



MODEL BRIDGE DESIGN

5 Steps to Building a Model Bridge

Garrett Boon

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1: Know the rules!

- Be able to define in your own words what the bridge must accomplish

2: Design the bridge

- "Center" the design around the loading point
 - Plan for extra bracing around loading point
- Choose a truss to use
 - Warren
 - Pratt
 - Howe
 - Design your own
- Draw the bridge to scale on graph paper
 - Forces you to choose sizes for everything
 - Label everything
 - Name the design and add a date

2b: Before building

- Get the wood
 - Hobby stores
 - [Specialized Balsa.com](http://SpecializedBalsa.com)
 - Pick out the "good" wood
- Tools
 - Glue
 - Saw/Exacto knife
 - Gram scale
 - Clamps/clothespins
- Workspace
 - Good lighting
 - Good ventilation

3: Build the bridge

- Step 1
 - Tape down the top and bottom chords
 - Glue on remaining pieces
 - Make sure everything is held firmly in place and let dry
- Step 2
 - Make two piles of books, spaced correctly apart
 - Tape trusses to piles
 - Glue bracing on top
 - Glue bracing on bottom
- Double check for leaning
 - Glue on lateral bracing
 - Weigh the bridge
 - Record weight and all specs of the bridge

4: Test the bridge

- Test before competition if:
 - You have time to build another bridge
 - You are only testing your bridge to a certain point
- Testing procedure
 - Bathroom scale (top loaded only)
 - Bucket and sand (top or bottom)
- Time
 - Practice if you have a time limit
 - Don't waste time loading, load the bridge quickly

5: Evaluation of the bridge

- Efficiency = mass that bridge held divided by mass of bridge
 - What is a good efficiency score?
- What failed?
 - Video taping
 - Careful examination of broken pieces
- Improving?
 - Design
 - Construction

Bonus: 25 Tips

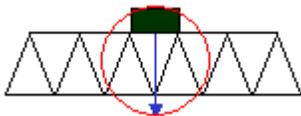
1. Know the Rules!

The most important thing you must do when building a bridge is to know the rules. You need to be able to say in your own words what your bridge must accomplish. I can't stress this point enough. Memorize the rules.

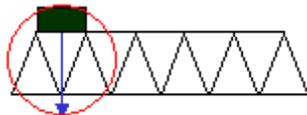
I can tell you lots of stories of people in Science Olympiad I have seen who didn't know the rules very well. They would bring their bridge to competition, only to have it disqualified because it was 2mm too wide. Not only was this very embarrassing, it could easily have been prevented had they spent a little more time reading and reviewing the rules.

2. Design the bridge

The design of your bridge needs to "center" around the point at which the bridge will be loaded. The loading point and the surrounding area have the most stress of anywhere on the bridge. You must plan to use extra bracing where your bridge is going to be loaded.



The red circle shows where the load is concentrated on this bridge.



On this bridge the load is concentrated on the end of the bridge.

If your bridge is going to be loaded in multiple places, be sure to include enough bracing for each loading point in the design of the bridge.

You need to choose a "truss" to use on your bridge. A "truss" is simply the design of the bridge. When you look at a side view of the bridge, you see the truss. Your bridge will consist of two trusses (sides) and the bracing that connects them. The two examples above use the Warren truss.

You can choose to use a common truss, such as the Warren, Pratt, or Howe. These trusses have been used by engineers in real bridges for many, many years. A lot of old railway bridges used one of these trusses. You can get more information about how each of these trusses reacts to a load on my [truss design page](#). I would certainly recommend using one of these three trusses if you are a beginner to model bridge building.

However, if you feel adventurous, you can also design your own truss. You could mix two of the trusses I mentioned above, and come up with a hybrid design. I did this on my [Fernbank Bridge](#). However, if you do decide to design your own truss, make sure you plug it into the [Bridge Designer](#). If you don't know how to use the Bridge Designer, see my [Bridge Designer Help page](#).

Once you have picked out the design, you need to draw it on paper. I would recommend getting some 11" by 17" graph paper. Or you could tape two (or more if needed) sheets of regular graph paper together.

It is a good exercise to draw at least one bridge design to 100% scale. That means every piece of your bridge that you draw on paper will be the same size as it is in real life. Now, I don't draw many designs to 100% scale anymore, I just draw the outline. However, it is good for beginning builders to see the full design on paper.

