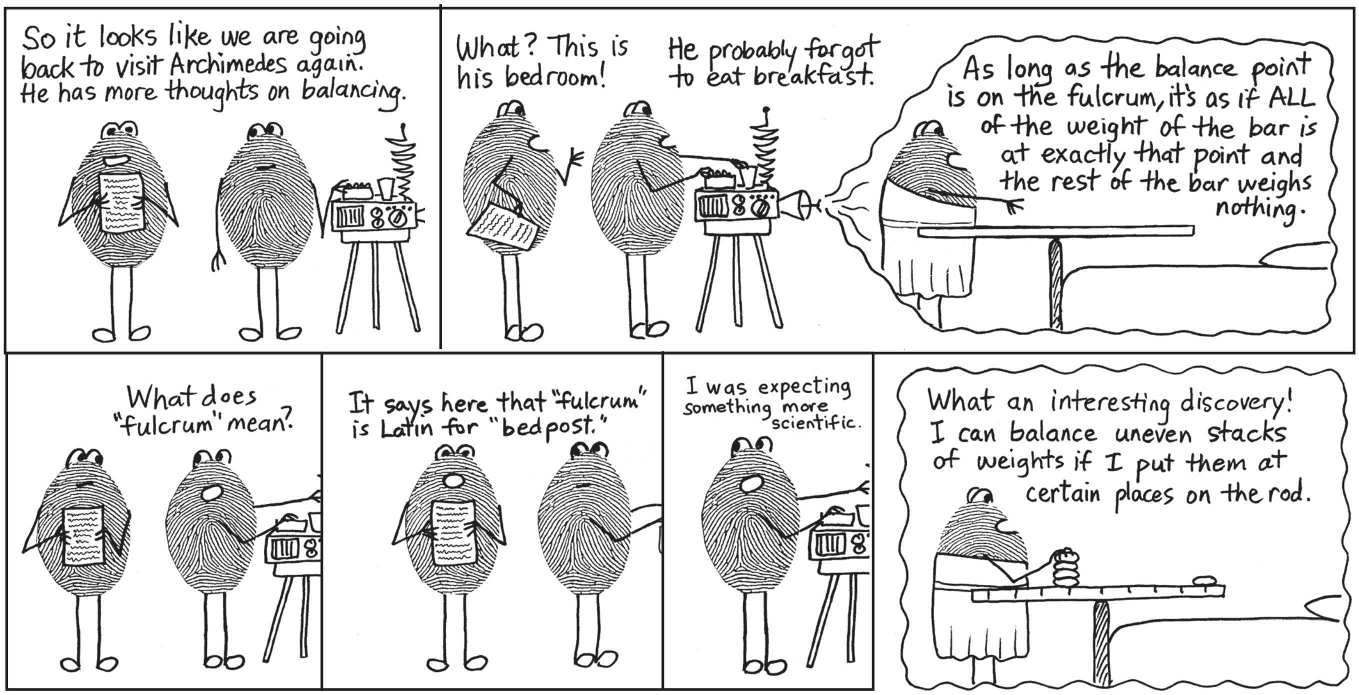
Adventure 2: Balancing, Lifting and Turning

Our adventure with balancing continues, as we send our volunteers to spy on Archimedes again.



Stop! We're going to interupt our interview with Archimedes so that we can give you the opportunity to make essentially the same discovery that he is about to make. However, to make it a bit easier for you, we're going to work with paper clips instead of the flat rocks that Archimedes is using.

ACTIVITY 2.1: Balancing numbers

You will need: *a few dozen paper clips that are all the same size, a pin, tape, a glue stick, scissors, a pencil that has still has its eraser (or an "eraser cap"), a can of soup (or any other fairly heavy can that can be a firm base), and a copy of the following pattern page printed onto regular paper (or carefully cut out that page and use it-- make sure to trim the torn edge so that it is very straight and parallel to the edge with the numbers)*

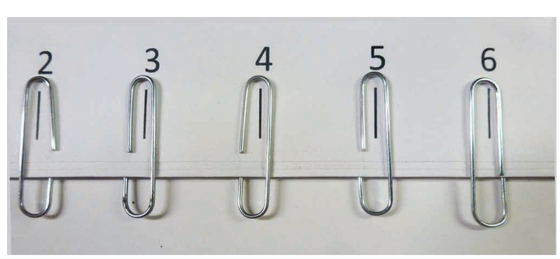
1) Push the pin into the pencil's eraser. My pencil had a nice "cap" eraser, but you can make it work with the pencil's eraser if it is big enough and if you don't poke it too many times.

2) Tape the pencil to the side of the can. This completes your balancing base. I like to use masking or duct tape, but any tape will do.

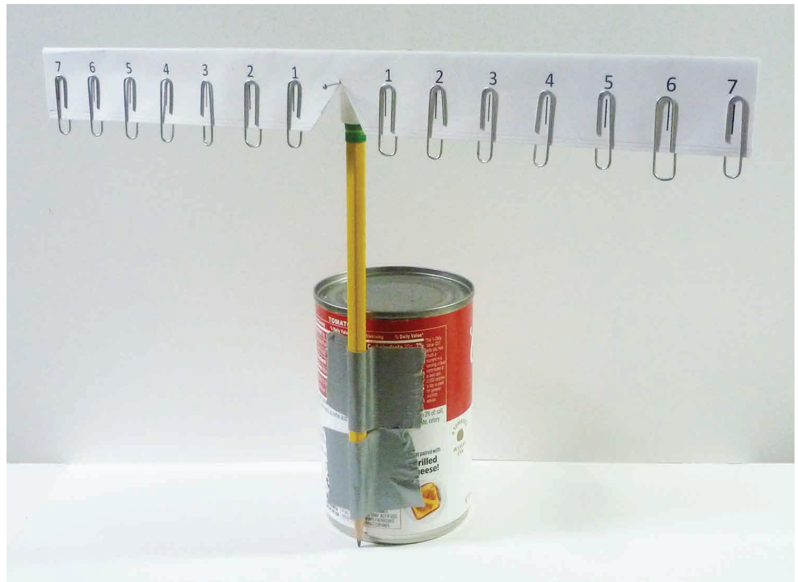
3) Fold the paper in half lengthwise, keeping the numbers on the edge. Fold in half again. Then once again. Be very exact with your folds! Run some glue stick between the folds. Close all the folds agin, press down firmly. You should now have something that looks like a paper ruler. (See photo on following page.)

4) Cut out the V notch (striped area).

5) Place paper clips right under the numbers, as shown in here in photo.

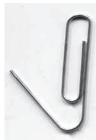


6) Balance the paper strip by placing the V notch right over the pin. If it doesn't balance, adjust the paper clips a tiny bit until it balances. If the strip wants to fall forward or backward, you cand bend the top edge of the strip just slightly. Experiment a bit until your strip is stable on the pin, as shown in photo.



It's not the prettiest contraption, but it will work.

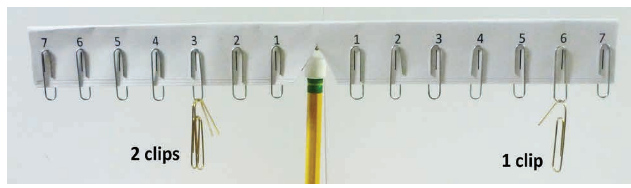
7) The rest of the paper clips will be used as weights. Open them just a bit so you can easily hook them onto the metal loops under the numbers.



8) Try hanging a clip on both number 6's. Does it balance? If it doesn't balance, adjust the end clips until it does.

9) Now let's try what Archimedes did and balance unequal numbers of clips. Hang one clip on the 7 on one side, and 7 clips on the 1 or the other side. It should balance. This means that the position at which you put a clip affects how much downward "pull" it will have. Clips placed at high numbers (which are far away from the fulcrum) will seem to have more "weight" than those at lower numbers.

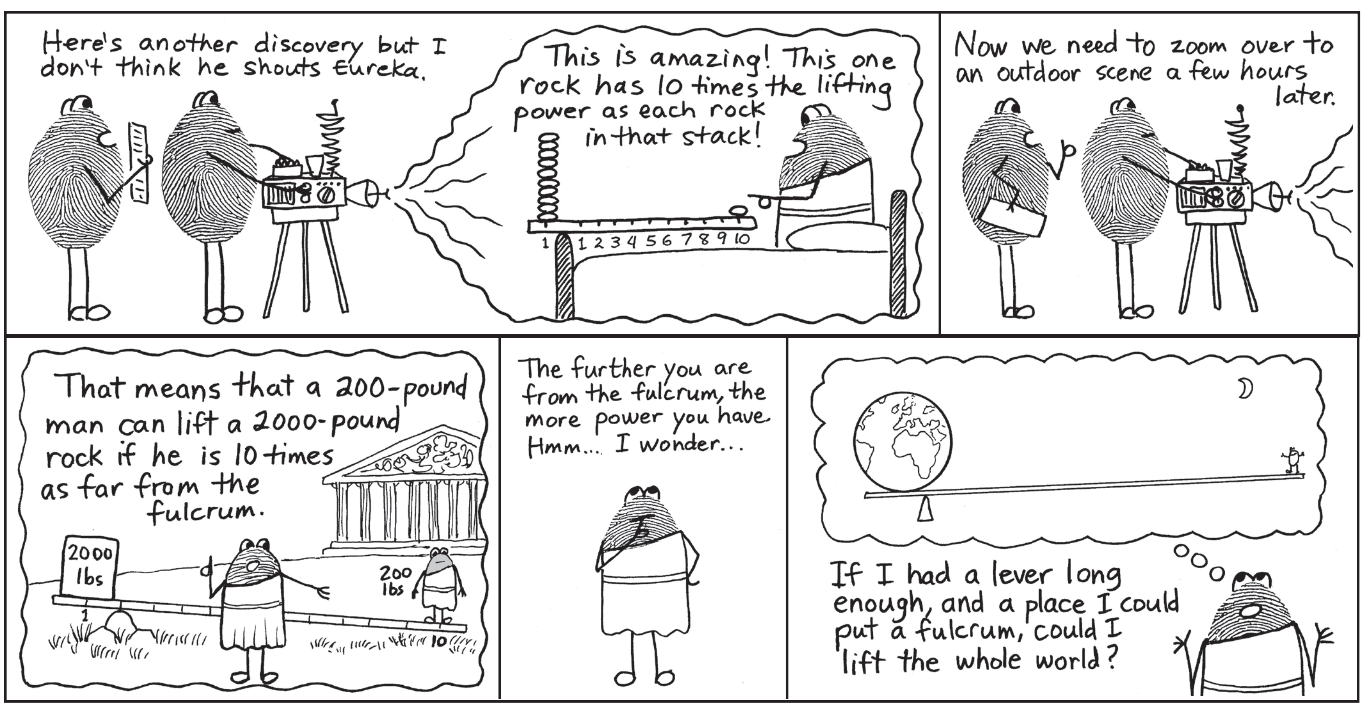
10) Try some simple math. You can show that 3+3 = 6. Put 2 clips on the number 3 on one side, and 1 clip on the number 6 on the other side. It should balance. This is shown in the photo. Two 3's equals one 6.

