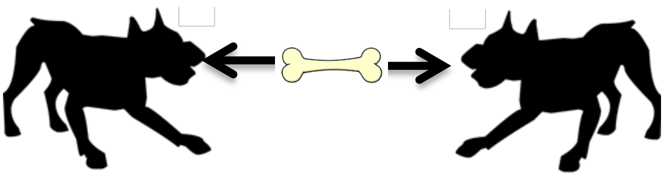
Forces Subject Knowledge

A force is a push or a pull.

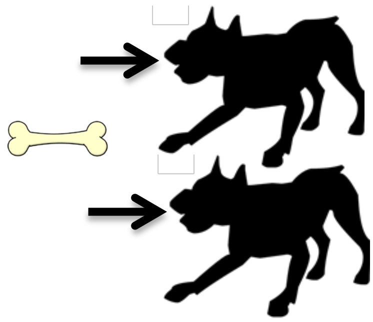
In general use, the word force can mean intense effort or even violence, but not so in science! No matter how small, a force is just a push or a pull. It must not be confused with other words that have specific meanings in science, such as pressure or power.
The size of a force can be measured and the unit of force is the **Newton.** Schools tend to have Newton meters which work by means of a spring.

- It is possible to have forces of **attraction**, e.g. the force that keeps our feet on the ground - the gravitational pull of the Earth.
- It is also possible to have forces of **repulsion**, e.g. the repulsion that occurs between two like magnetic poles.

It is important to know not just the size of a force but also the direction in which it acts.
e.g. A bone pulled with the same sized force by 2 dogs.

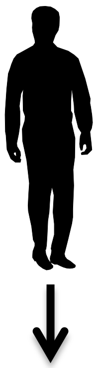


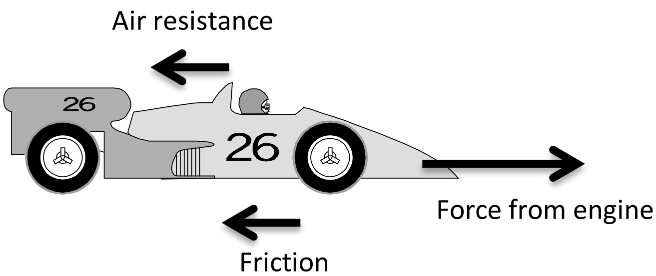
The bone stays still



The bone moves fast to the right

The direction in which the bone moves depends on the directions of the 2 forces.
So both the size and the direction of a force matter and the direction of a force is represented by an arrow, as shown in the examples below:





The forces that oppose the motion of the car are called friction & air resistance.

The force that pulls someone to the ground, or more accurately to the centre of the Earth, is called their weight: the force due to gravity – more of this later.

Forces and Motion:

It seems logical to suggest that a force is necessary for motion but not so!
Newton was the genius who stated the following law:

'A body remains at rest **or** moves with a constant speed in a straight line **unless** acted on by an overall force.'

Or put another way, if there is no net or overall force acting on something, there are two possibilities:

- the object will stay still, or
- if the object was already moving, it will continue to move with this speed in a straight line.

i.e. there is **no change in motion**

The first possibility is the one that appeals to our common sense and is easily observable, such as the case of a man sitting on the chair. There is no overall force and so he is still.

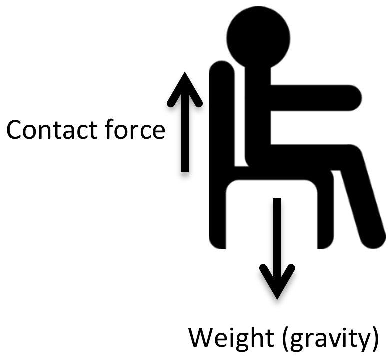
The second possibility seems to deny common sense because, on Earth, once something has been set in motion, such as a toy car given a push across the floor, it soon comes to a stop. The toy car does not carry on at a steady speed in a straight line. However, after the car has been pushed, it is still subject to a force - the friction that is produced between the wheels and the floor and this opposes the motion and it is this force that makes the car slow down and stop.

