IMAGINE! STEM @ Home

In this home activity pack, we look at some of the simple tools man has used through the ages (and still uses today), and then ask you to **"Imagine!"** how some of the bridges we see around the world today appear to defy gravity.

Finally, there is a competition in which we ask you individually to build a model bridge using only old cereal boxes, string, Sellotape and glue which will support a 300g can of Baked Beans. Full details at the end of the document.

We invite you to send a video of your Bridge attempts, both successful and those which don't quite defy gravity! to us for judging before the competition close date of 1 July please.

Prizes will be awarded for the best (and worst) attempts.

Please avoid including recognisable videos of yourself and be sure to get your parents' permission.

There will be two categories:

1. Pupils currently in years 7, 8 and 9.
2. Those in year 10 and above.

Please indicate which category you are entering.

Winners will be announced on 7 July and we hope to invite all competitors to Anglia Ruskin University later in the year to showcase their attempts.

SIMPLE MACHINES

We will look at three simple machines which have been used successfully through the ages, and how they have been adapted by engineers in the modern world. These machines are, **the lever, the pulley, and the wheel-and-axle.**

In general, engineers use the lever to magnify the force applied to an object, the pulley to lift heavy loads over a vertical path, and the wheel-and-axle to magnify the torque applied to an object. The **mechanical advantage** of these machines helps determine their ability to make work easier or make work faster.

Mechanical Advantage is the amount of help you can get by using a simple machine.

$$MA = \frac{\text{Force out of a machine}}{\text{Force input to a machine}}$$

Simple machines are extremely valuable to engineers since they can be used to accomplish large amounts of work with relative ease.
Many of todays most complex machines are a combination of one or more simple machines. The lever, pulley and wheel-and-axle can be found in many engineered devices, such as a crowbar, crane and bicycle.

Many engineers today, especially mechanical engineers, are very interested in simple machines and their ability to carry out an immense amount of work with minimal effort. To understand how this is achieved, it is necessary to recall that work is done by applying force to a load and transporting it over some distance. The more force applied and the further the load is moved, the more work is done. This idea is expressed mathematically as

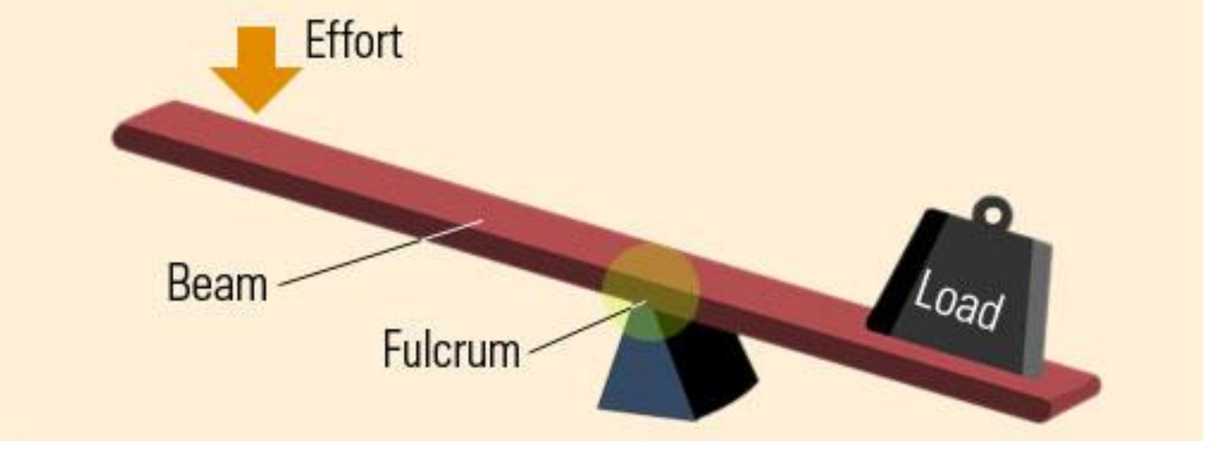
$$\textit{Work} = \textit{Force} \times \textit{Distance}$$

The Lever

A lever is simply a plank or ridged beam that is free to rotate on a pivot. It is perfect for lifting or moving heavy things. It is a very useful simple machine, and you can find them everywhere. Good examples of levers include the seesaw, crowbar, fishing-rod, oars, wheelbarrows and the garden shovel.

