Stemmies Experiment Week Three: Miniature Crane

Explaining Pulley Systems

This is a tricky experiment so ask a parent for help and have fun as a family if you're stumped

Materials:

- Popsicle sticks
- Popsicle sticks with holes drilled (to use with dowels and bobbins)
- Cups
- Bobbins
- Straws
- Glue (supplied in week 2)
- Tape
- Dowels
- String
- Rubber bands

Instructions:

Using the materials provided in your bag, watch the video (see link below) for an example as well as the information and examples pictured below, and build a CRANE! How do you do this…well let's get started:

1) Tape or glue (or better yet, ask your parents to help you use hot glue) popsicle sticks together to create a base for your crane.
2) Thread a small piece of a dowel through a bobbin
3) Put popsicle sticks with holes through them on the ends of the dowel and glue the dowel to them
4) Glue the two ends of the popsicle sticks that aren't already connected to the sides of your base but towards the front so that the bobbin is over the front of the base
5) Repeat steps 2-4 but instead of using whole popsicle sticks, use the ones that are cut in half and glue the assembly upright but behind the first one
6) Repeat steps 2-4 once again, using the cut in half popsicle sticks, but instead of gluing the dowel to the popsicle sticks, glue it to the bobbin and glue it upright behind the second one
7) Glue or tie one end of your string to the last bobbin (the one with that is glued to the dowel) and wind almost the entire piece around the bobbin
8) Wrap the end of the string once around the middle bobbin and then hang the end over the first bobbin (the tall one)
9) Thread the end of the string through the holes in a Dixie cup and tie it at the top
10) (optional) Stack cups under your base to make your crane taller
11) **HAVE FUN** and take your time doing this experiment. They will continue to challenge your mind and building skills.

What this experiment demonstrates:

This experiment demonstrates how pulleys and pulley systems make work easier. A pulley is simply a collection of one or more wheels (bobbin) over which you loop a rope to make it easier to lift things. Pulleys are examples of what scientists call simple machines. That doesn't mean they're packed with engines and gears; it just means they help us multiply forces. If you want to lift a really heavy weight, there's only so much force your muscles can supply, even if you are the world's strongest man. But use a simple machine such as a pulley and you can effectively multiply the force your body produces.

See example(s) on these next pages. For instructional video go to:

https://sjlmidland.org/k-8-education/stem-program

Share your designs and how much weight you supported! Make sure to take pictures as you build and test your crane. Please send any pictures we could include in our website photo gallery and weekly newsletter to Jan Sleight or Sarah Graham via email at **jsleight@sjlmidland.org** or **sgraham@sjlmidland.org**.

Now get building!!!

Keep in mind….. The more wheels (bobbins) you have, and the more times you loop the rope around them, the more you can lift.

More about what pulleys are and why they are important and will be used in your experiment with the elevator.

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Let's be clear about mass and weight!

Before we go any further, let's be very clear about the difference between weight and mass. This will help in a moment when we talk about using pulleys to lift *weights* (which are really *masses*) with a certain amount of *force*. In a nutshell:

- **Mass** is the amount of stuff something is made from or contains, measured in kilograms (or pounds).
- **Weight** is the amount of *force* with which Earth's gravity pulls on a particular mass: the more massive something is, the more gravitational force, and the more we say it weighs.

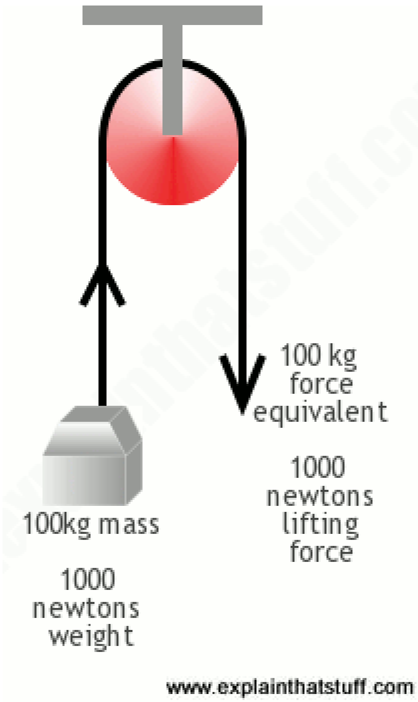
Photo: How much force is a newton? This orange has a mass of about 100g (0.1kg) so I need to supply 1N (one newton) of force to hold it in mid-air. Loosely speaking, we say the orange "weighs" 100g; strictly speaking, it weighs 1N.

How pulleys work

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.