In space, it is much easier to make sense of this because there is no friction and no air resistance because there is no air. Once a space shuttle has been set in motion, it does indeed carry on in a straight line at a steady speed. This assumes that the shuttle is not near to any planets so that there is no gravitational force acting on it. In this situation, a space shuttle will only need to fire the motors to produce a force that will make it speed up, slow down or change direction. It does not need the motors on to keep it going at a steady speed in a straight line. It will carry on at this speed for ever unless a force acts on it.

In the primary classroom, it is possible to observe nearly frictionless motion with a cheap air football or air hockey game – the plastic pucks are held up on a bed of air and so there is no friction with the floor and once hit they keep moving – until they bump into the sides, where they experience a force and change direction.

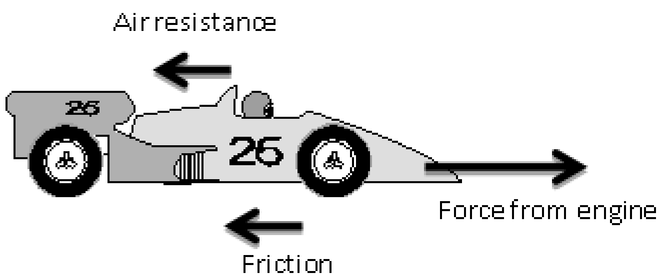
Newton's law makes us look at the world in a slightly different way. For example, when you are sat on a chair, you are 'at rest' (in the physics sense of not moving!) but you are still experiencing a gravitational force downwards to the centre of the Earth. Why then are you not accelerating downwards through the floor?

This is because the downwards force of your weight is balanced by what is called the contact force of the chair pushing back up:



These 2 forces are equal and opposite so there is no overall force on you, and you are 'at rest'.

Another example is of a car moving along at constant speed, say 30 mph, in a straight line:

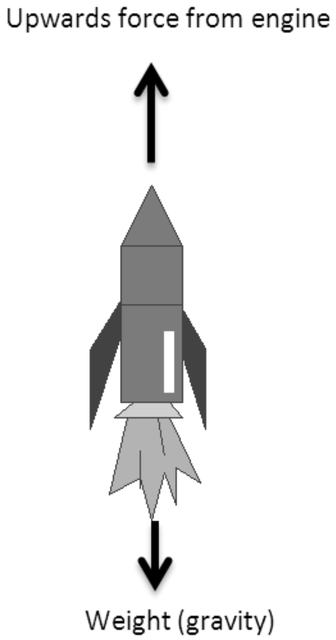


The engine produces a force forwards, but both friction, and air resistance, are opposing the motion.
The force forwards is equal and opposite to the sum of the forces of friction and air resistance backwards so there is no overall force and the car moves at steady speed in a straight line.
What about the situation when there is an overall force? Well, that is when Newton's second law comes into play:

Newton's Second Law states that:

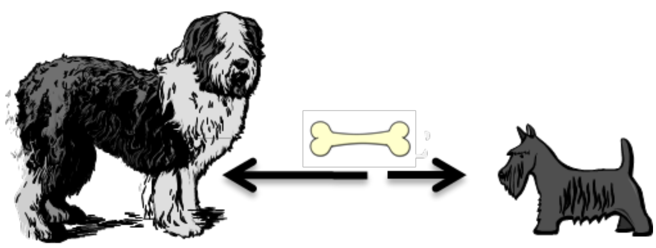
If something does experience an overall force, then acceleration will occur. This will result in **a change** in speed- it will speed up, slow down, or change direction.

An example of acceleration being caused by an overall force is a rocket taking off: A space rocket needs a huge engine to produce an enormous force upwards:



The weight of the rocket acts downwards but the upward force is much greater than the force due to gravity downwards so it accelerates upwards. The upwards force is so large that the rocket quickly reaches huge speeds.