Parts of a lever

Levers have four very important parts — the bar or beam, the fulcrum (the pivot or the turning point), effort (or force) and the load.



The beam is simply a long plank. It may be wood, metal or any durable material. The beam rests on a fulcrum (a point on the bar creating a pivot).

When you push down one end of a lever, you apply a force (input) to it. The lever pivots on the fulcrum, and exerts an output force on the load. A lever makes work easier by both increasing your input force and changing the direction of your input force.

The Three Lever Classes

The parts of the lever are not always in the same arrangement. The load, fulcrum, and effort may be at different places on the plank.

Class One Lever

In this class, the Fulcrum is between the Effort and the Load. The mechanical advantage is more if the Load is closer to the fulcrum. Examples of Class One Levers include seesaws, boat oars and crowbars.

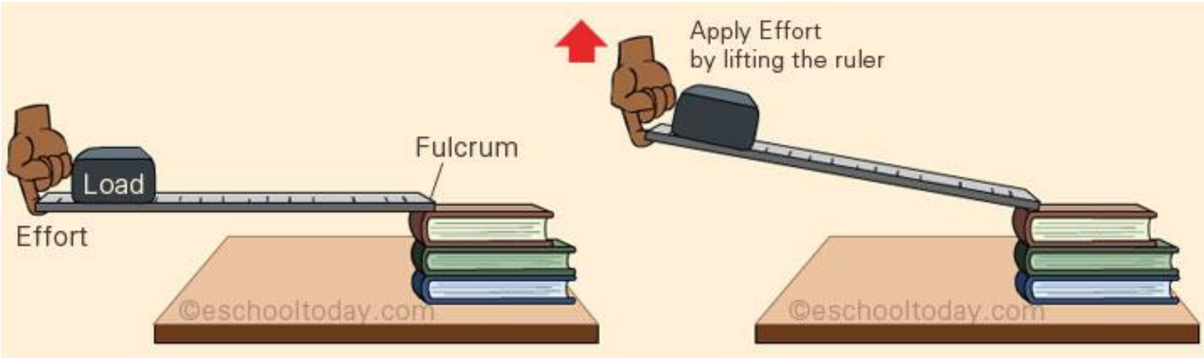
Class Two Lever

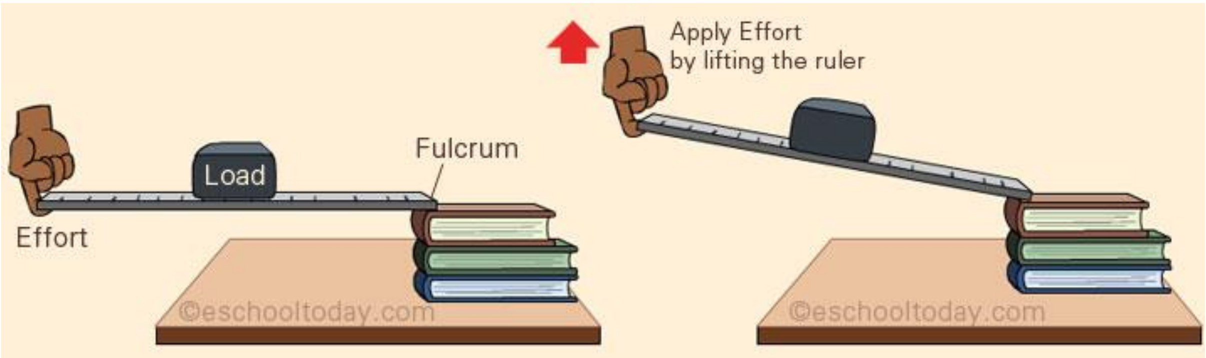
In this class, the Load is between the Effort and the Fulcrum. The mechanical advantage is more if the load is closer to the fulcrum. Examples of Class Two Levers include wheelbarrows.

