we bridge engineers are told what the constraints are - what we can and can not do. It varies from job to job, and that's what makes it fun.

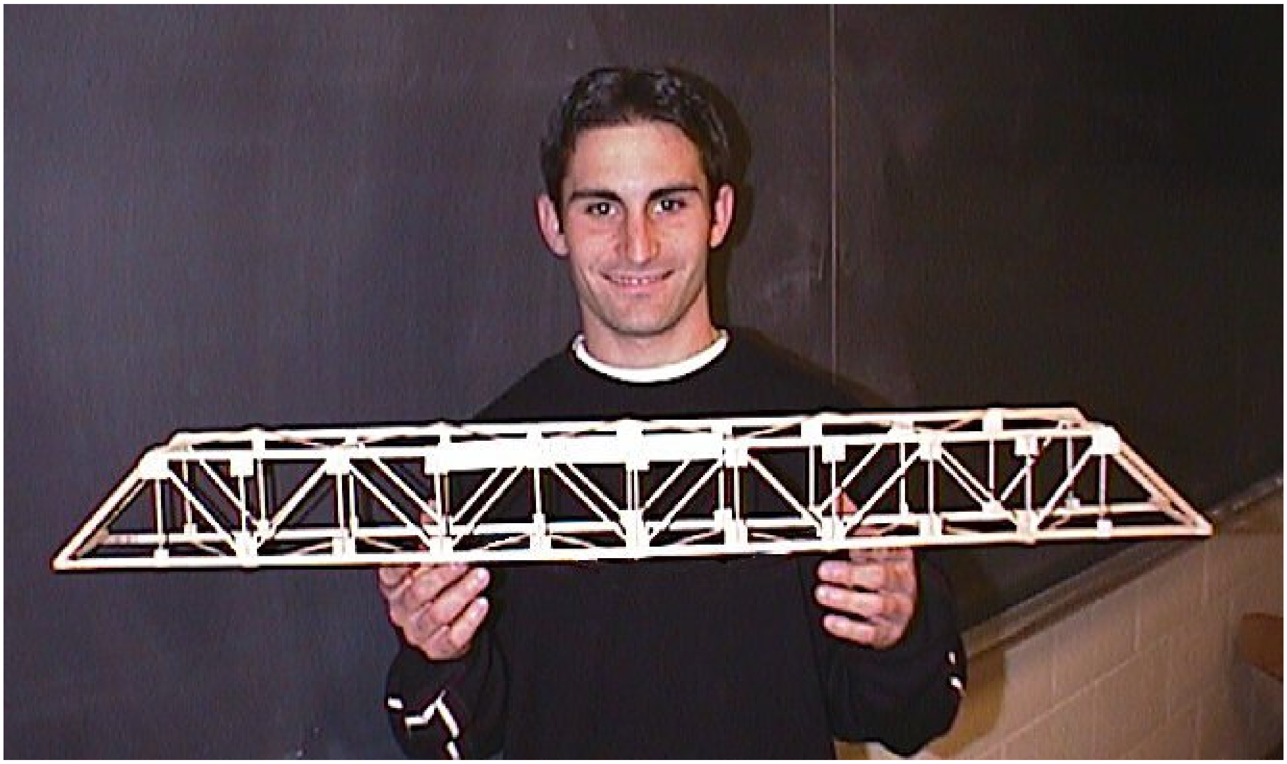
Form of Bridge

I will assume that you have been told that the bridge must span a certain distance and hold a certain weight (or the most weight compared to the other student's bridges). Am I right so far? The first thing that we must do is to pick a material. That was probably done for you by your teacher. The next thing that we must do is to pick a bridge form or type.