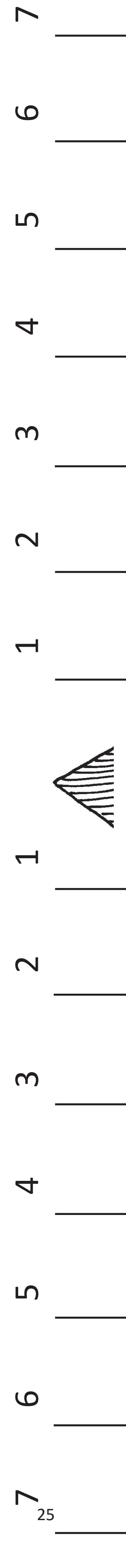


11) Now try your own combinations. Here are some suggestions: 4+3= 7 5+2 = 4+3 1+2+3= 6 2x3= 6

12) You can even do equations with parentheses. (1x3) means three clips hanging on the 1. (3x1) means one clip on the 3. Try to set up these equations on your balance bar:
(2x2) + 1 = 5 (1x3) + (1x2) = 5 (2x3) = (3x2) (2x7) = (2x2) + (2x5) 1+2+3+4+5+6+7 = 7x4

CHALLENGE: Set up an equation on your balance bar and then have a friend try to figure it out and write it down.

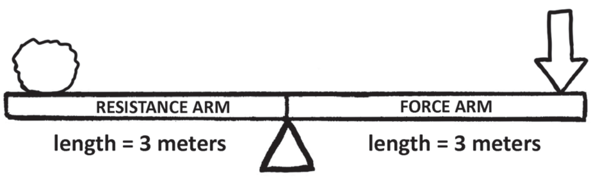


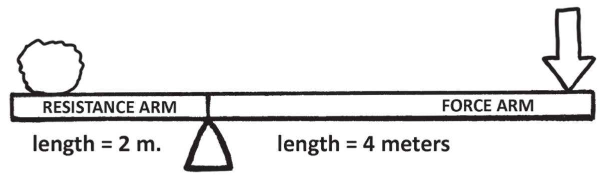

7
6
5
4
3
2
1
1
2
3
4
5
6
7

Archimedes had discovered what we call "the principle of the lever." Archimedes' most famous quote is "Eureka!" but his second-most famous quote is, "Give me a lever long enough, and I will move the world." Some variations of this quote add the phrase, "and a place to put a fulcrum" or "and a firm place on which to stand." Archimedes had hit upon a basic principle of physics that works at any scale, though actually moving the earth is impossible, of course.

Not only did Archimedes discover that a lever can help move very heavy objects, he also discovered that levers are governed by mathematics. You don't need to actually run an experiment with 10-ton objects to know what force is needed to lift them. You can easily calculate this with pencil and paper. The limiting factors in any real-life test of the principle of the lever are the strength of the lever (to not break when force is applied) and the strength of the fulcrum (to not crack under all the pressure being applied downward onto it). So in real life, this principle could appear to fail simply because of the limitations of the materials you are working with.

Levers give us ***mechanical advantage***. The amount of mechanical advantage a lever gives us can be calculated by measuring the distance of the lever on each side of the fulcrum. The side of the lever that has the load resting on it is called the ***resistance arm***. It is called the resistance arm, and not the load arm, because the resistance can be any kind of resisting force, not just a weight (a load) pressing down. The side of the lever that is applying the downward force to lift the object is called the ***force arm***.

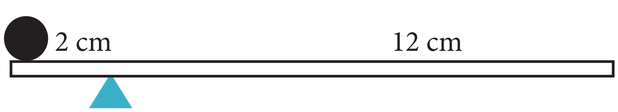




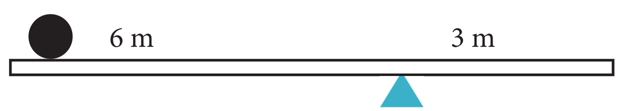
The amount of mechanical advantage is calculated by dividing the length of the force arm by the length of the resistance arm. In the diagram on the left, this gives us 3 divided by 3 (3/3) which is equal to 1. By definition, to get any mechanical advantage, we need a number higher than 1. In the diagram on the right, if we divide the length of the force arm by the length of the resistance arm, we get 4/2 which is equal to 2. This lever gives us a mechanical advantage of 2. The higher the number, the easier it will be to lift the load. The mechanical advantage does not have to be a whole number. You can have a mechanical advantage of 1.5 or 7.3 0.25. However, a mechanical advantage less than 1 means it isn't an advantage at all—it means the work will be harder for you!

ACTIVITY 2.2: Calculate the mechanical advantage of these levers

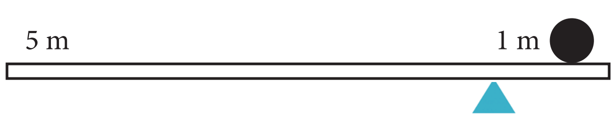
The answers are printed on the bottom of the reverse side of this page. (Don't check your answers until you have completed all of them. This will prevent you from accidentally seeing right answers before you do the problems.)
NOTE: The measurements (meters, centimeters, inches) won't be in your answer. Your answer will be just a number.

1)


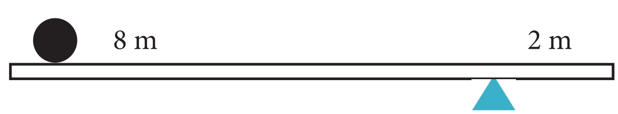
Mechanical advantage = _______

2)


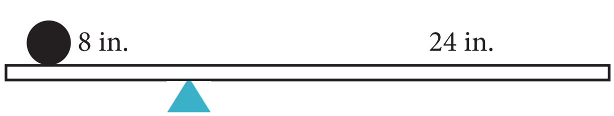
Mechanical advantage = _______

3)


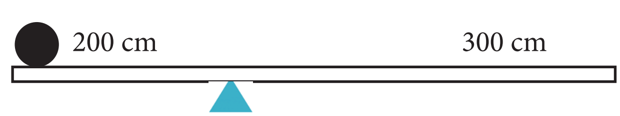
Mechanical advantage = _______

4)


Mechanical advantage = _______

5)


Mechanical advantage = _______

6)


Mechanical advantage = _______

ACTIVITY 2.3: Solve these balancing puzzles

Find the missing numbers in each lever puzzle below. Remember, these levers are balanced, so that means that the weight times the distance on one side equals the weight times the distance on the other side.

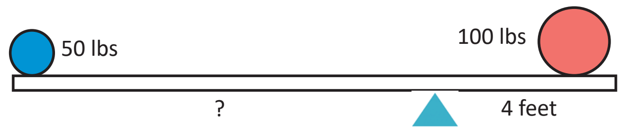
(weight of blue circle) x (distance 1) = (weight of red circle) x (distance 2)

The answers are printed on the back of the next page. Don't check your answers until you are finished with all of the puzzles. NOTE: Your answers will have units attached to them this time, such as kilograms, meters, feet, or pounds

1)

Weight of blue circle = ________

2)



Distance 1 = _______

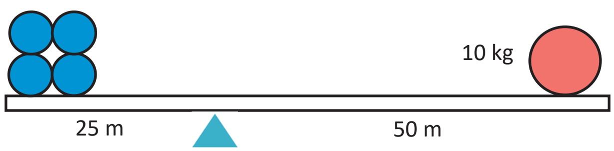
3)

Weight of red circle = _______

4)

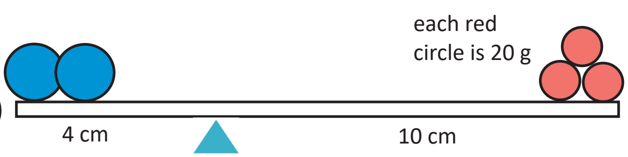
Distance 2 = _______

5)



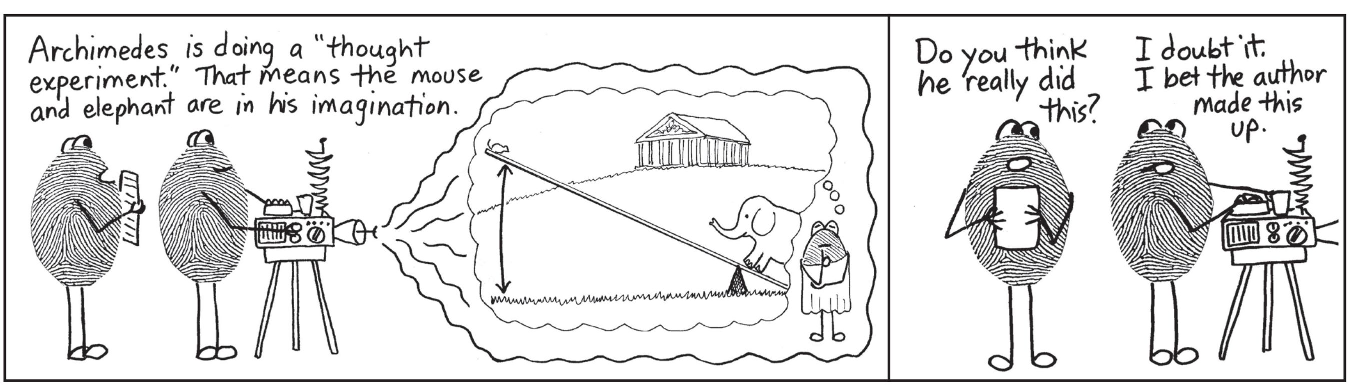
Weight of each blue circle = _______

6)



Weight of each blue circle = _______

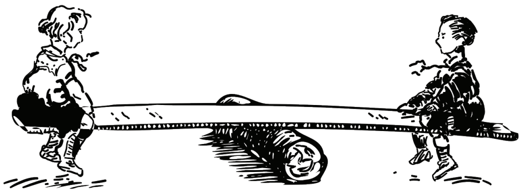
Archimedes made another discovery about levers. He found that although a really long lever gives you excellent mechanical advantage, the distance that the lever has to move is greatly increased. An elephant and a mouse can operate a teeter totter (seesaw) together, but the mouse will have a wild ride, going high up in the air. The elephant's ride will be boring by comparison. It will hardly go up and down much at all. But even though the mouse and the elephant are having such different experiences, the amount of "work" each one is doing is the same.



ANSWERS TO ACTIVITY 2.2 1) 6 2) 1/2 or .5 3) 5 4) 1/4 or .25 5) 3 6) 3/2 or 1.5

Believe it or not, there is a lot more we can say about levers! Engineers came up with a way to classify different types of levers. There are three ways you can arrange the force, load and fulcrum.

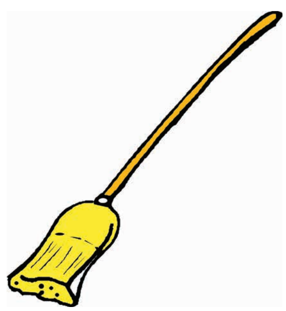
FIRST CLASS LEVERS have the fulcrum in the middle, the load on one end and the force on the other end. The classic playground seesaw (which is hard to find nowadays) is a first class lever. Other examples include scissors and light switches.



SECOND CLASS LEVERS have the load in the middle and the force and fulcrum at the ends. Examples of second class levers include wheelbarrows, doors and staplers. In the wheelbarrow, the wheel functions as the fulcrum. In the door and the stapler, a hinge functions as the fulcrum.