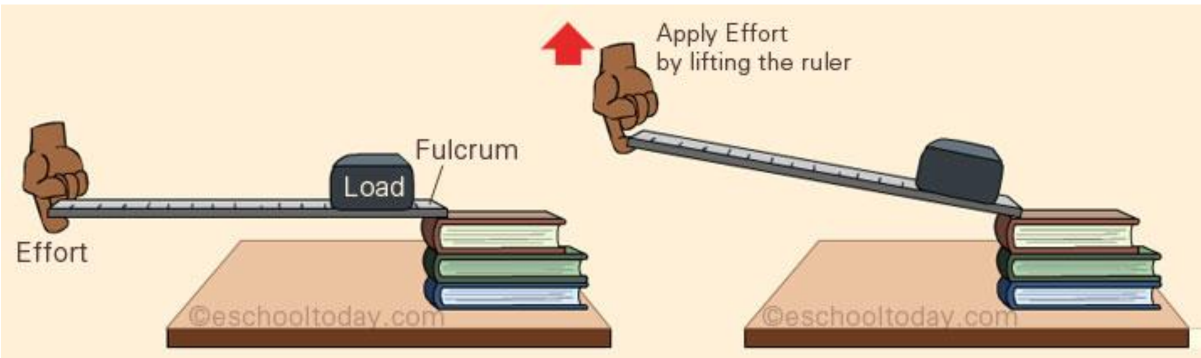
Class Three Lever

In this class, the Effort is between the Load and the Fulcrum. The mechanical advantage is more if the effort is closer to the load. An example of Class Three Lever is a garden shovel.

TRY THIS AT HOME







You will see that less effort is required to move the load the closer the load is to the fulcrum. (A Class 2 lever).

Look at the following video on levers.

https://www.youtube.com/watch?v=YlYEi0PgG1g

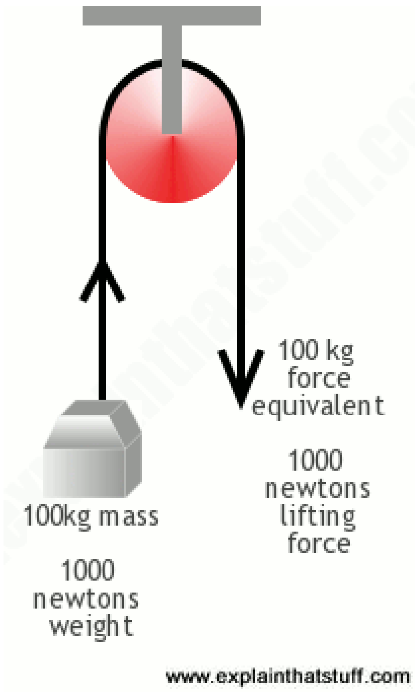
PULLEYS

Similar to Levers, Pulleys allow for the lifting of heavy objects with less effort by exchanging force for distance.

To use a pulley, a rope is wrapped around a wheel. The wheel is mounted to a sturdy beam or other secure object and a hook is attached to one end of the rope to secure the object that is to be lifted. The other end of the rope is then pulled to lift the object.The more wheels you have, and the more times you loop the rope around them, the more you can lift.

One wheel

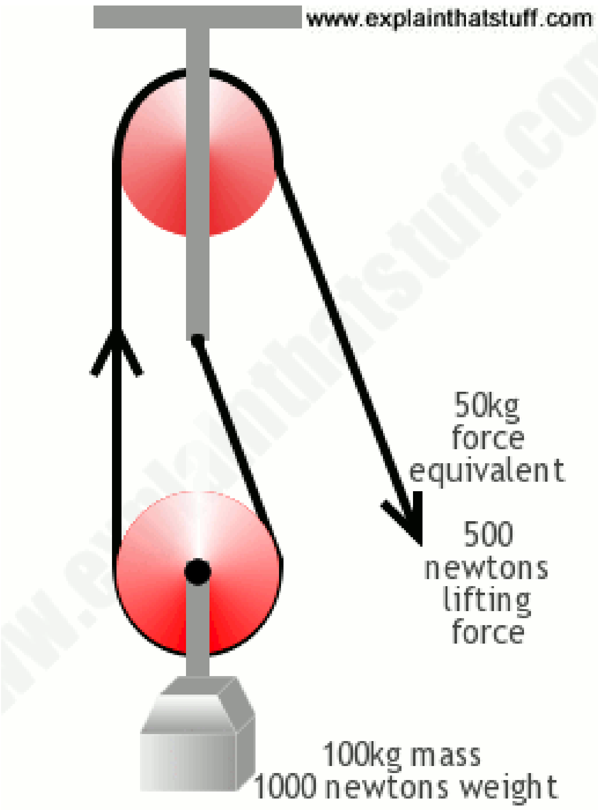
If you have a single wheel and a rope, a pulley helps you reverse the direction of your lifting force. So, as in the picture below, you pull the rope down to lift the weight up. If you want to lift something that weighs 100kg, you have to pull down with a force equivalent to 100kg, which is 1000N (newtons). If you want to raise the weight 1m into the air, you have to pull the loose end of the rope a total distance of 1m at the other end.