The same principle would be true if a small dog pulled in one direction with a small force and a large dog pulled in the opposite direction with a much larger force:

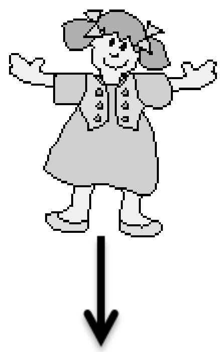


The bone would accelerate in the direction of the winning, large dog - providing he is not quite as soft as he looks in these pictures!

Mass and Weight:
We use the word weight loosely in everyday language and very often in a way that is not scientifically accurate. For example, we tend to say that we weigh nine stones or fifty five kilograms or whatever. In fact, that is our mass and not our weight. We do not need to worry too much about primary children mixing up these words, but it is important that we understand them.

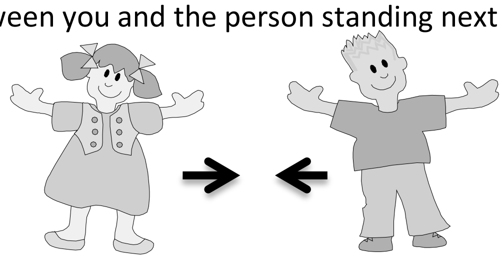
It is quite easy to distinguish between mass and weight if it is born in mind that, in science, weight is a **force**. Force is only measured in Newtons. So, officially, weight should always be given in Newtons.

Mass is measured in Kilograms and is a measure of the amount of matter in a body. Mass has just size and does not include direction. It does not need to be represented by a line with an arrow.
Weight is a force and is the pull (or gravitational attraction) that a body feels towards the centre of the Earth. Weight is measured in Newtons and it has size and direction: it can be represented by a line with an arrow.

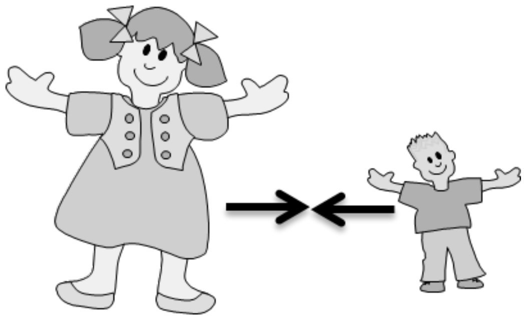


Weight (gravity)

We have said that the force due to gravity (weight) is the pull that a mass experiences towards the Earth. Why does a mass experience this pull?
Many people feel that gravity is something to do with magnetism or the spin of the Earth but this is **not** the case. The gravitational force is a force of attraction (never repulsion! - that would lead to some exciting situations as we were repelled by the surface of the earth!!). The gravitational force of attraction occurs between all masses. There is a small force of attraction between you and the person standing next to you!!



The size of this force depends on the size of the masses. The force is larger if one or both of the masses is larger:



The size of the force also depends on the distance apart of the masses and the force is less if the masses are further apart.

Hence the force of gravitational attraction between you and your neighbour is very small because your masses are relatively small. Sadly, this means that you cannot really fall into an attractive person's arms and blame gravity. Well, I suppose you could give it a go…

The force between you and the ground is significant because the mass of the Earth is so large, as shown in this (very much not to scale) diagram:

So a person's weight is the force of attraction between two masses: the person and the Earth.

The gravitational force of attraction between the Earth and the Moon is what keeps the Moon in orbit around the Earth. Similarly, the gravitational attraction between the Earth and the Sun is what keeps the Earth in orbit around the Sun.

A quick way to lose weight?!!!
If a person goes to the Moon, their mass (the amount of matter in their body) does not change. So if an astronaut had a mass of 60 Kg when they left Earth, they would still have a mass of 60 Kg when they arrived on the Moon's surface.

However, they would weigh less on the Moon! The pull they feel to the ground on the Moon (their weight) is less than the pull they feel on the Earth.