Besides drawing the basic design on paper, also draw in some of the information you get from the [Bridge Designer](#). I would label which pieces will be in compression and tension, and the amount of force on each piece. That is the information you get from the Bridge Designer.

I also like to give each bridge design a name, and write that at the top of the drawing. But sure to include the date that you designed the bridge.

2b. Before Building the Bridge

There are few things you need to know and get before you can start building the bridge. The first thing to get is naturally the wood. Now, your particular rules may specify what type of wood you have to use. Most likely it is Balsa or Basswood, both of which can be found at local hobby stores, and multiple places online (such as [Specialized Balsa](#)). Or perhaps you must use popsicle sticks or toothpicks.

Not all wood is equal. Now you may be thinking, "It's a toothpick, they're all the same." Well, that isn't the case. Some toothpicks will be stronger than others. It is the same with popsicle sticks, and Balsa and Basswood. Here are some tips on choosing good wood:

Balsa will give you the most problems getting good wood. This is because Balsa wood is sold in a wide range of densities and stiffness. So you may find two sticks of wood at a hobby store that are the same size, but one may be twice as strong as the other.

How do you get good wood? When you work with Balsa wood a lot, you can begin to recognize signs that will tell you about the strength of the wood.

Stronger wood is more dense. You can do a "squeeze" test, where you lightly squeeze the end of a piece between your fingers. If the balsa begins to crush easily, then you have a low density, low strength piece. The opposite is true, if the piece is hard to squeeze, then it is stronger. However, there is a time and place for both low and high-density wood.

Now I don't want you to start squeezing every stick of Balsa wood in your local hobby store. Also, you don't have to completely flatten the wood to use the squeeze test. Barely start putting pressure on the wood, and if it begins to crush, stop squeezing. That way, you don't ruin the end of that piece of wood.

Typically, wood that is lighter in color is also lower in density than darker wood, which is usually high density. Remember that the higher the density, the stronger the piece of wood is.

I have worked with enough Balsa wood for so long, that I can roughly tell the density by the weight of the wood. I can go to the hobby store, pick up a 1/8 inch square piece, and by using the squeeze test and by the weight of the stick, I usually have a good idea about the strength/density of the stick of wood. Basswood is naturally much more dense than Balsa, so you can't use the squeeze test for it.

For more information about Balsa and Basswood, [click here](#). Also check out my webpage about [choosing good popsicle sticks](#).

Glue

Next to the wood, glue is the most important component of your bridge. Now, your rules may limit what type of glue you can use, so do the best with what you have.

For Balsa wood, yellow wood glue thinned with water (about 70% glue 30% water) is a good choice. Polyurethane based glues (such as Gorilla glue) are very strong, but they are heavy and slow to dry. Cyanoacrylate (CA glue) is a good choice if you want a very fast drying glue. For more information about glue, see my [Glue Tips](#) page.

Tools

There are a couple tools I would recommend that you get. One, is some sort of saw, like this one:



They aren't very expensive, and if you are going to be doing a lot of cutting you won't regret getting one. I would definitely get one if you are going to be cutting Basswood or popsicle sticks.

Another option for a cutting tool is an Exacto knife. A real Exacto knife is extremely sharp, and you must be very careful using it. I don't let my middle school students even handle an Exacto knife unless they can show me they are mature enough, or already have experience with one. If you buy one, make sure you get one with a cap. Even though I do most of my cutting with the saw, sometimes you just have to have an Exacto knife.

In addition to a cutting tool, clamps are also very helpful. Clothespins work very well, and most people already have some lying around. Not all clothespins are equal. You want some that are fairly strong, but not strong enough to crush the wood. This is especially important if you are working with low density Balsa wood.

I also have some clamps that I got from the dollar store that I really like. They open up much wider than clothespins, and are slightly stronger. They are a little trickier to use, but I have found them to be very helpful.



I have found having a gram scale around to be extremely helpful, especially for Science Olympiad. [The scale I use](#) measures to 0.01 of a gram. I bought it off Ebay for only \$20, including shipping. I consider this the best investment I have made to date. A gram scale that measures to 0.01 grams like this might be too expensive to buy if you are only building only a couple of bridges or less. However, you may know someone who would let you borrow one. Most schools have a digital gram scale of some sort.