THIRD CLASS LEVERS have the force in the middle and the load and fulcrum at the ends. Examples of third class levers include baseball bats, brooms, and chopsticks. Any time you are using a stick to swat or bat or push, you are using a third class lever. Other examples include tennis rackets, hammers, fishing rods, or even your arm.

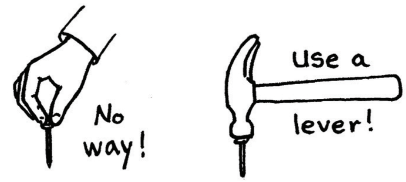

Even if we understand the differences between the three types of levers, it can be hard to remember which one is first or second or third class. You might be saying, "Why do we even care? When we will ever need to know which is which?" Fair enough question, but if you end up going into any type of engineering, physical therapy, kinesiology, or sports medicine, you will run into these classifications in the first year of your studies and you will be expected to know the answers on a test. If you don't plan on going into a profession that uses levers, you never know where this information might show up in every day life. If nothing else, you can impress your relatives at the next family gathering, identifying levers being used to serve and eat food. This next activity will give you a song that makes learning these classifications very easy.

ACTIVITY 2.4: "The Lever Rap" Song

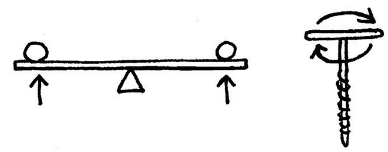
Let's have some fun with this not-funny physics stuff. On the reverse side of this page you will find the lyrics to a rap song about the three types of levers. You can access the audio files for this song by going to ***www.ellenjmchenry.com/music****. Scroll down until you see the Lever Rap song. There is a version with the lyrics and also a "karaoke" version with just the drum beat.*

The Lever Rap

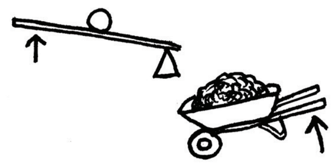
by Ellen J. McHenry



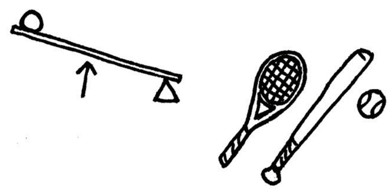
If you have a job that's hard to do,
Like pulling a nail or turning a screw;
Your fingers won't do it, so be very clever,
You need a machine that's called a lever.



Levers come in classes: first, second, third.
Force, load and fulcrum are the key words.
In a first class lever, the fulcrum's in the middle.
If I seesaw with you, you seem to weigh little!

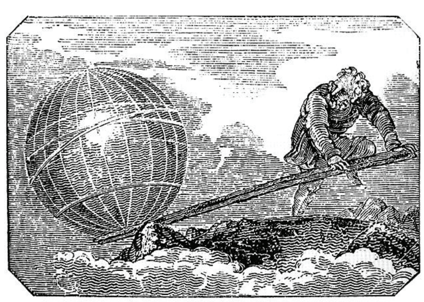


A second class lever has the fulcrum at one end;
The load's in the middle—give a ride to a friend
In a big wheelbarrow, where the force is your muscle,
If you call your friend "The Load," you'll get into a tussle!



If you want some speed to swat or bat,
The third class lever is where it's at.
The fulcrum's at one end, the load's at the other,
The force is in the middle. But don't hit your brother!

When you use any lever, you'll find, of course,
You can always trade distance for a gain in force.
If you make the lever long, moving loads is a snap.
And this is the end of the lever rap.



"Give me a lever long enough, and a fulcrum on which to place it, and I shall move the world!"
Archimedes (about 200 BC)

www.ellenjmchenry.com

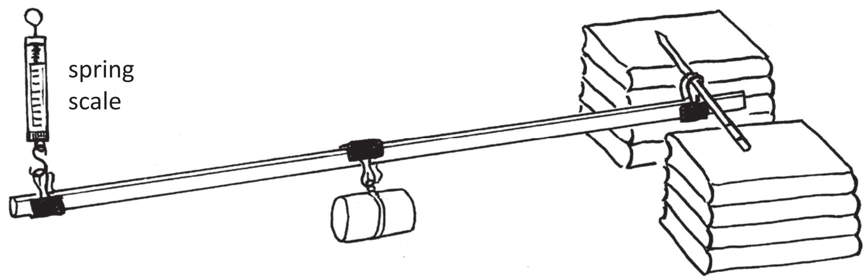
ANSWERS to ACTIVITY 2.3: 1) 20 kg 2) 8 feet 3) 1 kg 4) 60 cm 5) 5 kg 6) 75 g

ACTIVITY 2.5: Experiment showing mechanical advantage in a second class lever (wheelbarrow)

If you are not able to do this experiment right now, but you have Internet access, you can watch a video version of this lab by going to the YouTube playlist for this curriculum and finding the video titled "Simple Machines: The Lever" by funsciencedemos.

You will need: *a meter stick (or yard stick), three large binder clips, a pencil, some books, a spring scale that measures in grams, a thick rubber band, a paper clip, and a weight (a can of soup will work)*

Use your materials make this set up:



You've set up a second class lever, with the fulcrum being the pencil. The load will hang from the clip in the middle and the force will be a lifting force at the end with the spring scale attached (so you will be able to measure the force). In a wheelbarrow, you'd have a wheel instead of the pencil and there would be a metal basket in the middle instead of a clip with a weight hanging from it.

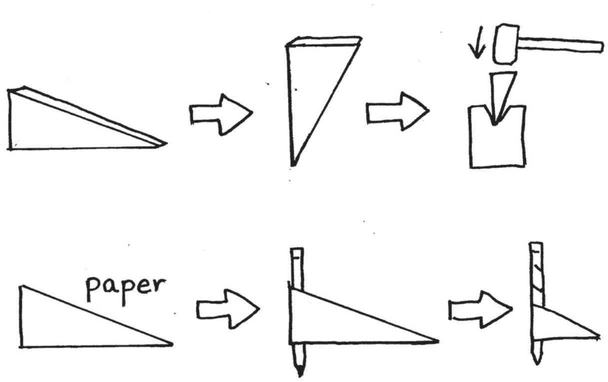
Place the thick rubber band around the soup can (or whatever you are using for a weight) and use a paper clips to hang it from the middle clip. Slide the binder clip all the way to the end where the spring scale is. The clips can be touching. Lift the stick up while holding the top of the spring scale so that the scale will be measure the force needed to lift the weight. If the weight was directly under the scale, the scale would show you exactly how heavy the weight is. However, since the weightis not directly under the scale, the scale will read just a bit less than the actual amount of weight. But for our purposes here, it will be close enough.

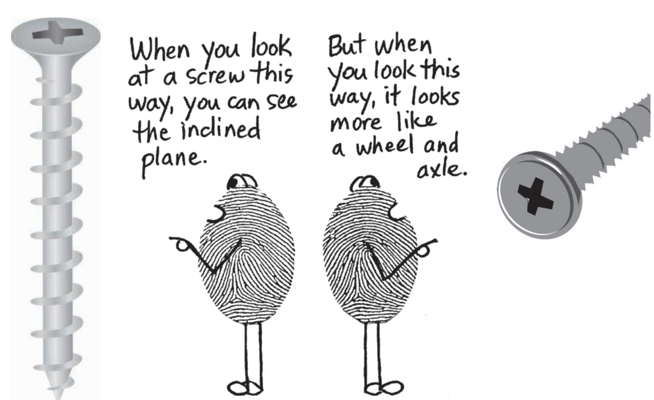
Now move the clip with the weight to the middle of the stick. Lift the stick again and look at what the reading is on the spring scale. Does it read less? Then move the weight closer to the pencil. Read the scale again. Finally, move the weight as close to the pencil as you can get it. Lift the stick and check the scale. How much force is required to lift the can when it is almost at the fulcrum?

Thinking about what you just saw in this experiment, would longer handles on a wheelbarrow make it easier to lift loads? Why is the wheel of a wheelbarrow usually right underneath the metal basket?

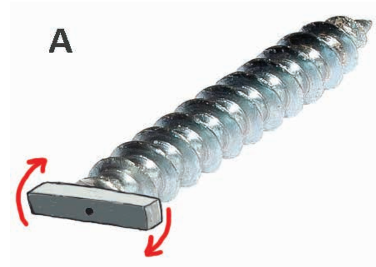
In the Lever Rap, the first sentence says, "If you have a job that's hard to do, like pulling a nail or turning a screw..." According to this song, a screwdriver is a lever? But a screwdriver doesn't lift—sit twists. A screwdriver looks more like a wheel and axle than it does a lever.

You've probably studied ***simple machines*** when you were a little younger. If so, you might remember that usually we are told that there are six different kinds of simple machines: levers, wedges, pulleys, screws, inclinded planes, and the wheel and axle. Actually, this list can be boiled down to just two: ***the lever and the inclined plane***. All the rest are variations of these two. It's easy to see how a wedge is very much like an inclined plane. Just turn an inclined plane up so its tip is facing down and you have a wedge. It's a bit harder to see how a screw is derived from an inclined plane, but if you cut a long triangle out of paper then wrap it around a pencil, you can see the connection.



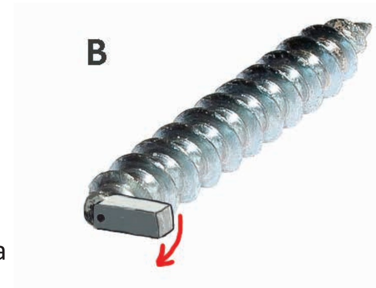


Yes, a screw is a combination of several simple machines. Something that has more than one simple machine is a ***complex (or compound) machine***. A screw certainly does not seem complex but technically it does combine several simple machines. It even has a hidden lever.

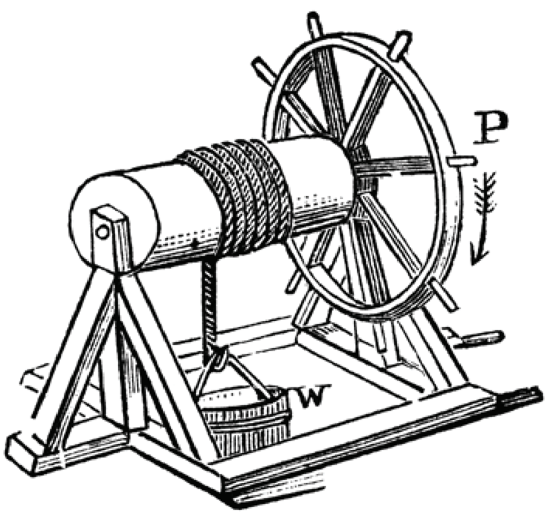


A screw would still work if we modified the head and made it look like a bar instead of a circle. (Diagram A) If your fingers were strong enough, you could twist the bar to make the screw turn. Now that it looks like a bar, it reminds us of a seesaw, a first class lever, with a fulcrum in the middle. One end goes down while the other end goes up.

Technically, we could still make the screw turn if we cut off one half of the bar. (B) It would be much harder to turn the screw, but if you were putting the screw into something soft, like Styrofoam, it would work. Now it looks like the fulcrum is at one end and the force is at the other end (the red arrow) reminding us of a second class lever. If we wanted to make this lever easier to turn, we could increase its length. In real life, we would not want a long bar sticking out from a screw. Instead, we rely on a screwdriver to give us mechanical advantage.