Two wheels

Now if you add more wheels, and loop the rope around them, you can reduce the effort you need to lift the weight. Suppose you have two wheels and a rope looped around them, as in the figure below. The 100kg mass (1000 newton weight) is now effectively supported by two sections of the same rope (the two strands on the left) instead of just one (ignoring the loose end of the rope you're pulling with), and this means you can lift it by pulling with a force of just 500 newtons—half as much! That's why we say a pulley with two wheels, and the rope wrapped around it this way, gives a **mechanical advantage** (ME) of two.

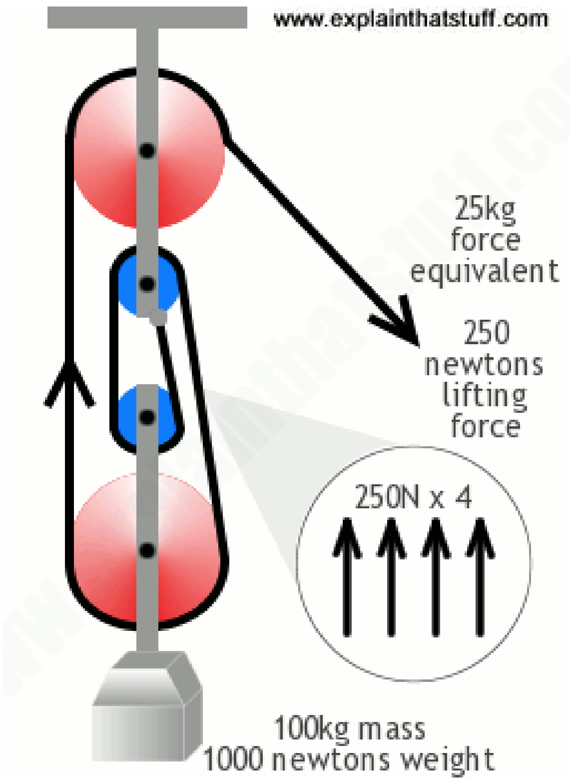
Mechanical advantage is a measurement of how much a Simple Machine multiplies a Force. The bigger the mechanical advantage, the less force you need, but the greater the distance you have to use that force. The weight rises 1m, but now we have to pull the loose end of the rope twice as far (2m).



The reason? To make the weight rise 1m, you have to make the two sections of rope supporting it rise by 1m each. To do that, you have to pull the loose end of the rope 2m. Notice that we can also figure out the mechanical advantage by dividing the distance we have to pull the rope by the distance the weight moves.