I like to have a digital scale when I am measuring very small pieces of wood. I weigh each and every stick of wood that I get and then calculate the density and stiffness coefficient. I am highly selective on the wood I use in a bridge or tower.

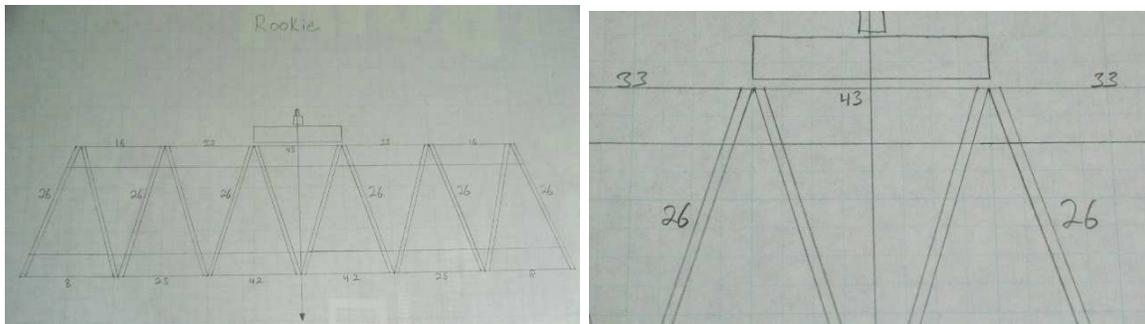
There may be other tools and things you may want, but I have listed the basics.

Workspace

Where are you going to be building your bridge? Places like a garage or workshop work great, but not everyone has that option. You can build the bridge almost anywhere (except on the new kitchen table). You want to work in a place with good lighting, good ventilation, and have a trashcan nearby.

3. Build the Bridge

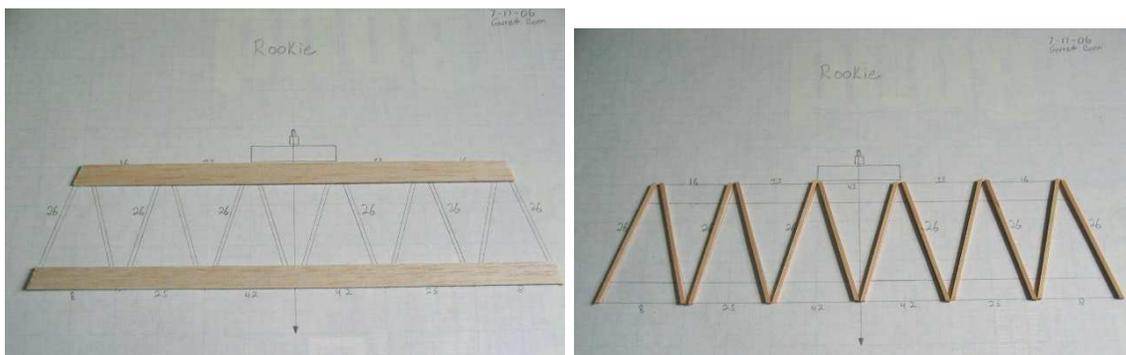
Now we come to the actual construction of the bridge. The first thing you want to do is lay out the full scale drawing in the location you chose to build your bridge. You might want to tape the drawing down, but that isn't necessary.



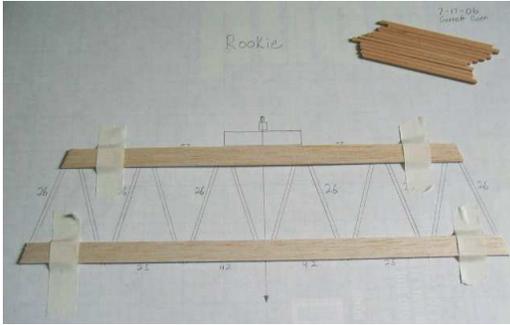
You can see the numbers on the drawing. Those numbers are the % of total load on that piece. I have also drawn a “loading block” for visual purposes.