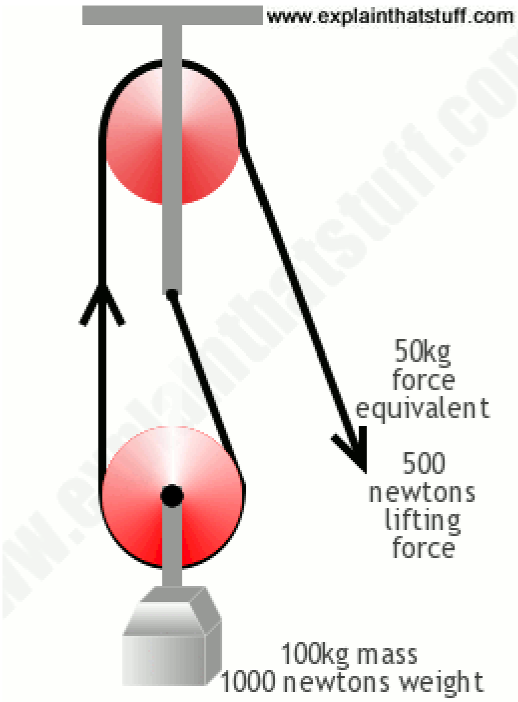


Artwork: How pulleys work#1: With one wheel, a pulley simply reverses the direction of the force you apply. It doesn't alter the force in any other way.

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.

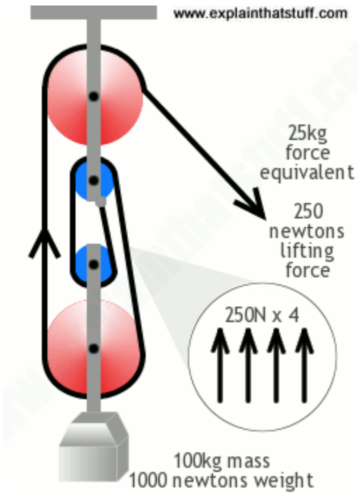
Mechanical advantage is a measurement of how much a simple machine multiples a force. The bigger the mechanical advantage, the less force you need, but the greater the distance you have to use that force. The weight rises 1m, but now we have to pull the loose end of the rope twice as far (2m). How come?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



Artwork: How pulleys work#2: With two wheels, it's as though the weight is hanging from two ropes (the two strands of the same rope on the left), and a pulley halves the lifting force you need. It's like lifting the weight with two ropes instead of one. But you now have to pull the end of the rope twice as far to lift the weight the same distance.

Four wheels

Okay, what 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.

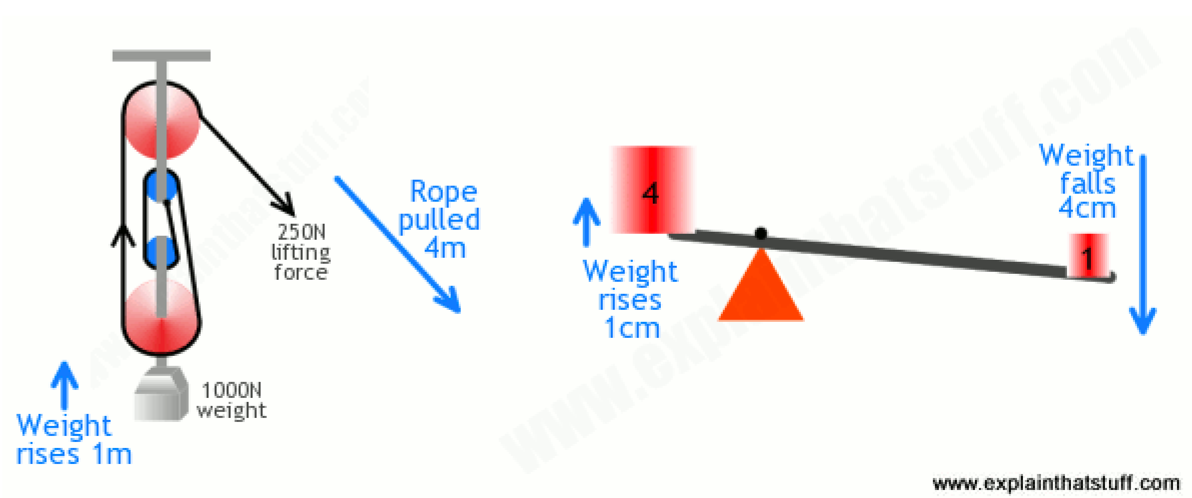


Artwork: How pulleys work#3: With four wheels and the rope working in four sections, a pulley cuts the lifting force you need to one quarter. But you have to pull the end of the rope four times as far.

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 smaller distance.



Artwork: How a pulley works like a lever: Just like with a lever, a pulley can "magically" create more force—but only if you use that force over a longer distance. Why is that? Read on below!

What's the catch?

Pulleys sound brilliant—and they are. But surely there must be a catch? If you can lift 100kg (1000 newtons) by pulling with the force-equivalent of only 25kg (250 newtons), surely you're doing only a quarter as much work and using only a quarter as much energy? And if that's true, you could build some kind of a pulley that would actually produce energy for you: put in only one unit of energy and get four units out! Sounds brilliant!