Four wheels

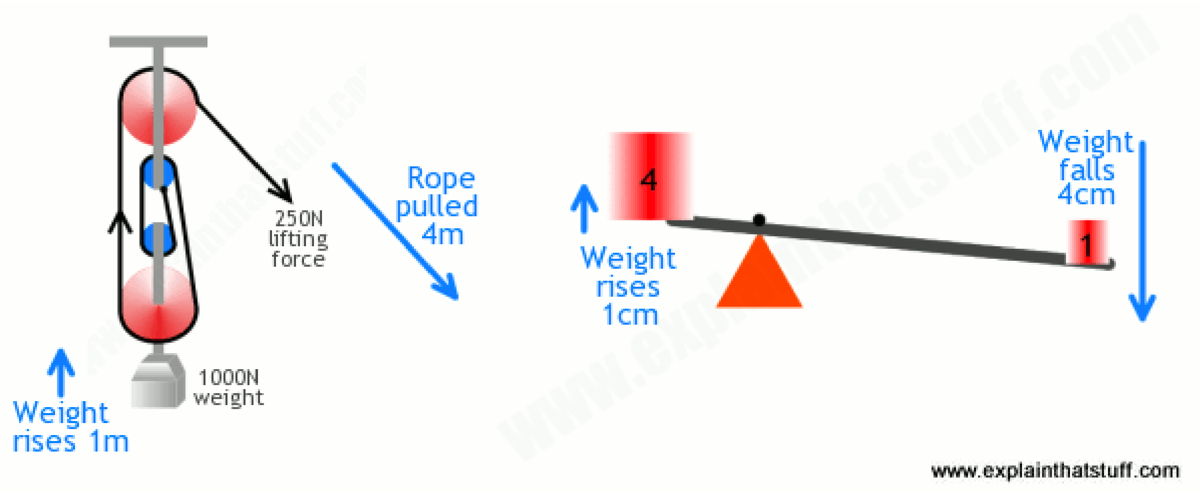
Similarly, if you use four wheels held together by a long rope that loops over them, as in the picture below you can see that the 100kg mass (1000 newton weight) is now hanging from four sections of rope (the ones on the left, ignoring the loose end of the rope you're pulling with). That means each section of rope is supporting a quarter of the total 1000 newton weight, or 250 newtons, and to raise the weight into the air, you have to pull with only a quarter of the force—also 250 newtons. To make the weight rise 1m, you have to shorten each section of the rope by 1m, so you have to pull the loose end of the rope by 4m. We say a pulley with four wheels and the rope wrapped around like this gives a mechanical advantage of four, which is twice as good as a pulley with two ropes and wheels.



How a pulley is like a lever

You can probably see that a pulley magnifies force in a similar way to a seesaw, which is a kind of lever. If you want to lift someone four times heavier than you on a seesaw, you need to sit four times further away from the balancing point (fulcrum) than they are. If you move your end of the lever down by 4cm, their end of the seesaw moves up only 1cm. As they rise up, they gain a certain amount of potential energy equal to their weight multiplied by the distance they move. You lose exactly the same amount of energy—equal to your weight (four times smaller) times the distance you move (four times larger). You can shift their much bigger weight because you move your end of the seesaw over a much bigger distance: the leverage of the seesaw makes it possible to produce more force by working over a bigger distance.

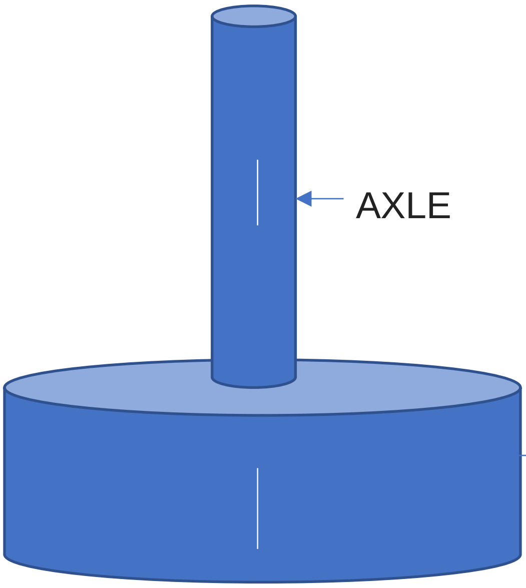
The same thing is happening with a pulley, except that you're pulling on a rope instead of moving the end of a seesaw. To lift something four times heavier, you can use exactly the same force but only if you pull the rope four times further. If you look at what's happening on both sides of a pulley, and multiply the force by the distance moved, you'll find it's the same. On your side, you use a small force over a large distance. On the other side, there's a much bigger weight but it's moving a shorter distance.



Follow the link below to see Pulleys in action:

https://www.youtube.com/watch?v=LiBcur1aqcg

THE WHEEL AND AXLE



The Wheel and Axle is a Simple Machine for amplifying Force.