Wheels (including the head of this screw before we chopped it up) are a variation on the principle of the lever, but it does get complicated. A wheel is like a infinite number of levers all combined into a circle shape.



The windlass was already in use by Archimedes' time.

A wheel and axle are like two cylinders stuck together. The larger cylinder is designated as the wheel and the smaller cylinder is the axle. In this drawing of a "windlass," the axle is the cylinder around which the rope is wound, and the wheel really does look like a wheel. In other situations, the wheel might be harder to identify, but in the windlass it is very easy.

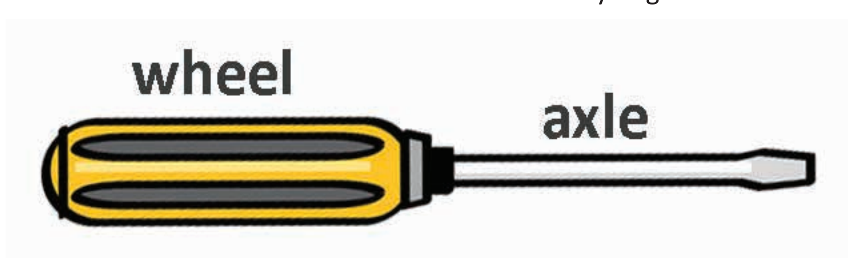
The circle with the larger diameter (the wheel) gives you mechanical advantage. The way you calculate the mechanical advantage is to measure the radius of both wheel and axle. The radius is the distance from the center of a circle to its edge.

$$\text{MECHANICAL ADVANTAGE} = \frac{\text{radius of wheel}}{\text{radius of axle}}$$

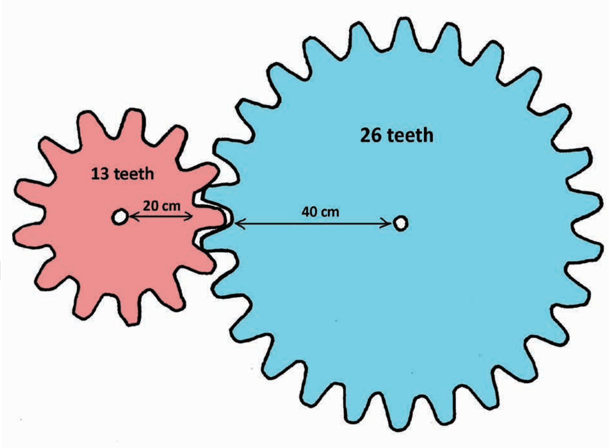
The line means "divided by." (When we write fractions we use this "divided by" line, though often we forget what it means.)

If the radius of the wheel in this picture is 60 centimeters and the radius of the axle is 20 centimeters, the wheel will give us a mechanical advantage of 3. We'd have three times our normal lifting power. If we wanted even more lifting power, we could make the axle even smaller. An axle of only 10 centimeters would give us a mechanical advantage of 6. However, as we discovered with our levers, when you achieve greater mechanical advantage (a gain in force), you always have an increase in distance. Here, the increase in distance will mean that you have to turn the wheel twice as many times.

The screwdriver that we might have used to turn our screw (instead of reshaping its head into a bar!) is also a wheel and axle. The long metal shaft is the axle and the handle is the wheel. According to our formula for mechanical advantage, to make a powerful screwdriver the handle should be substantially larger than the diameter of the long shaft. We are limited, however, by the size of our hands; we have to be able to comfortably wrap our fingers around the handle. Another limiting factor for handle size is our preference for having tools that don't take up too much space in our toolbox.



A ***gear*** is an example of a wheel that does not have an axle. It has a pivot point in the center, but it does not have another cylinder coming out of it. Gears can be smooth, or they can have ***teeth***. Gears can be used to gain mechanical advantage. Similar to the wheels and axles on the previous page, the diameter of the gears can be used to determine mechanical advantage.



One gear will be the ***driver***. This is the gear that will be either connected to a motor or will be turned by hand. The other gear is called the ***follower*** (or the ***driven***).

$$\text{MECHANICAL ADVANTAGE} = \frac{\text{radius of follower}}{\text{radius of driver}}$$

The red gear will be our driver. It has a radius of 20 centimeters. The blue follower has a radius of 40 centimeter. Our mechanical advantage is 40/20 = 2. This means that the "work" you put into turning the red gear will be doubled. Good deal!

You can also calculate the mechancial advantage by using the number of teeth:

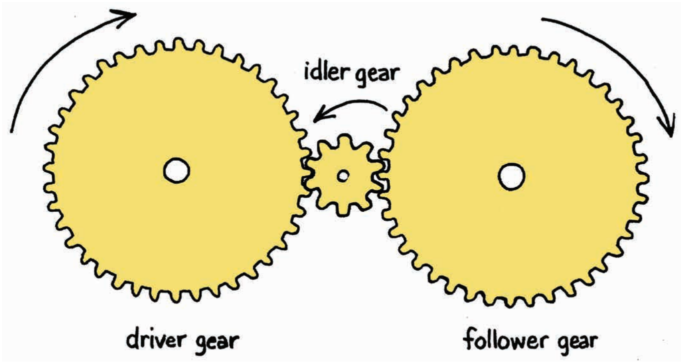
$$\text{MECHANICAL ADVANTAGE} = \frac{\text{number of teeth on follower}}{\text{number of teeth of driver}}$$

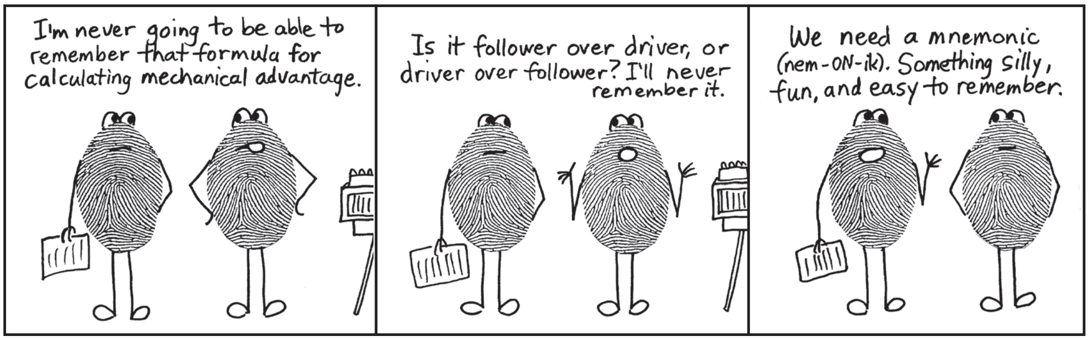
This would be 26/13 = 2, the same answer we got using the radius. We'd also get the same answer if we used the circumference (distance around the outside) of the circles.

Now let's make the blue gear our driver. For every full turn of the blue gear, the red follower goes around twice. The result will be that the smaller gear will be turning twice as fast as the large one. This situaion is called a ***speed multiplier.*** Sometimes this is exactly what you want in a complex machine. You want to have a gear that speeds up motion. However, sometimes you want more power, not speed. When we had the smaller red gear as our driver, we had a mechanical advantage of 2, making our turning motion twice as powerful (even though we had to do more turning). When we have a mechanical advantage of more then 1, the gears are acting as a ***force multiplier.***

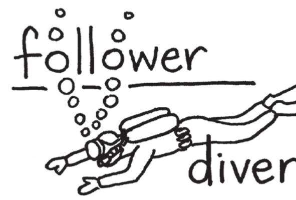
A classic example of a force multiplier is a 10-speed bicycle. The lowest ("first") gear is very small. You use the smallest gear when you are going up a steep hill and you don't mind sacrificing speed in order to achieve a gain in force. If you try using the lowest gear while riding on a flat surface, you realize how incredibly fast you must pedal. But when you were riding up that hill, the speed at which you were pedaling seemed about right.

If you watch gears in action, you'll notice that the driver makes the follower turn in the opposite direction. In cases where you need your follower to go the same direction as your driver, you can put a gear between them. This middle gear is called an ***idler*** *(IDE-ler)* because it doesn't affect the mechanical advantage at all. (To be "idle" means to do nothing.) The size of the idler isn't important; any size will work. This diagram shows a tiny idler but you could also have a large idler and tiny drivers and followers. You can also have more than one idler. An odd number of idlers will result in the driver and follower turning the same direction, but an even number will make them turn in opposite directions.



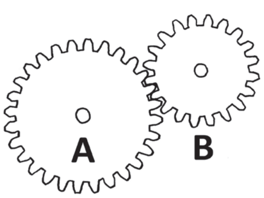


How about this mnemonic *(nem-ON-ik)*? The word "driver" is similar to the word "diver," (You won't forget that the real word is driver, not diver.) A diver is down below the surface, so this helps you remember that the "driver" gear radius is below the line. The two letter O's in the word "follower" will then remind you of round air bubbles being created by the diver. Air bubbles float up, so the word with the O's (follower) is on the top, above the diver.

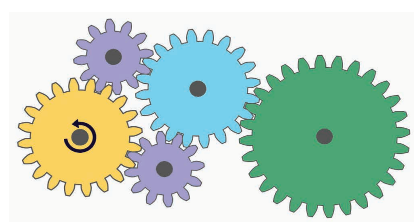


ACTIVITY 2.6: Do some thinking and a little math (Answers at the bottom of page 45.)

Answer these questions for the gears shown below.
1) If gear A is the driver, will this result in a speed multiplier or a force multiplier? ________________
2) If gear B is the driver, what will be the mechanical advantage if gear A has a radius of 24 cm and gear B has a radius of 12 cm? _______



Answer these questions for the gears shown below. (Notice the arrow on the yellow gear.)
3) Which direction will the green gear turn, clockwise or counterclockwise (anticlockwise)? ______________
4) Would the green gear still turn the same way if you removed one of the purple gears? _______



5) If a driver gear has 18 teeth, and its follower has 36 teeth, will this result in multiplication of speed or force? ________

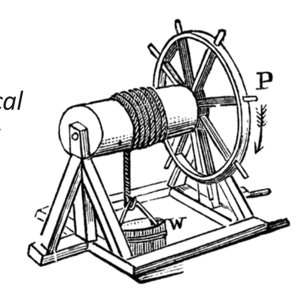
6) What is the mechanical advantage of gears where the follower has a radius of 12 cm and the driver's radius is 60 cm? _____

7) Look at the colored gears again. Will the green gear be experiencing more, or fewer, complete turns per minute than the yellow gear is? (What did we learn about idlers? Do they contribute to force or speed?) _____________