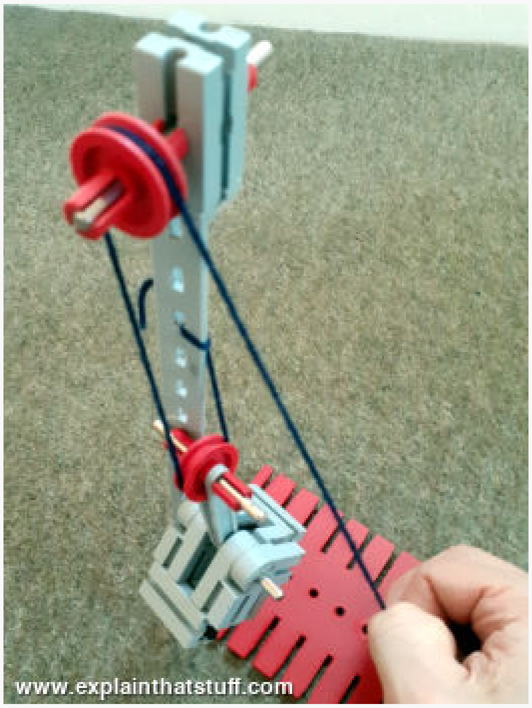


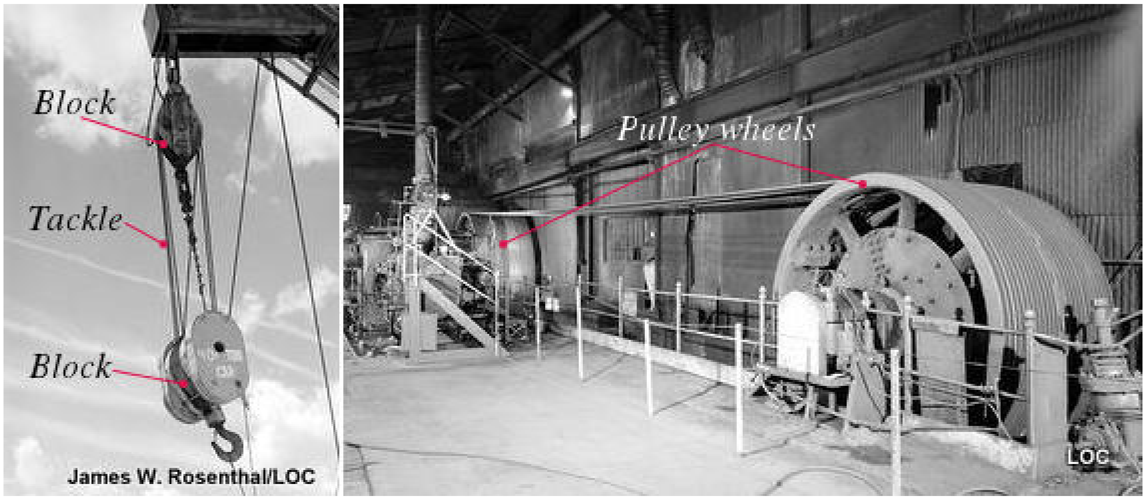
Photo: Is there a hidden catch when you're using a pulley? Why not make your own simple pulley from a construction set (or just homemade materials like cotton reels and string) and test it for yourself. There's no better way to understand how pulleys work. With a simple two-wheel pulley like this, it's easy to see that you have to pull the string twice as far as the weight lifts up.

Unfortunately, such amazing things are *strictly* prohibited by a law of physics called the conservation of energy, which says you must always put in as much energy as you get out. So let's think about pulleys in terms of energy. If you raise a weight of 100kg (1000 newtons) a distance of 1 meter off the ground, you have to do the same amount of work whether you use a pulley or not: you have to move the same force over the same distance. If you use a pulley and reduce the force you're using by a quarter, you still have to do the same amount of work. It's just that you have to pull the end of the rope *four times further* to make each of the four supporting sections of rope rise by the same amount. That's the catch with a pulley. You pull with less force, but you have to pull further (and, generally speaking, use the force for longer). Far from using less energy with a pulley, you actually have to use a little bit more because of the friction where the rope rubs against the pulley wheels. But it seems and feels easier to use a pulley, and that's the important thing!

Photos: Pulley equipment. 1) These small pulley wheels have hooks on them so they're easy to hang from the ceiling. Note how the wheels have grooves in them so the rope doesn't slide off them. Photo by Paula Aragon. 2) Giant pulley wheels on the arm of a large railroad maintenance crane. This one uses huge strong wire rope.

What is a block and tackle?

In engineering, the kind of pulley I've been describing here is sometimes called a **block and tackle**: the wheels and their mounts are the blocks and the ropes that loop around them are the tackle. In my examples, one block is fixed at the top and the other block moves up with the load. More generally, to engineers, a pulley is a wheel over which you loop a rope or a belt to connect one part of a machine to another, whether it's lifting things, transmitting power, or doing anything else. In simple science, though, we tend to use "pulley" just to mean a bunch of wheels and ropes for lifting.



Photos: Two types of pulleys. Left: A block and tackle is a pulley-based system for lifting things, made of blocks (the wheel sections) and tackle joining them together. This one was used for lifting rocket equipment at NASA's Marshall Space Flight Center. Photo by James W. Rosenthal, Historic American Engineering Record, courtesy of US Library of Congress. Right: Pulley wheels can also be used to join different parts of a machine together. Here, a pulley wheel on a large engine is driving another pulley wheel on a machine some distance away. In this case, the pulleys are simply transmitting power. Photo: Historic American Engineering Record, courtesy of US Library of Congress.