Step 1

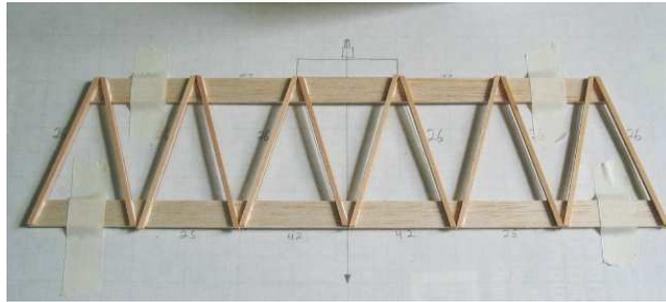
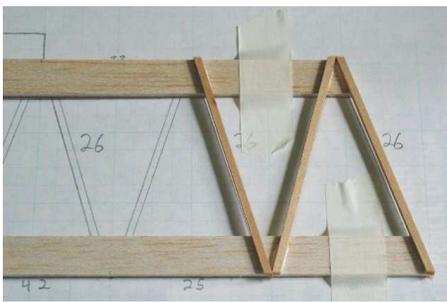
Cut out every piece you will be using for this side of the bridge. You can use your drawing to help make sure every piece is the correct side.



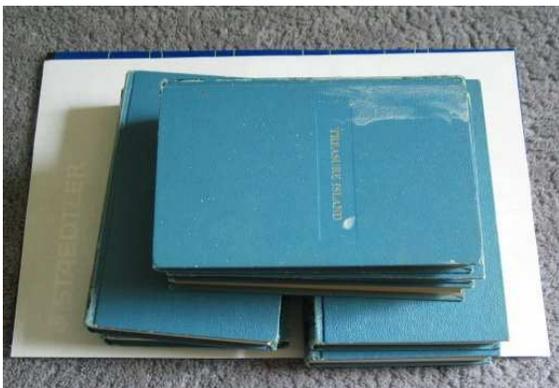
Now take all the pieces off the drawing. Tape down the top and bottom chords. Make sure to tape in-between where the other pieces are supposed to go!



Double check, and make sure that they are exactly in place. Now you can glue on the remaining pieces to the truss.



Lay something heavy over the entire truss, to help hold down all the pieces. I normally use books or any heavy object around.



Note: If you are using different sizes of pieces for the compression and tensions members, you need to glue on the smaller pieces first, then lay something over the bridge until it dries. Then glue on the bigger pieces and once again lay something over the bridge.

Repeat this process to make the other side of the bridge.

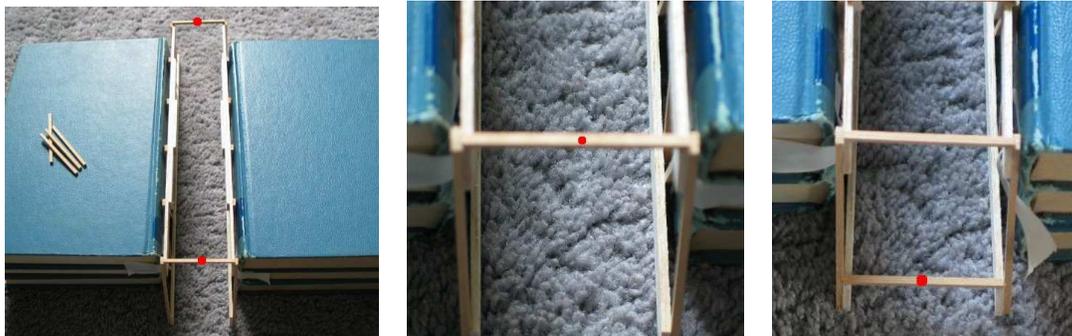
Step 2

Once the two sides are completely dry, you can proceed with the next step. Make two piles of books, spaced apart the exact width you want the bridge to

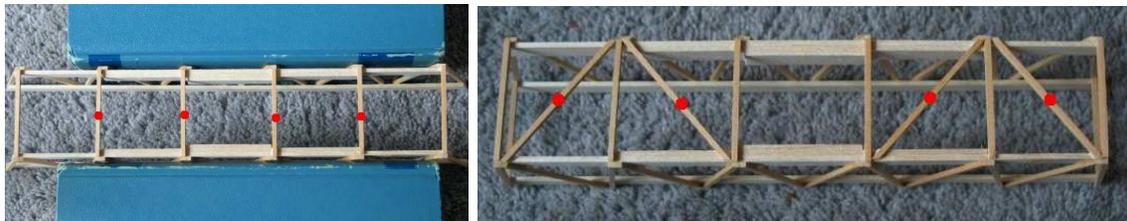
be. The two piles don't need to be the exact same size, but both piles can't be any taller than the height of your bridge. Encyclopedias work great for this.