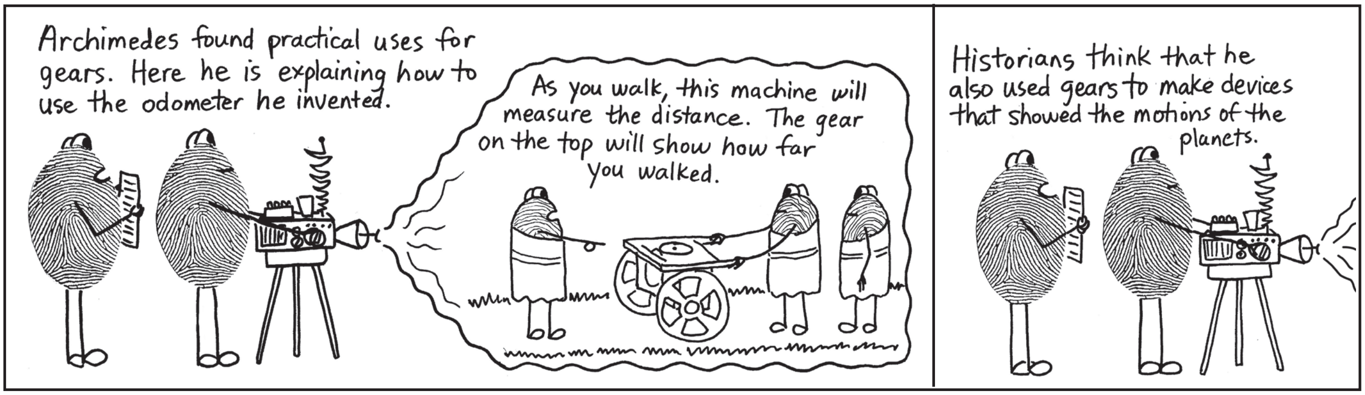
8) An employee in the Fabulo Tool Company had a great idea. Why not make a super powerful screwdriver that gives the user a mechanical advantage of 20? Most screwdrivers only give an advantage of 2-5. The CEO and the board of the company weren't as enthusiastic as the employee about this wonderful idea. All Fabulo screwdrivers have a standard shaft size of half (.5) a centimeter. Why the lack of enthusiasm for a screwdriver with a mechanical advantage of 20? ____

____

9) Eratosthenes was sent to the town well to draw a large bucket of water. Without any mechanical advantage, he can only lift a bucket weighing 150 mina. (One mina equals about 450 grams, or one pound.) Fortunately, Archimedes had designed a windlass for the well. The wheel of the windlass had a diameter of 45 daktyloi. (The word "daktyloi" comes from the Greek word for "fingers." One daktylos was about 2 cm.) The axle of the windlass was about 15 daktyloi. By using the windlass, will Eratosthenes be able to lift a bucket weighing 300 mina? _____

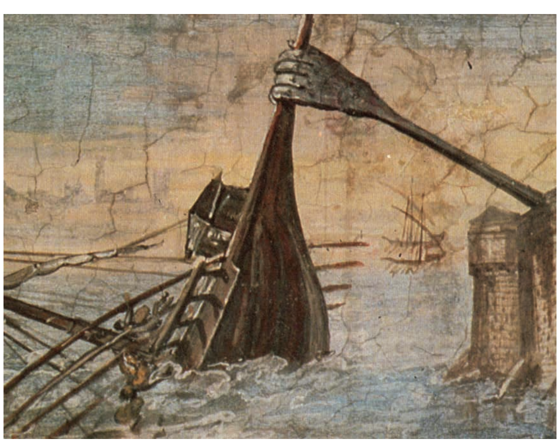


Meanwhile, back in ancient Greece, our volunteers have moved on to another episode in the life of Archimedes. We find him on a road in his home town of Syracuse. Archimedes has used gears to make a machine that will measure out long distances. Greeks did not measure in miles or kilometers, of course. Archimedes' friends might be measuring in "stadia" (about 185 meters or 200 yards).



The most famous example of the use of gears in the ancient world is the Antikythera mechanism. It was found in a shipwreck off the coast of Greece in 1901. No one knew for sure what this device did until 2008 when a team of researchers from Cardiff University used x-rays to decipher tiny bits of writing and to get a better look at some of the inner gears. It became clear that this ingenious device was a "clock" for the motion of the sun, moon, and planets, and could predict solar and lunar eclipses. Historians are fairly sure that the device was made during the second century BC (the 100s). Since Archimedes lived during the third century BC (the 200s), he can't have made the device himself. However, the device is so clever that historians tend to think that it must have been based on similar devices designed by Archimedes. We know that Archimedes was the greatest inventor in ancient Greece and was one of the few people with a good enough understanding of gears to be able to invent something like this.

Archimedes was not only an expert in the use of gears, but he also seems to have been the first person in history to realize the incredible potential of pulleys. Pulleys consist of a group of wheels that work together to give mechanical advantage. The stimulus that got him thinking about the power of pulleys was the threat of invasion by the Roman and Carthaginian armies. Sicily was, unfortunately, located between these two empires. The king of Syracuse asked Archimedes to please save their city if he could. So, (as we learned in our first adventure), Archimedes set to work designing both offensive and defensive devices. He showed the craftsmen how to improve their catapults, making them able to hurl much heavier objects with increased accuracy. His most famous defensive device was called "the claw." Archimedes put a huge metal grappling hook on the end of a very strong rope that was suspended from a huge lever hanging over the city's wall. A system of pulleys allowed soldiers to have such an incredible mechanical advantage that they could pull an enemy ship up out of the water after the hook had grabbed it. As the end of ship went up into the air, people and gear fell out. Then the soldiers manning the pulleys could suddenly release the ship, causing it to go crashing down into the water, hopefully breaking the hull.



The painting shown here is from the year 1600. The artist choose to show the claw as an iron hand. It is unlikely that it really looked like this.

ACTIVITY 2.7:   Watch some videos right now, if you can

The very best way to learn about pulleys is to see them in action. If you can possibly do so, take time right now to access a few videos. You can go to the YouTube playlist for this curriculum, or you can search for some yourself. We highly recommend starting with "Simple Machines: The Pulley" by funsciencedemos, and episode 228 on the "Smarter Every Day" channel. (This curriculum doesn't have any business connections with those channels.)

Here is a recap of what you learned in the videos.

In diagram A, the pulley is changing the direction of the rope but it is not giving any mechanical advantage. In diagram B, the pulley is giving a mechanical advantage of 2, so it is half as hard to lift the weight. Why does simply changing the location of the pulley make such a difference? In diagram A, all the weight is pulling down on the rope that runs from the weight to the pulley. In diagram B, you have two ropes holding up the weight, therefore, each rope only has to bear half of the weight. The other half of the weight is being supported by the hook on the ceiling (not shown in the diagram).

A quick and easy way to calculate the mechanical advantage of a pulley system is to count the number of ropes holding up the weight.

FIXED PULLEY   MOVABLE PULLEY

Diagram A   Diagram B

The diagrams below (C-F) show some pulley systems that use both fixed and movable pulleys. The red W's show you how much of the weight each rope is holding. In diagram C, each rope is holding half of the weight, indicated by W divided by 2, (W/2). In diagram D, each rope is holding one third of the weight, (W/3), because the force arrow is pulling up, not down. In diagram E, we don't have any additional mechanical advantage because now the force arrow is pulling down, so we still have three ropes bearing the weight. In diagram F, we have four ropes holding the weight, so each rope only has to bear one fourth of the weight, (W/4), and we have a mechanical advantage of 4.

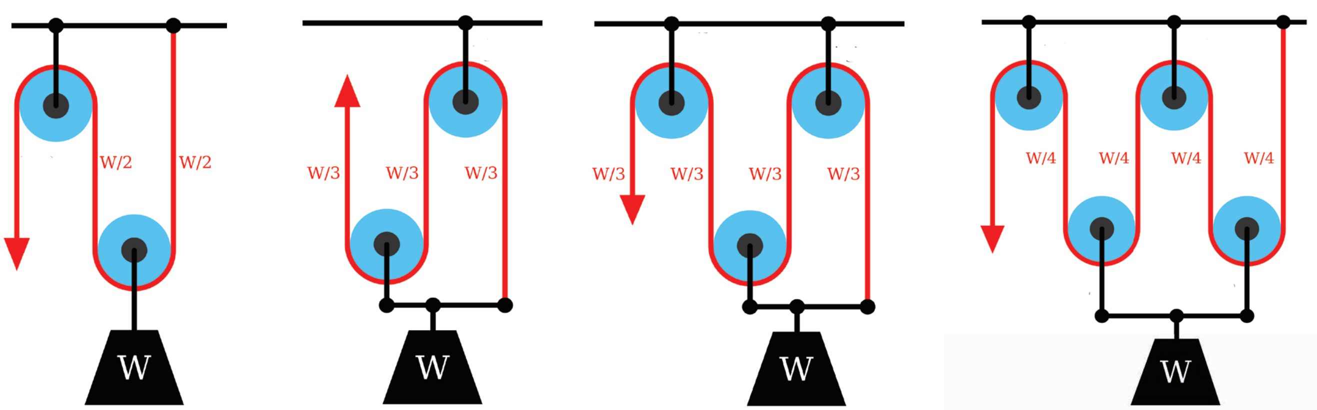


Diagram C   Diagram D   Diagram E   Diagram F

ACTIVITY 2.8: Online Gear Games

Gears are hard to make, which is why we're not going to suggest doing a hands-on lab where you have to make your own gears. If you happen to have a 3D printer and want to make some gears, it is easy to find patterns online. Instead, we're going to recommend a few websites where you can experiment with gears.

https://javalab.org/en/gear_en/

This is an easy way to play with gears! You can place as many gears as you want to on the virtual board. See if you can get the last gear in line to spin super fast. Then, see if you can make the last gear go so slowly that it doesn't even look like it is moving. Make several lines of gears going out from a central gear. Cover the board with gears or make them form a square. What else can you do with them?

(If this web address doesn't seem to work, try searching for "Javalab gears" using a search engine.)

https://www.engineering.com/gamespuzzles/connectit.aspx

This is actually a game where you progress through levels of difficulty. The goal is to arrange your gears so that the last one in the line matches up with a toothed bar that slides over to finish the puzzle. The first few levels are easy so that you can get the idea. By the time you hit level 8 or so, you really have to think! (HINT: You will eventually have to use a 2-step strategy, moving the bar halfway, then reorganizing your gears to move it the rest of the way.)

ACTIVITY 2.9: How much of the lever rap can you remember?

You might want to listen to the song at least one more time before doing this activity. Then, see if you can fill in these blanks without looking at the lyrics. (If you really get stuck, go ahead and peek.)

If you have a ______ that's hard to do, like ___________ a ______, or turning a ________,
Your ____________ won't do it, so be very ____________; you need a machine that's called a _________.

Levers come in classes: ____________, ______________, ______________,
Force, _________ and _______________ are the key words.
In a first class lever, the fulcrum's in the ________________,
If I ________________ with you, you seem to weigh ______________.