This is because the **Moon** has **less mass** than the Earth. The size of the force of attraction between any two masses depends on the size of the masses:
Thus the pull between you and the Moon (your weight on the Moon) would be less than the pull between you and the Earth (your weight on the Earth) merely because the mass of the Moon is less than the mass of the Earth.

If your weight (pull down) on the Earth is 600 Newtons and then you went to the Moon your weight would be about 100 Newtons.

Many people think that there is no gravity on the Moon but this is **not** true. On the Moon, you would weigh about a sixth of your weight on Earth. You would have the same mass though and the same shape!

This leads to the interesting possibility of me winning the Olympics high jump - as long as I was competing on the Moon and everyone else was on Earth!! I weigh less on the Moon and so my muscles could make me jump considerably higher on the Moon than on the Earth. This is why when men first went to the Moon, these highly educated, well trained men at the height of their intellectual powers bounced around like children on a bouncy castle!

Similarly, if you went to a planet which is much more massive than the Earth, you would weigh more and you would find it very hard to jump and would feel very weighed down.

Also if someone grew up on a planet which is much more massive than the Earth, then presumably their muscles would adapt to this and be very strong, if they then moved to live on Earth they would be super strong (but no flying like Superman!!).

Falling Objects
Do heavier objects fall faster than lighter objects? Common sense suggests that they do but this is **NOT** the case.

A feather flutters to the ground when it is dropped because of air resistance. Air resistance acts on everything that moves through the air and is a force which opposes the motion, i.e.

it causes the moving object to slow down. Engineers are very conscious of this when designing cars and so modern cars are highly streamlined to reduce the effect of this air resistance as much as possible.

Some shapes result in less air resistance and some result in more. A feather experiences much air resistance, a coin very little. Thus when a feather and a coin are dropped at the same time from the same height, the coin hits the ground first.

It may seem surprising but when this same experiment is repeated in a tube from which all the air has been removed, i.e. a vacuum, the feather and the coin hit the ground at exactly the same time. It is very strange to see a feather drop in this way. You can see this by watching the first part of this video: https://www.youtube.com/watch?v=E43-CfukEgs

This same experiment was repeated on the surface of the Moon by the American astronauts and the coin and the feather hit the ground at exactly the same time. There is no atmosphere on the Moon and so there is no air resistance.

In the 17th century, Galileo was the genius who looked at this phenomenon with fresh eyes. Legend has it that he climbed to the top of the leaning Tower of Pisa and dropped two cannon balls over the side. One canon ball was heavier than the other. Galileo's professor was highly sceptical about Galileo' ideas and so Galileo had the professor lie at the bottom of the tower with his ear to the ground!! This was so that the professor could listen out for the two thuds as the one cannon ball hit the ground before the other one. The professor was dismayed to only hear one thud - they had hit the ground at the same time.

This is an important principle in science. If air resistance is the same for two objects which are dropped, they will gain speed at the same rate as each other even if one is much heavier than the other. So, if they are dropped from the same height, they will hit the ground at the same time as each other.

Why is this the case?
The pull of gravity is **not** the same on all objects. In other words; all objects do not all have the same amount of gravity acting on them. Larger masses experience a larger pull because of gravity and so they experience a bigger pull downwards.

This begs the question, 'Why, if heavier things have a bigger pull downwards because of gravity, do they not fall faster than light things?'

In order to answer this question, it is first necessary to think about acceleration. The effect of gravity is to make something fall and, ignoring air resistance, all bodies will fall with the **same acceleration**.

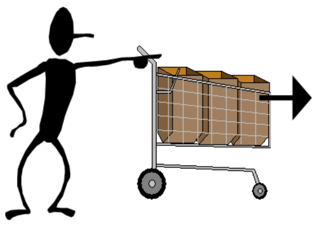
Acceleration is not an easy concept and it is quite different from gravity. The acceleration of a falling object is **caused** by the pull of gravity. An unbalanced (overall) force causes something to accelerate. Acceleration means that something is changing speed - getting faster or slower. It can also mean something is changing direction. A falling body just keeps getting faster and faster, as long as it experiences the unbalanced force of gravity.