Tape both sides of the bridge to the inside of the piles. The outside part of each side needs to be up against the pile it is taped to. You want to make sure that each side is perfectly vertical, and isn't leaning at all. **This is extremely important.** You can easily adjust the two piles of books to take out any lean.

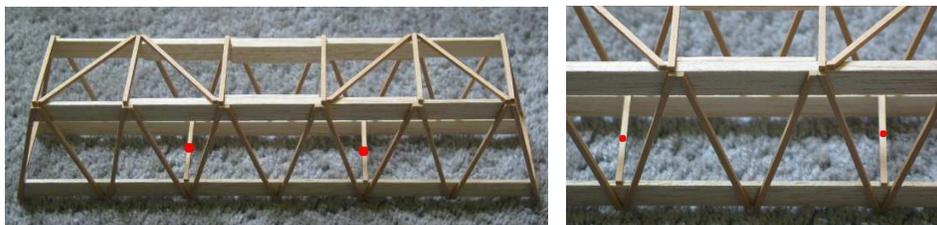
Now, you will glue the two sides together by gluing on lateral bracing. First glue two pieces to connect the ends of each side on both top and bottom.



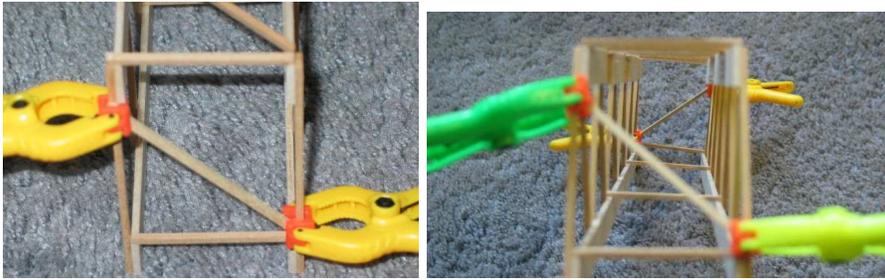
Now glue on more lateral bracing as shown:



Now carefully un-tape the bridge and move the piles of books out of the way. Carefully flip the bridge over. The bottom of the bridge doesn't need as many connectors as the top, but still I would add two more.



After you let the bracing dry, you want to double check that your bridge isn't leaning. Even the slightest bit of lean will greatly reduce the strength of your bridge. I can't stress that point enough. If your bridge is leaning, you will need to use lateral bracing to pull the bridge back into shape. You will need either some sort of clamps such as clothespins.



Now you will want weigh the bridge. Make sure to write down the weight, as it will be very important in determining the efficiency of the bridge. The bridge in the pictures weighs 15.95 grams.

4. Testing the Bridge

Now comes the fun part. You finally get to destroy the bridge you have spent hours making. There are a couple of different methods of testing, you choose which one will bring you the most enjoyment.

However, there are a few cases where you don't want to test your bridge. If you are building a bridge for a competition, and that competition happens to be only a couple days away, you don't want to test the bridge. Only test your bridge if you have enough time to build a new one. I guarantee you won't want to be building late the night before competition, not to mention you never do as good of a job when rushed.

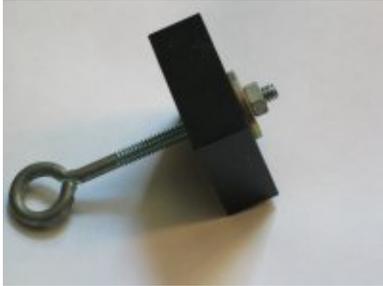
Also, you may not want to test your bridge if the goal of your competition is to break the bridge. If you are going to keep adding weights until the bridge breaks, you probably don't want to test it beforehand. Unless you only test the bridge a little bit, so that you know it can hold at least some weight. Once again, don't test it if you are very close to a competition.