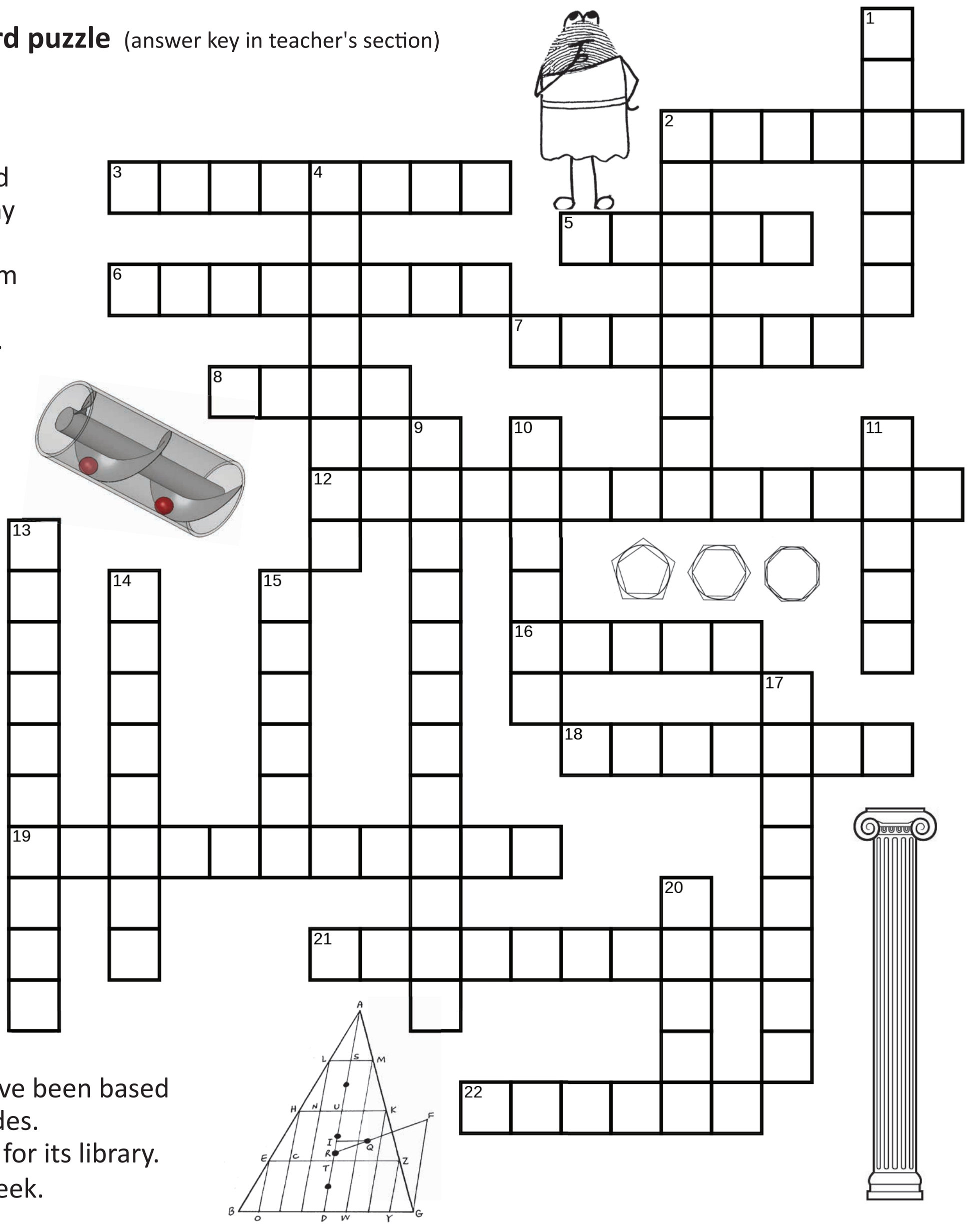
A ____________ class lever, has the _____________ at one end,
The ___________'s in the middle, give a _________ to a friend
In a big __________________ where the force is your ______________.
Don't call your friend "The __________" or you'll get into a tussle!

If you want some speed to _________ or _______,
The ____________ class lever is where it's at.
The fulcrum's at one end, the __________'s at the other.
The ___________ is in the middle, but don't hit your ______________!

When you use any ___________, you'll find, of course,
You can always trade ________________ for a gain in ______________.
If you make the lever ____________, moving loads is a snap.
And this is the ________ of the _________ ______!

ALSO...
watch epdisodes 12-15
of the *Eureka!* series.

ACTIVITY 2.10: A review word puzzle (answer key in teacher's section)



ACROSS:
2) The island where he lived.
3) Archimedes studied this arched shape-- the path traced out by any projectile.
5) In a ____ class lever the fulcrum is in the middle.
6) The driver gear turns the ____.
7) The parts of a lever are the force, load and _____.
8) Archimedes used a giant lever and some pulleys to make "the ____" (a device that could pick up ships).
12) Archimedes loved to study circles. He tried to calculate the value of "pi" which is the ___________ of a circle divided by its diameter.
16) Archimedes certainly would have discovered that this type of gear can be used to make the driver and the follower turn in the same direction (not to multiply force or speed).
18) Archimedes did a lot of work with center of ______ though he would not have called it by this name.
19) The _______ device might have been based on earlier inventions by Archimedes.
21) This city in Egypt was famous for its library.
22) This means "I found it!" in Greek.

DOWN:
1) Archimedes considered that one of his greatest achievements was figuring out the relationship between the ______of a sphere and the ______ of a cylinder that exactly contains the sphere. (same word in both blanks)
2) The city where Archimedes lived
4) The principle of _____ was what Archimedes discovered while in this bathtub.
9) He was the librarian of the best library in the ancient world. He also calculated the circumference of the earth.
10) The most famous mathematician before Archimedes. He might have been Archimedes' teacher.
11) The "Archimedes _______" is a simple machine that ancient people used to move large volumes of water.
13) In a first class lever (like a seesaw) one side is the force arm and the other side is the _______ arm.
14) The ancient Greeks were experts at this type of math. It deals with lines and shapes.
15) Archimedes used a series of this type of simple machine to make it possible for him to pull a ship by himself.
17) This wheel and axle structure was already in use before Archimedes was born.
20) The language Archimedes spoke

ANSWERS for 2.6
1) speed 2) 2 3) clockwise 4) yes 5) force (When the driver is smaller than the followers, this results in force multiplication.)
6) 1/5 (one fifth) Mechanical advantage of less than 1 means are not gaining force, but gaining speed instead. 7) fewer turns per minute
8) A mechanical advantage of 20 would mean that the screwdriver handle would have to be 10 cm in diameter, which is too large for an ordinary person's hand. 10/.5=20 9) yes (The mechanical advantage given by the windlass is 3. Therefore, with the windlass, he would be able to lift three times what he can lift without the windlass. The windlass will increase his lifting power to 450 mina.)

CHAPTER 2:

ACTIVITY 2.11 Identifying levers (or other simple machines) in ordinary household objects

You will need: a variety of objects found around the house that use leverage. Here are some ideas: pliers, hammer, scissors, fly swatter, nail clippers, stapler, chopsticks, racket, table knife, fork, spoon, bottle opener, manual can opener, tweezers, tongs, wrench (spanner), meat grinder, old fashioned (manual) egg beater, etc.

Do this activity in a way that suits your student(s). If you are working with a large group, you might need to pass the objects around. If you have a small group, they can just gather around one table. You can decide how you want to manage responses, as well. You can call on students one at a time and ask them to identify a simple machine, or you allow open and informal comments. Classroom management is at your discretion. The goal of the activity is to encourage critical thinking and analyzing, and any way you can accomplish this is fine.

ACTIVITY 2.12 Identifying levers in parts of the body

This activity will give your student(s) a chance to move around, which is always a wonderful thing for classroom settings! Demonstrate each type of leverage and then have the student(s) analyze their own body movements.

SUGGESTION: You might want to ask for ideas first, before giving the answers below. For each category, give the student(s) a few minutes to think, and see if they can come up with their own answers. The first and third class levers will be easier that the second class lever.

First class levers in the body: (There aren't very many of these.)

1) Tilting the head, either side to side or back to front.

The top of your spine, right under your skull, acts as the fulcrum. Your head is the seesaw, even though it is round, not flat. The muscles in your neck (and going up the back and sides of your head) provide the force. Imagine your head to be a 3-dimensional seesaw. You can make your ears be the riders of the seesaw by tilting your head to the left, then to the right. Your ears go up and down. When you tighten one side, making it the force, you automatically relax the opposite side, allowing it to be pulled. When you tilt your skull forward then backward, it again acts as a seesaw, with your face and the back of your head as riders.

Challenge: Can you tilt your head in an oblique ("catty-corner") way so that your head tilts down not really side to side but also not really back to front? Your two muscles group will have to cooperate, so it will take some concentration.

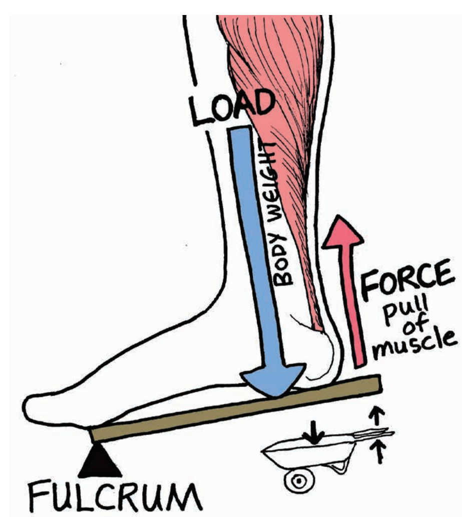
2) Bending your torso at the waist.

This is similar to tilting your head. The vertebrae at the bottom of your spine act as the fulcrum. Your torso is the seesaw, even though it is not long and flat. The muscles on each side of your body take turns supplying the force. The muscles not supplying the force must relax and allow themselves to be stretched. Muscles only contract; they can only pull, not push.

Second class levers in the body: (There aren't many of these, either.)

1) The calf muscle, or gastrocnemius *(gas-tro-NEE-me-us)*, lifting the body to a tip-toe position

Look at this diagram to see how this can be a second class lever. Notice the similarity to a wheelbarrow. The ball of your foot acts as the fulcrum, the load is the weight of your body, and the force is supplied by your calf muscle. It is very important that the calf muscle is attached to the back of the heel bone. The force needs to act on the <u>end</u> of the lever, keeping the load in the middle. If the load was on the end, it would no longer be a second class lever. The way to exert force is to contract your calf muscle, making it shorter.



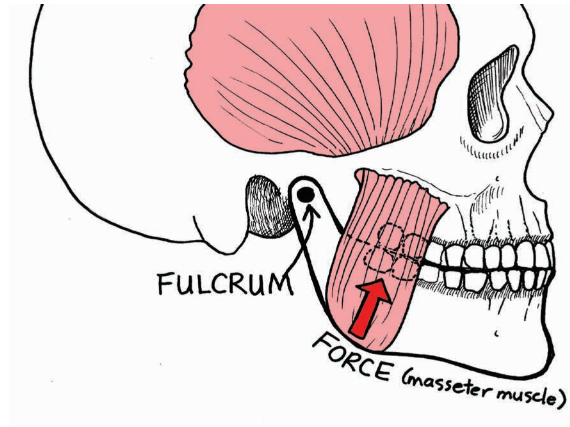
Challenge: How many times (in a row) can you go from standing to tip-toe? The first 10-20 times will be easy.

Challenge: Try move your foot side to side without moving your leg.

2) The jaw, while we are chewing food

Think of a nutcracker. While using our molars to chew, the load is right under the force. Notice how the back molars in this diagram are right under the masseter muscle. This isn't a perfect second class lever (a nutcracker is a much better example) but it is close enough to qualify. (For a description of how the jaw can be a third class lever, see the next section.)

Challenge: Put your fingers on your jaw and also on the side of your head, where your temples are. Open and close your jaw. Can you feel the muscle that is shaded in pink in this diagram? It goes quite a ways up the side of your head. Keep sliding your fingers up your scalp until you can no longer feel any motion when moving your jaw.