To understand this situation, it will be easiest initially to pretend that there is no air resistance at all. Ignoring air resistance, a heavy object and a light object will both fall at an identical rate. This means that they will speed up at exactly the same rate and so hit the ground at the same time. It is therefore wrong to say that a larger mass 'takes longer to accelerate' than a smaller one or 'a larger mass accelerates more slowly'. Ignoring air resistance, they will both increase in speed at exactly the same rate and so hit the ground at the same time.

The shopping trolley analogy:

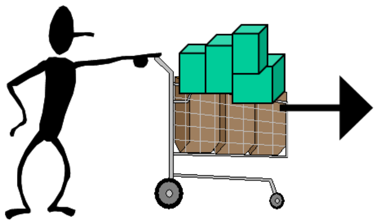
I find this all becomes more intuitive when I think about my weekly shop in the local supermarket. The start of my trip around the supermarket is relatively easy because my trolley is empty and it does not require a large force to set it in motion.

- An empty shopping trolley only needs ***a small force*** to make it speed up from standstill to say 4 mph.

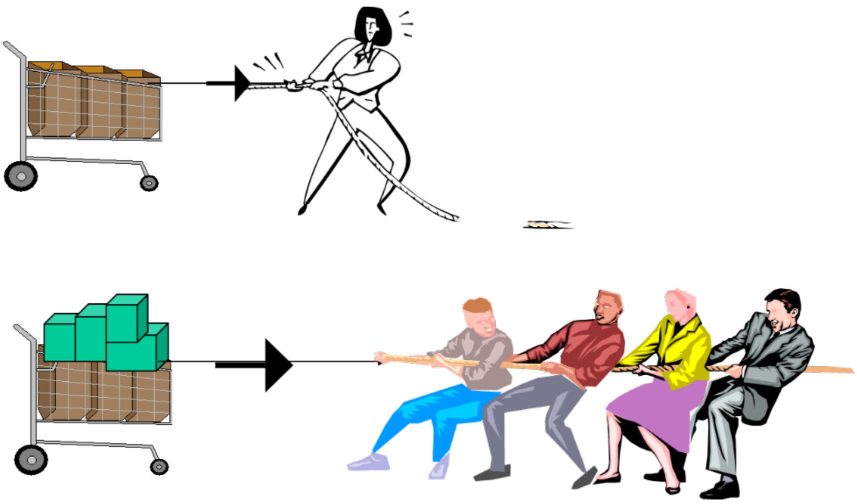


However, as the shopping continues, the trolley soon fills up. It becomes harder to push the trolley when it is full.

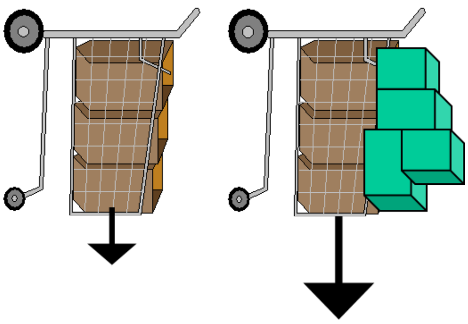
- A full shopping trolley needs **a much larger force** to make it speed up at the same rate**,** from standstill to 4 mph**.**



The same would be true if I decided to pull my shopping trolley, rather than push. A full trolley needs a larger pull than an empty trolley to speed up at the same rate:



Now, I do not like supermarket shopping and I sometimes think about dropping the trolley over a cliff! Think about falling shopping trolleys, i.e. imagine dropping two shopping trolleys over a cliff – one being full and the other empty:



- The light, empty shopping trolley experiences a pull down due to gravity and accelerates until it hits the ground.
- The heavy trolley experiences a **larger** pull down due to gravity but accelerates at exactly the same rate as the lighter one and so speeds up at an identical rate and hits the ground at the same time.