As the wheel and axle are physically fastened together, if the wheel is turned one revolution, then the axle turns one revolution also. However, the white line on the wheel will have travelled a much greater distance than the white line on the axle.

We already know that work done is measured as Force Applied x Distance Moved, so it follows that the output force available at the Axle must be much larger than the force applied at the wheel in order for the Work Done to be the same.

https://www.youtube.com/watch?v=ndT35aqDfAQ

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BRIDGES

Man has used bridges through the ages to simplify the movement of people and goods across hostile terrain. Bridges are generally thought of as static structures, but they actually act more like dynamic, living beings. They change in response to different loads, weather patterns, and other types of stress in order to function.

Many of the bridges we see today are based on designs thousands of years old, and it's mainly improvements in the materials available to engineers which facilitate the design of the massive structures we see round the world today. Over thousands of years of human civilization, engineers have gradually developed more sophisticated bridge designs that can span ever greater distances.

Beam bridges are the simplest bridge form and may comprise only a tree trunk laid between river banks. The problem is that this type of bridge can only stretch so far before it collapses under it's own weight.

Gravity isn't such an issue with a building, even a very large one, because the ground below them is always pushing back. The most profound force affecting bridges is gravity, which is constantly pulling at them, trying to drag them down to earth. When it comes to bridges, the space under the decking provides no support against gravity, so why are bridge failures a relatively rare occurrence, and what is it that keeps them from tumbling down due to the force of gravity?

To understand, we need to think about the forces bridges are subjected to.

Tension: the pulling force
Tension in structures isn't the same thing you feel when you forget to study for a test. Tension is a pulling force. It stretches materials. Link your hands together and pull. You feel tension. Stretch a rubber band. You see tension in action. The rubber stretches, and the band gets longer. It's in tension.

Materials in tension for example are rope bridges, telephone wires, and the cables supporting a lift.

Compression: the pushing force
Compression is a pushing force, it squashes materials. If you put your hands together and push hard, you feel compression. Hold a balloon between your hands and press, the balloon is in compression. An example of materials in compression are the legs of chairs, pillars supporting bridges and book shelves.

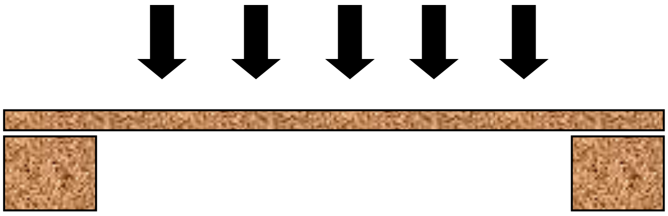
When a load is applied to a beam, the top half of the beam shortens (in compression) and the bottom half gets longer (in tension).

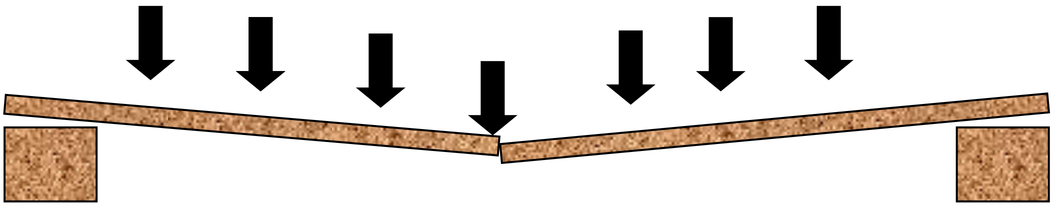
Follow the link below

https://www.youtube.com/watch?v=N_DLcS1BVc4

BEAM BRIDGES

The farther apart its supports, the weaker a beam bridge gets. As a result, beam bridges rarely span more than 250 feet.



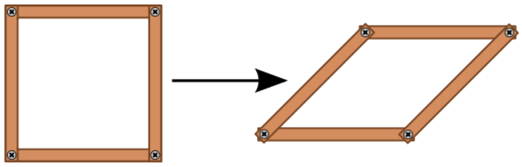


This doesn't mean beam bridges aren't used to cross great distances it only means that there may be a series of beam bridges joined together, creating what's known as a "continuous span."