Testing Method #1

I use two main testing procedures. Both are fairly simple to set up, and most anyone can do either. The first way I use to test all my popsicle bridges. I simply set the ends of the bridge on two blocks, and put a non-digital bathroom scale on top of the bridge. I push down on the scale with my hands until the bridge breaks. The key here is to carefully watch the scale to catch the exact weight the bridge fails at. You have to pay close attention. If I think the bridge will hold a lot of weight, I will not use my hands to push on the scale. Instead, I carefully lower myself onto the scale **feet first**. This method only works for top-loaded bridges. Once again, you have to pay close attention to the scale, and note when the bridge breaks.

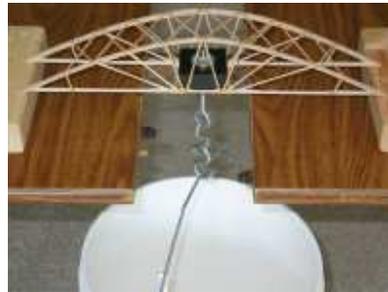
Click this link to watch me testing a popsicle stick bridge with this method:
<http://www.garrettsbridges.com/popsiclebridge.html>

Testing Method #2



The second method I use for all my Science Olympiad bridges and towers. This method works for both top and bottom loaded bridges. First I take the leaf out of our old table, and simply lay the bridge over the gap. You can pull two tables close together if you don't have a table with a removable leaf. I then put a loading block on the bridge. The loading block I use comes from Pitsco, and follows the Science Olympiad rules. You can cut your own loading block from a piece of plywood. The loading block will need to have a small hole in the center (1/4 inch).

I then attach an eyebolt to the loading block, and hang a chain from the bolt. With a S-hook, I attach an empty 5-gallon bucket to the chain. I then proceed to fill that bucket up with sand. I stop when the bridge fails or I am satisfied with the amount held. This way can be used with either top-loaded or bottom-loaded bridges. When the bridge fails, I simply weigh how much sand it held.



This second way is slightly more difficult to setup and do, but it provides more suspense. The first method can be done in less than a minute, where the second way might take 5-15 minutes.

If you are building a bridge for Science Olympiad or similar competition, I recommend the second method. I would also recommend that you practice loading the entire amount of sand (15kg) within the specified time limit. And if you want to go to the advanced level, there is a whole art to pouring the sand. But the main thing is to not waste your time pouring the sand. The longer you take, the longer the bridge has to hold the load. Pour quickly but steadily.

There are also some competitions that will have a machine loading the bridge. Of course the machine will be able to load the bridge to a much greater extent

than either of these two methods. In that case I would recommend not testing your bridge beforehand.

Safety First

Always wear proper eye protection when you are testing a bridge. Always. You never know when the bridge will explode and send wood fragments into your eyes.

Go to this link to watch me testing the bridge built in this guide:

<http://www.garrettsbridges.com/samplebridge.html>

5. Evaluating the Bridge

So you have tested the bridge, either at home or a competition. But now what? If you haven't already, I would recommend plugging in your design to the [Bridge Designer](#), and adding a load in the program equal to the one your bridge held. By doing this, you can see exactly how much load was on each of the bridge members when they broke.

To measure the efficiency of the bridge, simply take the amount of weight the bridge held and divide that by the mass of the bridge. Of course you need to make sure to use the same units for each. I usually measure the mass of the bridge in grams, but load the bridge in pounds. So I convert pounds to kilograms by dividing the number of pounds by 2.2. Then, since that is kilograms, I multiply that number by 1000 to get the number of grams the bridge supported. Now I can divide that number by the mass of my bridge in grams.

The bridge in the pictures weighed 15.95 grams, and held 39 pounds. 39 pounds converts to 17.73 kilograms, which is of course 17730 grams. Dividing 17730 by 15.95 gives me 1111. So the bridge's efficiency score was 1111. That basically means the bridge held 1111 times its own weight. Please note I am not paying attention to the number of significant digits here.

This might sound complicated, but it really isn't once you get used to doing it.

What is a good efficiency score for a bridge to have? That depends on the restrictions you had for building the bridge. A bridge from toothpicks probably won't be able to have as high efficiency as a bridge from popsicle sticks. This is due to several reasons, but I won't go into those here.