This is just the same as the pulled trolleys in the supermarket, but the picture has been turned on its side. The heavier trolley needs the larger pull to make it speed up at the same rate as the lighter trolley and so hit the ground at the same time. This is exactly why falling objects speed up at the same rate, whatever their mass.

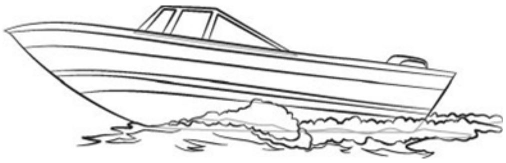
So try out the experiment with the shopping trolleys and see if you agree that it is easier to pull a light trolley than a heavy one. Then find a cliff…

This means that a 2kg mass dropped from the same height as a 1kg mass reaches the floor at exactly the same time, i.e. heavier objects do not fall faster.

Friction

Friction is a force that opposes motion and is caused by the motion between two surfaces in contact, e.g. rubbing your hands together which then become warm. Air resistance is caused by friction with the air molecules and a parachute increases the amount of air resistance because it has a bigger surface area.

Water resistance is caused by friction with the water molecules and so fast boats are streamlined to reduce this.



The friction between a car and the ground and the air resistance are forces that need to be overcome. However, friction can be a useful force. Try driving on ice! The friction between the car and the ground is very important when cornering.

Also friction enables you to walk and so walking on ice is hazardous.

For this cyclist friction is both useful and a nuisance.

Useful

- saddle
- handlebar grips
- pedals
- brakes
- tyres (try cycling on ice!)

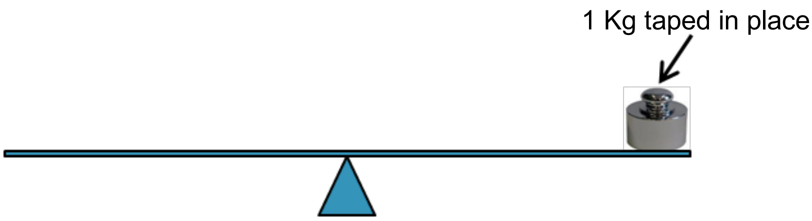
Nuisance

- air resistance
- bearings

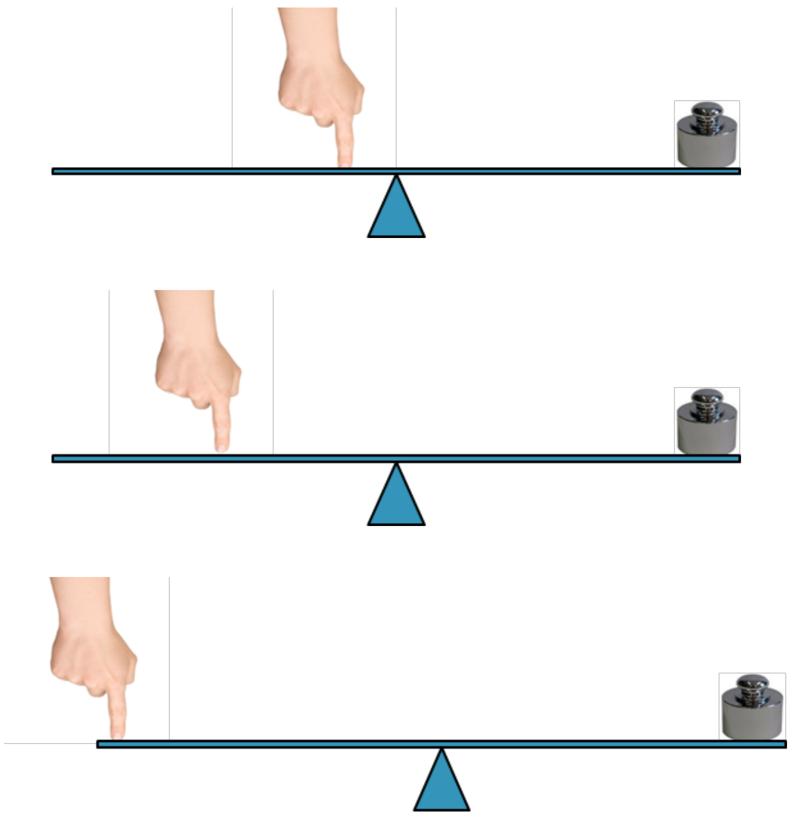
Levers, pulleys and gears are helpful because they allow a smaller force to have a greater effect. They are best explored practically at primary level.