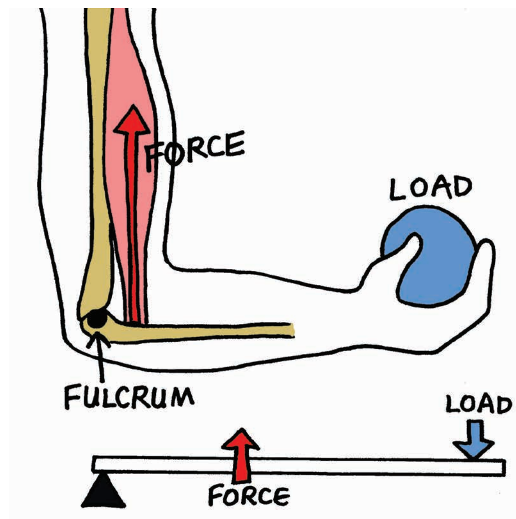


Third class levers in the body:

There are far more third class levers in the body than there are first or second. This is not a complete list.

1) Lifting the forearm (from elbow to wrist)

This is shown in the diagram. The force is provided by your biceps. This muscle attaches to the bones in your forearm, but close to the elbow. The fulcrum is at a point inside your elbow joint. If the attachment point of the muscle on the forearm was closer to the hand, you would have a better mechanical advantage, but you would sacrifice range of motion. The placement is at a point where you get adequate range of motion but still have enough power in the muscle to be able to lift most of the loads we need to lift during our daily routines. A good design!



2) Lifting the hand (using wrist as fulcrum)

If your wrist is the fulcrum and the load is something you are moving with your fingertips, the force must be between the two of them. Feel your palm and the back of your hand as you bend you hand. Can you feel the muscles and tendons pulling?

3) Lifting your arm from the shoulder, your leg from the hip, your lower leg from the knee.

4) Sitting up from a lying down position

You don't have a whole lot of mechanical advantage for this, so you often need to use your arms to get you started.

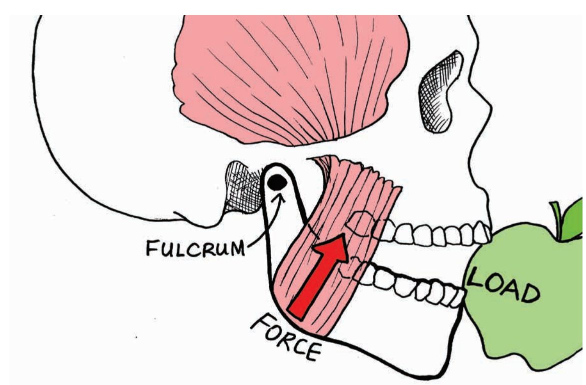
5) Lifting each finger, with the bottom knuckle as the fulcrum.

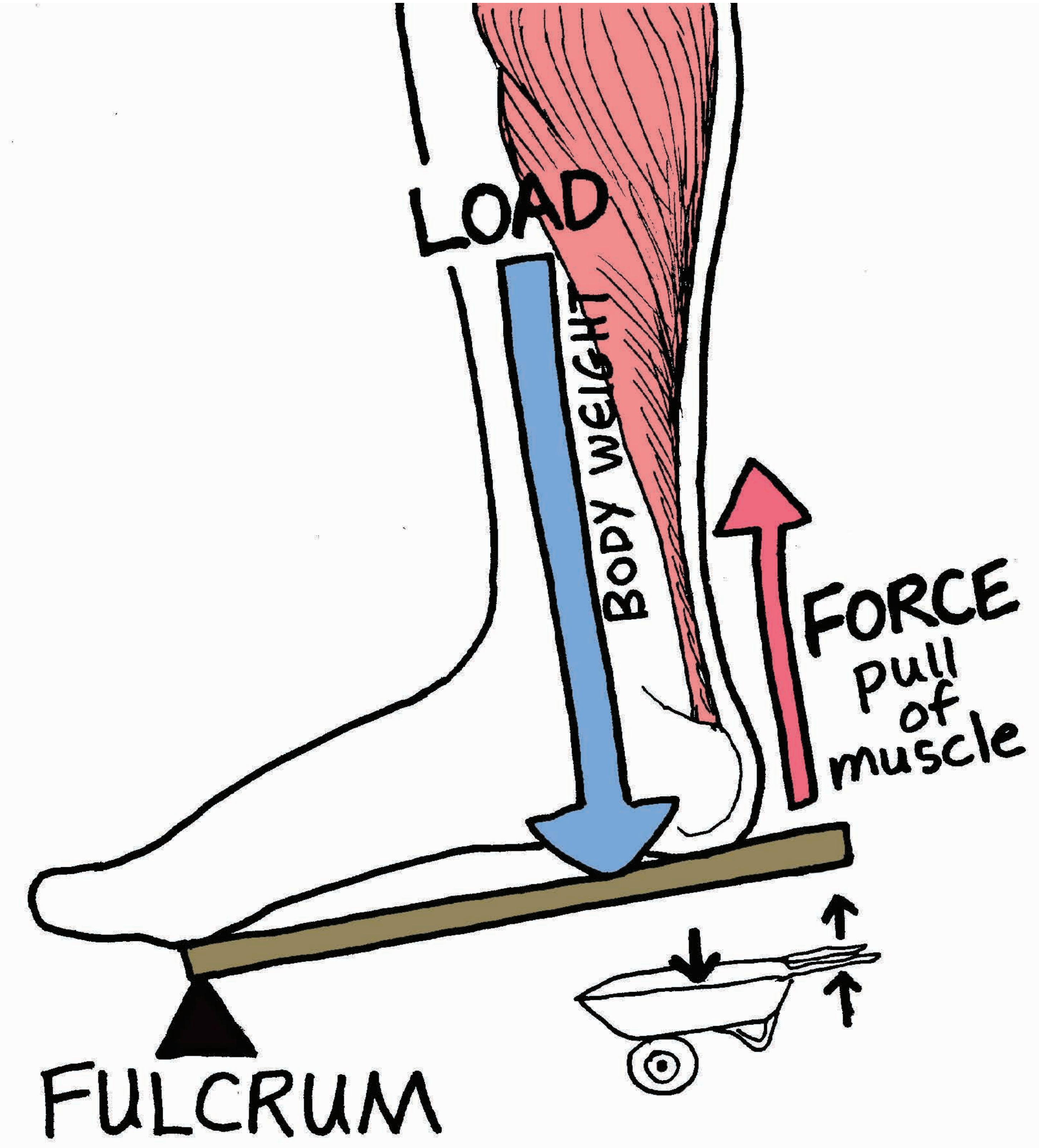
6) Moving each finger bone (each phalange)

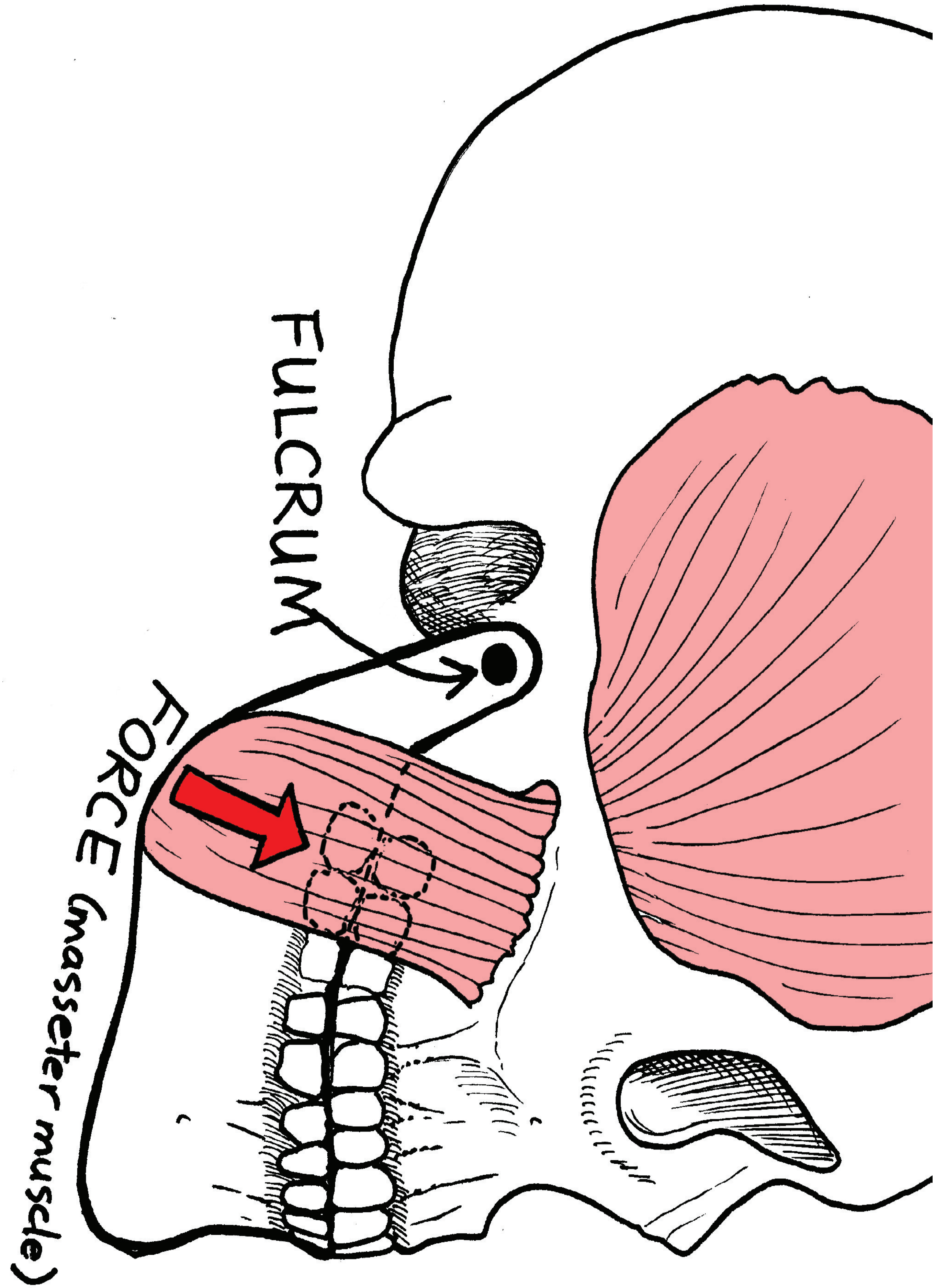
Since the finger bones are linked together with tendons and muscles, it is very difficult to move the tip of a finger without moving any other segments.