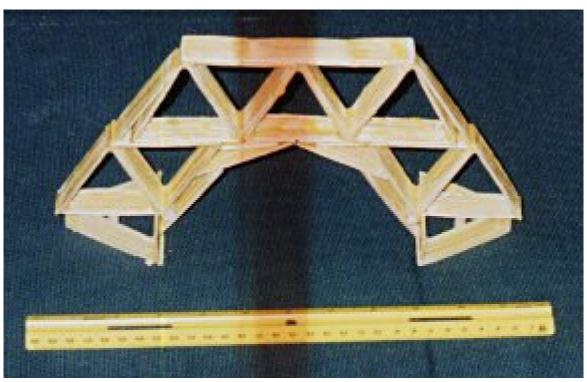
Picture courtesy of Overland Models

For the type of project that you most likely have been given, probably the best design would use the Warren truss bridge as shown above. The Warren truss is a favorite of the railroads. Each truss (there are two, one on each side of the bridge) is composed of equilateral triangles. The bridge shown in the picture is a "Warren truss with verticals" so each equilateral triangle is divided into two smaller triangles. You can accommodate various span lengths by varying the length of your members (the sides of the triangles) and/or the number of panels (the number of triangles). If you decide to add panels you should add them to the center section where the chords (the upper and lower members) are parallel and the structure is the deepest.



A nicely constructed 34 inch-span Warren truss with verticals built by Ocean County College student Andy McConnell. It supported 188 times its weight!

Picture courtesy of Ocean County College



An interesting adaptation of the Warren truss is the bridge built by high-school student Tim Kaucher. It was made out of 400 toothpicks and Elmer's Wood Glue, and *it supported his teacher*

Picture courtesy of Tim Kaucher

Another use of the Warren truss can be seen here in one of the spaghetti bridges built by students at Johns Hopkins University.

Picture courtesy of Professor Michael Karweit, Johns Hopkins University

The Importance of Connections

It is impossible to overstate the importance of connections to the strength of your bridge (or any structure for that matter). **Really!**

Look at the picture at the top of the page. Notice the "gusset plates" at the connections? This kind of detail is extremely important. Stresses flow like water. Where members come together there are stress concentrations that can destroy your structure. It would be very useful if you could visit a truss bridge and take a look at the connections there. If you are building the bridge out of balsa wood cut out and glue gusset plates similar to what Andy McConnell did in his well built bridge shown above. If you can use only toothpicks you may wish to glue little triangles of parts of toothpicks around the joints to make a kind of gusset "plate".

Here is a connection detail of one of the spaghetti bridges.

Picture courtesy of Professor Michael Karweit, Johns Hopkins University

The Properties of Balsa Wood

It is probable that your project will use balsa wood (botanical name: *Ochroma pyramidale*). The lightest of the commercially available hardwoods, it grows naturally in the humid rain forests of Central and South America. The best stands of balsa usually appear on the high ground between tropical rivers where there is plenty of rainfall and good drainage.

Balsa wood is so light because the cells of the wood are big and very thin walled, so that the ratio of solid matter to open space is very small. Woods typically have a gooey cement, called lignin, holding the cells together. In balsa, the lignin content is at a minimum. Only about 40% of the volume of balsa is solid substance. In a living balsa tree, the remainder of the volume is filled with water. That gives the tree, which can grow to 60 to 90 feet tall, the rigidity to stand. Each balsa cell is naturally pumped full of water until it becomes rigid much like a tire full of air. Green balsa wood must be kiln dried to remove most of the water before it can be sold.

If you are building a structure out of balsa wood (or any other wood for that matter) you should bear in mind that as a natural material its properties will vary considerably from piece to piece. Some of the variables involved include where and when it was grown, the orientation of the grain, the presence of irregularities, and the density of the individual sample.

You should select your pieces so as to eliminate any obvious imperfections.

You can use the following property values for design purposes:

Density	163 ± 10 kg/m³	0.00589 ± 0.00036 lb/in³

Compressive Strength¤ low density medium density high density	4.7 MPa 12.1 MPa 19.5 MPa	680 lb/in² 1750 lb/in² 2830 lb/in²
Tensile Strength¤ low density medium density high density	7.6 MPa 19.9 MPa 32.2 MPa	1100 lb/in² 2890 lb/in² 4670 lb/in²
Elastic Modulus - Compression **Elastic Modulus - Tension**	460 ± 71 MPa 1280 ± 450 MPa	66,700 ± 10,300 lb/in² 185,300 ± 65,400 lb/in²

¤ Low Density = 75 kg/m³ (0.0027 lb/in³); Medium Density = 150 kg/m³ (0.0054 lb/in³); High Density = 225 kg/m³ (0.0081 lb/in³) For the details behind these empirical data see Dalhousie University Department of Mechanical Engineering website.

All else being equal, you should select pieces of greater **density** because the strength increases more than the mass does. If you really want to optimize your project, you can calculate the forces in your trusses and then select your highest density wood for the members with the highest stresses.