The Power of the Triangle

There are many types of triangles: *equilateral* triangles (all three sides have equal length), *scalene* triangles (none of the sides have equal length), *isosceles* triangles (at least two sides have equal length), *right-angled* triangles, *obtuse* triangles (one angle is greater than 90degrees), and *acute* triangles (all angles are less than 90 degrees). But all triangles have one thing in common (apart from having three sides): they are **stable.**

The best way to understand this is to think of a different shape, for example a square. If you make a square from four metal rods with hinges at their corners, you will find that it doesn't stay square. It can easily be transformed into a parallelogram. You don't have to bend the sides to do that, it happens just because of the hinges at the corners.



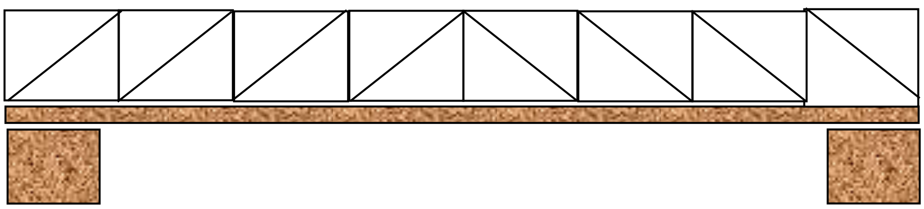
For a triangle, no matter what type, this can't happen. It's inherently rigid. That's a very special property to have, and why you see triangles all over the place in the world around you. In electricity pylons, cranes, bridges, and many houses.

The following video looks at the relative rigidity of Squares and Triangles.

https://www.youtube.com/watch?v=mBHJtWbsiaA

So, adding triangles to a beam bridge adds Support, Stability and Stiffening to the bridge structure.

By distributing the weight, this TRUSS system makes a BEAM BRIDGE more rigid.



The reason we see so many different types of bridges today is simply that, over thousands of years of human civilization, engineers have gradually developed more sophisticated bridge designs that can span ever greater distances. This gradual evolution, and increased length of bridges has been made possible partly by a deeper understanding of engineering, but also by the development of far stronger materials. Arch bridges were popular in the Middle Ages, for example, because they were quick and easy to build from locally sourced materials and lasted a long time with little or no maintenance.