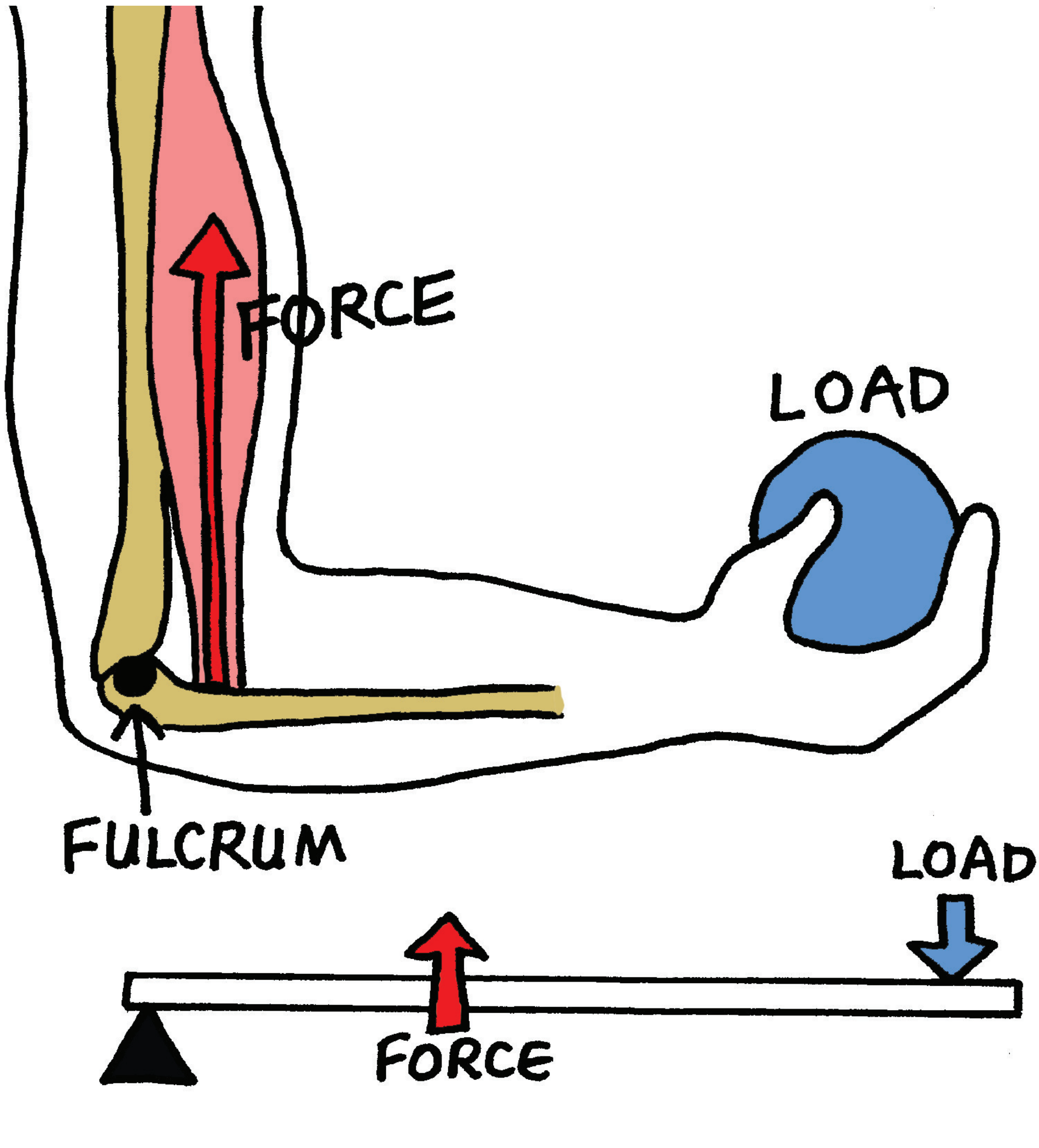
7) Your jaw when you are biting into something, like an apple.

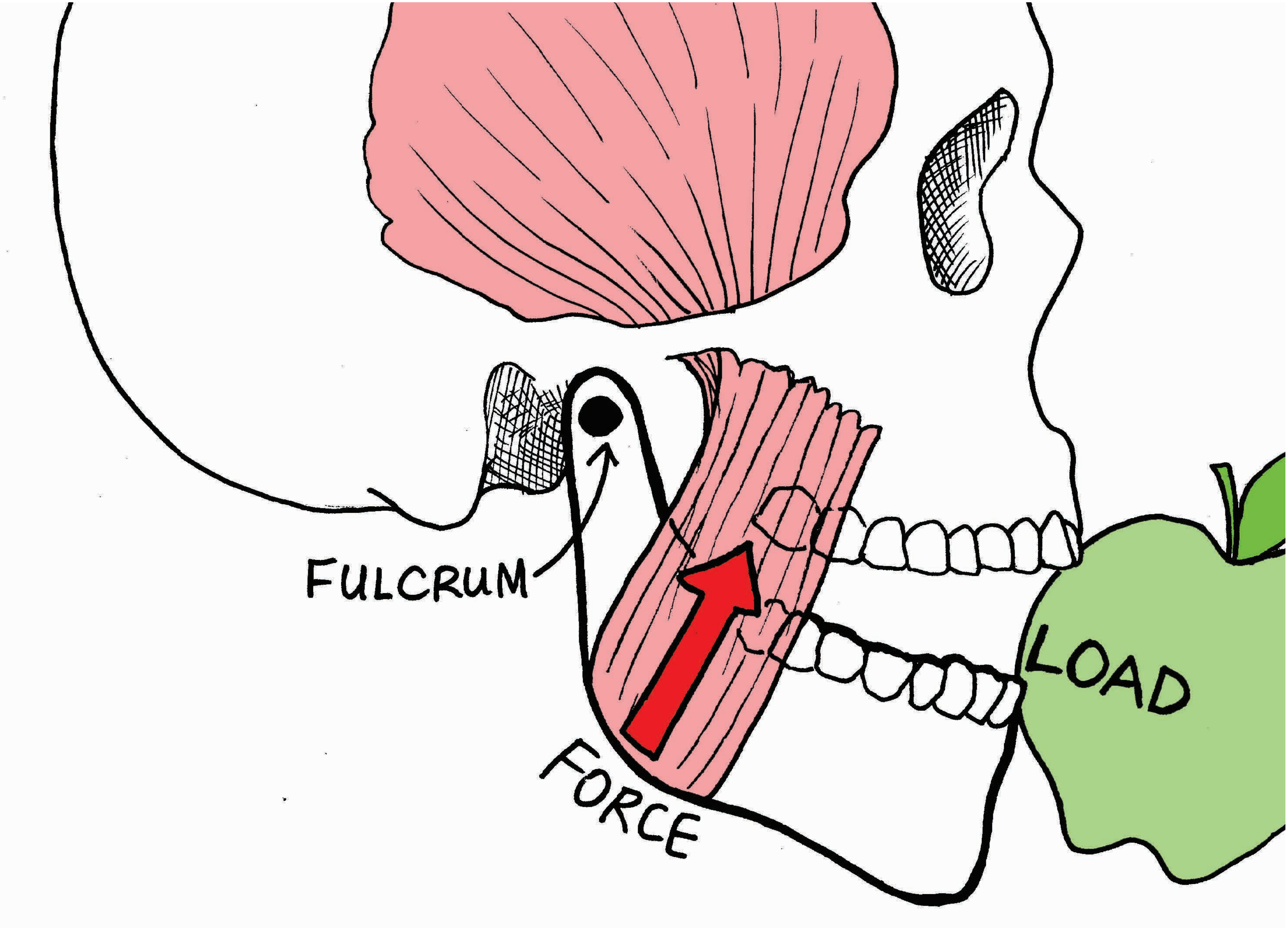
You can see in this diagram that the load (whatever you are biting) is at the end of the lever (your jaw bone). This arrangement makes the jaw a third class lever.




LOAD
BODY WEIGHT
FORCE
pull
of
muscle
FULCRUM


FULCRUM
FORCE (masseter muscle)


FORCE
LOAD
FULCRUM
LOAD
FORCE


FULCRUM
FORCE
LOAD

ACTIVITY 2.13 An easy pulley demo without having to buy or make pulleys

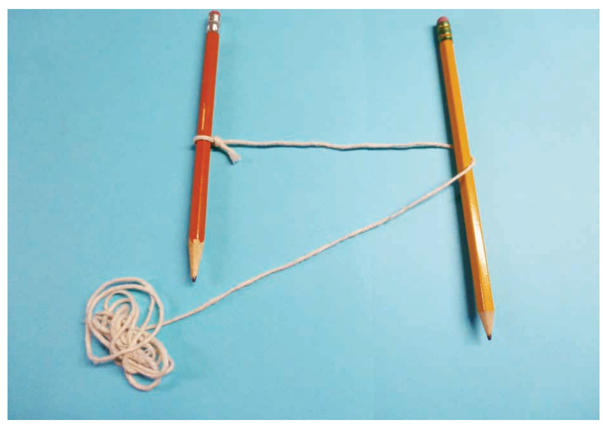
You will need: a long piece of rope, two brooms or mops with sturdy handles (or pieces of PVC pipe, or large dowel rods), and three people to do the demonstration
ALTERNATIVE: Try a scaled-down, table-top demo using pencils and string, if you don't have enough floor space.

1) Tie one end of the rope to one of the handles. Have someone hold this handle tightly, parallel to the floor. This will be person 1 and handle 1.
2) Loop the rope around the second handle once, and have someone hold this handle, also parallel to the floor. This will be person 2 and handle 2.
3) Have these two people stand opposite, facing each other, about 2 meters (6 feet) apart.
4) Have the third person grab the free end of the rope, and (standing very close to person 1) pull on the rope. Person 2 will try to keep the handles from being pulled together. It's like a tug-of-war between person 2 and person 3. Notice how hard or easy it is to keep the handles from being pulled together.
6) Now pass the rope around handle 1 again, then around handle 2 again. Then try the tug-of-war again. Was it easier this time for person 3 to pull the handles together?
7) Make another loop around handle 1 and then handle 2. Try the tug-of-war again. How hard was it to keep the handles apart?
8) Every additional loop you make will increase the mechanical advantage for person 3, because you are making a pulley system.

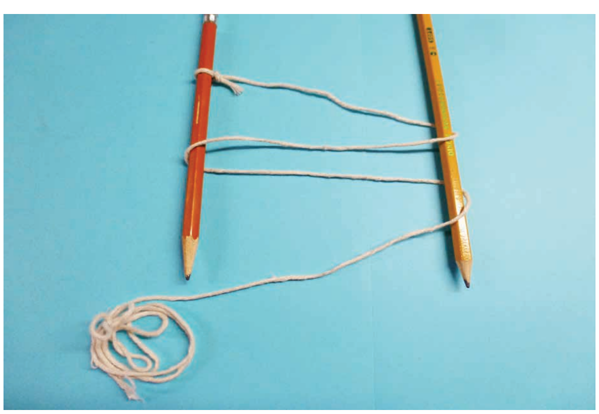
PENCILS ARE USED IN ORDER TO SHOW THE LOOPING MORE CLEARLY.
Also, the strings are shown very far apart, just for clarity. Your ropes/strings can be much closer together.

1

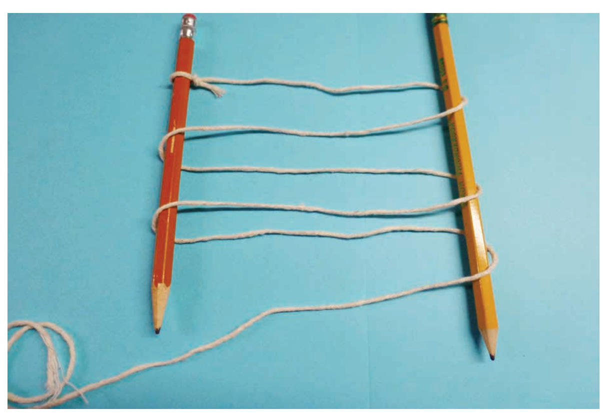
2



3



4



Answers to crossword puzzle, activity 2.10