Levers

The very best way of understanding levers is to experience them, and the best way of doing that is to control variables by ***fixing*** (with tape) a 1Kg mass in place at the end of a piece of wood that is about 1 metre long. You need something for the wood to balance on – a triangular piece of wood from the infant shapes tray, or even a wooden rolling pin held in place. The balance point is called a fulcrum. The thing being lifted (in our case the 1Kg mass) is called the load, and the size of the force needed to lift it (the push from the hand) is called the effort.

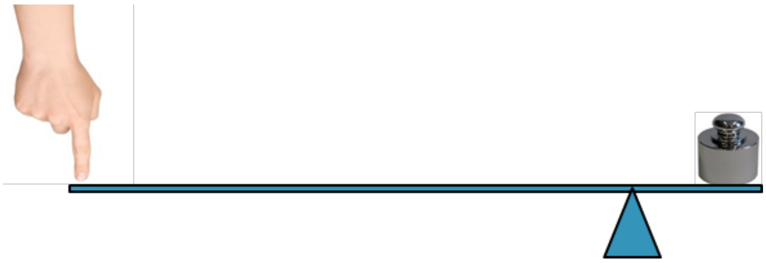


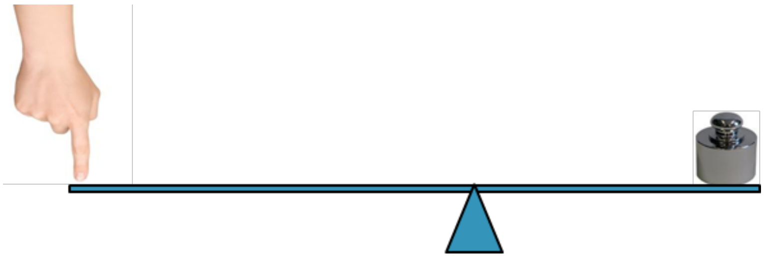
You only need to have a couple of these kits, and the pupils can take turns in feeling the forces needed to lift the 1 Kg mass when their hand pushes at different places along the piece of wood, as show here:



This works so well – it requires a very little force to lift the 1 Kg when you push from the end of the piece of wood, but this force needs to be larger as you move your hand towards the balance point (fulcrum). It is almost impossible to push hard enough to lift it when your hand is very close to the fulcrum. Each child needs to experience this. It is possible to measure the force needed at each place, by using a push meter (inexpensive and readily available from primary science suppliers).

Then a different approach can be used: the push down is always done right at the end of the piece of wood (as shown below), the 1 Kg is still taped in place at the other end, and now the fulcrum itself can be moved along.

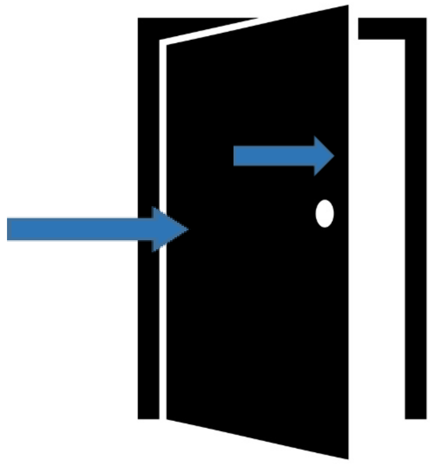




Once again, the difference in the forces needed at the different places is really noticeable – much less force is needed when the fulcrum is close to the mass.