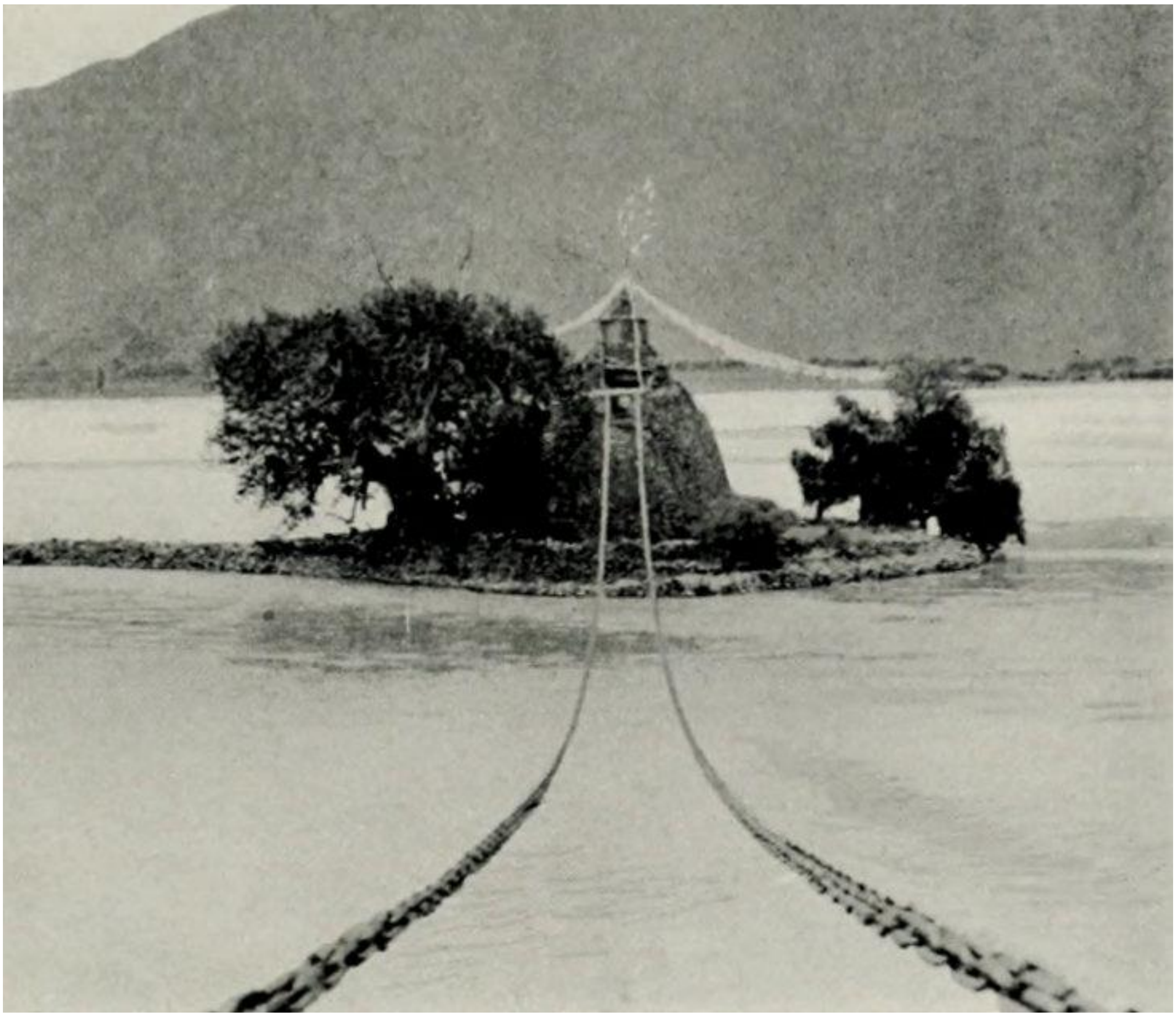
Arch bridges are the easiest type of bridge to recognize, they are one of the oldest types of bridges and have extraordinary natural strength. Instead of pushing straight down as beam bridges do, the weight of the arch bridge and any additional load on the bridge is carried outward along the curve of the arch to the supports at each end.

These supports are called abutments. Abutments distribute the load from the bridge and keep the ends of the bridge from spreading out. The Romans were masters of the arch bridge. Many of their arch bridges used little or no mortar, or "glue," to hold the stones together. The goal of an arch bridge is to carry all loads in compression, without any tensile loads present. The stones in the structures stay together by the sheer force of their own weight and the compression transferred between them. The size of the arch, or the amount of curvature, has a major effect on the effectiveness of this type of bridge.

https://www.youtube.com/watch?v=CP3fMa9iq8w

Modern bridges benefit not only from the scientific progress made through the centuries, but also from major advances in the materials available to the designers.

Though suspension bridges are thought of as a modern invention, they existed in a simple from as long ago as the 14th century. The Iron Chain Suspension Bridge in the picture below was built in Tibet in 1430 and was still standing in 1948 though no longer in use and in need of repair.



Chushul Chakzam, about 65 kilometres (40 mi) from Lhasa on the Yarlung Tsangpo River

https://www.youtube.com/watch?v=rbrhwTvrxHk

You Tube – BRIDGE DESIGN AND DESTRUCTION

The following videos sum up some of the variables in Bridge design.

https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&cad=rja&uact=8&ved=2ahUKEwj0pJvvisLlAhXTuHEKHfXMDTEQwqsBMAB6BAgHEAQ&url=https%3A%2F%2Fwww.youtube.com%2Fwatch%3Fv%3DlBP7739C83s&usg=AOvVaw213y1nQLbfNh5KPJBzFNhl

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FINAL PRACTICAL ACTIVITY (COMPETITION).

Build a Bridge – any design with a span of at least 30cm which will support a 300g can of Heinz Baked Beans placed at the centre of the span.

The only materials which can be used are cardboard from old boxes of cereal, string, cellotape and glue.

Submit video(s) of your Bridge (with Beans) to stemclub@chelmsfordses.org.uk

Good Luck!