The best bridge I have built so far is my [Fernbank Bridge](#). It had an efficiency score of over 4200. However, I had virtually no restrictions as to how I could build the bridge, and what materials I could use. For Science Olympiad, the

best bridge I built only had an efficiency score of 1584 (2004). Each year, as the rules change for Science Olympiad, the efficiencies will fluctuate.

So I can't exactly say what would be a good score for your bridge, unless it would be this: Better than anyone else in your competition ;). There are simply too many variables in the various competitions to predict a good score without knowing the details of that competition. If your competition has been run for more than one year, you can ask what was the best bridge last year. If the bridge requirements haven't changed since then, you can get a good idea of what your bridge needs to hold.

But efficiency is only part of evaluating a bridge. If you want to improve, you need to know how and why your bridge broke. Or, if your bridge didn't break, and held the maximum weight, you need to be able to know how to make the bridge lighter without losing strength.

This is where the [Bridge Designer](#) is extremely helpful. It shows you where the load is distributed throughout the bridge. If a certain area of your bridge broke, you know you have to make those pieces stronger. Or if the bridge didn't break, the program will show you where the load isn't as concentrated, so you can reduce weight of those pieces.

Overall, bridge evaluation is a difficult subject with a lot of variables. I can't tell you exactly how to make your bridge better without seeing your bridge.

One thing you may want to consider is taping the testing of your bridge. You can then watch it in slow mode, and perhaps get a clue where the bridge broke first. However, just watching from one angle sometimes won't be of any help. The ideal situation would be to have a camera on both sides of the bridge, as well as one camera looking through the bridge. But that isn't a really practical solution. Sometimes you just have to guess at where the bridge broke, and go from there. Once you build and test several bridges, you should start seeing trends as to how the bridges break.

If you watched the video of me testing the bridge I built in this guide, you may have noticed the one piece that popped loose shortly before the bridge collapsed. What happened in this case is that one glue joint wasn't good enough, which caused that piece to break loose. You probably noticed the bridge started bending a lot more after that piece came loose.

I certainly hope this has been helpful to you. If you have any more questions, I would be more than happy to try to answer them. Just contact me through the form at <http://www.garrettsbridges.com/contact.php>

25 Tips:

1. Humidity affects the weight of your bridge. Keep your bridge in a closed container with a few grains of rice.
2. Go easy with the glue bottle. As a general rule of thumb, if you can see it than you are using too much.
3. Keep your hands clean! Oils and grease from your skin can ruin your glue joints.
4. Perfect practice makes perfect. The more bridges you build, the better your construction skills will be.
5. Keep your bridge from twisting by using [lateral bracing](#).
6. An L-beam is more efficient than a square, but harder to build.
7. Balsa wood comes in a wide range of densities. Weigh each piece that you buy.
8. It is cheaper to buy Balsa in sheets and cut your own wood strips.
9. It's still true, measure twice and cut once.
10. Keep a log of every bridge you build. Record notes and dimensions; you won't remember later on.
11. Try to videotape testing your bridge. You may get a clue on what failed first.
12. Always keep safety in mind when using sharp tools. Most mistakes are made when you aren't paying attention.
13. By cutting a piece in half, you more than double its strength in compression.
14. Good lighting when working will help you perfect those little details.
15. Always test your bridge before taking it to a competition, but leave enough time to build another.
16. Draw out your bridge on graph paper to make sure that it is symmetrical. I prefer the 11" x 17" graph paper.

17. Different trusses have different ways of spreading out the load.
<http://www.garrettsbridges.com/trussdesign.html>
18. Wood has about the same strength in tension, no matter how long it is.
19. CA glue is a fairly strong, light, fast-drying glue used by many builders.
<http://www.garrettsbridges.com/gluetips.html>
20. Balsa wood sands very easily. Be careful not to sand off too much.
21. You can mix wood glue with water to cut down on weight. Doing this also helps the glue to seep into the wood, creating a stronger joint.
22. Remember to close your glue bottle when you are done using it.
23. Basswood will bend easier than Balsa wood. Try steaming or soaking your wood to help it bend. <http://www.garrettsbridges.com/bendingwood.html>
24. Use Lap joints whenever possible to get the best strength.
<http://www.garrettsbridges.com/bridge-joints.html>
25. What you want to look for in glue: drying time, price, weight, and strength.