It is good to ask the pupils if they can see a pattern in their results. Less force is needed to lift the load when the push down is further away from the fulcrum.

A door is a simple way of showing how useful this principle is – the hinges act as fulcrum.
It is easy to shut the door by pushing next to the door handle, which is always a good distance away from the hinge (fulcrum). Try to shut the door by pushing it much closer to the hinge – it is almost impossible.



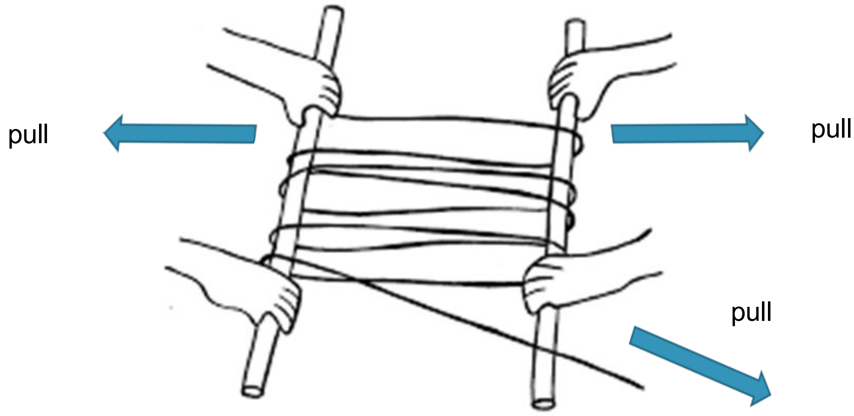
Pulleys

The simplest pulley just means that you can pull *down* on a rope to lift something, which is easier for our bodies (especially our backs) than pulling up. The same force is needed with or without the pulley, but it is just easier for us with it because we can use our weight to help pull it down.

Like levers, the thing being lifted is the load and the force needed is the effort. The load and effort are equal with a simple pulley.

This can be demonstrated in the classroom by asking another adult to hold a rolling pin firmly on the top of a door (this provides a nice smooth, round surface to reduce friction) and throw a rope over it. Attach a heavy bag to one end of the rope and pull down on the other end to lift that bag – a simple pulley!

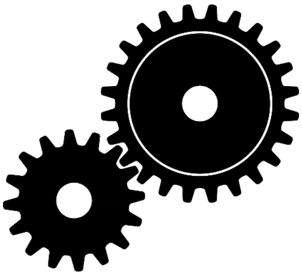
It is possible to make more complex pulleys, such that the effort needed to lift the load is reduced. These are done in secondary schools but are not very easy to make or explain! The easiest way is with two (strong) broom handles and a long rope :



One person holds each broom handle and their aim is keep the two handles apart. The third person is pulling on the rope which is looped over the handles and is trying to pull the handles together.

Begin with the rope looped over the handles just once – it fairly easy for the two holding the handles to pull enough to keep them apart, no matter how hard the person pulls on the rope. Then loop the rope over the handles again and repeat a number of times. Once there are many loops, as in the picture above, the person pulling the rope easily pulls the two handles together. The effort has been reduced. How does this work? Ask the person pulling the rope what they noticed – the pull needed is much less, but they will find that the length of rope they pull through their hands increases. The force needed is less, but the distance you need to use that force increases.

Gears



It is by far the best thing for pupils to experience gears practically and to see them working.There are various kits that can be used in primary. Exploring their own bikes makes it all real for them. They can discuss why gears are helpful and when they use the different gears. They can experiment by putting a bike into a low gear and turning the pedal once to see how far it goes, and then repeating this with a high gear.

Videos can also be really useful, such as:
https://www.bbc.co.uk/teach/class-clips-video/articles/zmcpy9q

Health & Safety:

Teachers always need to risk assess practical activities for their children and defer to their health and safety advisor for the most up-to-date source of health and safety guidance. This training cannot be relied upon as source of health & safety guidance.