

Physics

Levers and Gears: A lot for a little

A surprising number of the tools and machines we rely on every day – from door handles and cricket bats to clocks and bikes – can be explained in terms of a few simple ideas. The same principles allowed ancient civilizations to build enormous pyramids and the mysterious astronomical device known as the Antikythera Mechanism.

In this lesson you will investigate the following:

- How do simple machines allow us to achieve a lot with little effort?
- What is mechanical advantage and how does it apply to levers, wheels and gears?
- How do gear systems work?

So gear up for a look at how some of our most useful machines work.



This is a print version of an interactive online lesson. To sign up for the real thing or for curriculum details about the lesson go to www.cosmosforschools.com

Introduction: Levers and Gears



A reconstruction of the Antikythera Mechanism.

In 1900 a team of divers discovered a 2000-year-old shipwreck near the Greek island of Antikythera. Inside the wreck they found an incredible range of treasures including beautiful bronze statues and glass bowls. They also found a plain-looking lump of bronze no bigger than a shoebox.

Closer examination revealed that the object had gear wheels embedded in it – as though it was some kind of ancient clock. It soon became known as the Antikythera Mechanism but its internal structure and purpose remained mysterious for decades.

Later investigations using X-rays uncovered thirty interlocking gears and inscriptions of the ancient Greek words for “sphere” and “cosmos”. These discoveries suggested it was a sophisticated machine designed to track the motions of the planets and the phases of the moon. The ancient Greeks could use this information to work out when to hold the Olympic Games and other religious festivals. They could even predict astronomical events such as eclipses.

Scientists and historians were shocked. Nobody could believe that such a complex machine was made 2000 years ago!

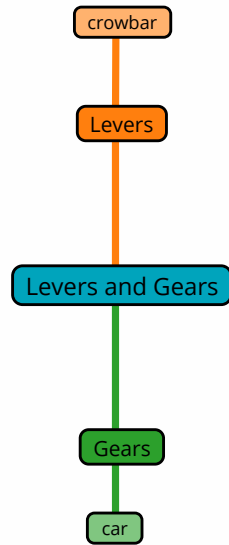
And when you think about it, it is amazing that an ancient civilization managed to build an ingenious time-keeping device out of a small collection of simple gears.

Read the full *Cosmos* blog post [here](#).



Question 1

Brainstorm: How many tools or utensils involving levers or gears can you think of? Add them to the mind map below, giving as many examples as possible. One example of each has been given.



Gather: Levers and Gears

COSMOS
LESSONS

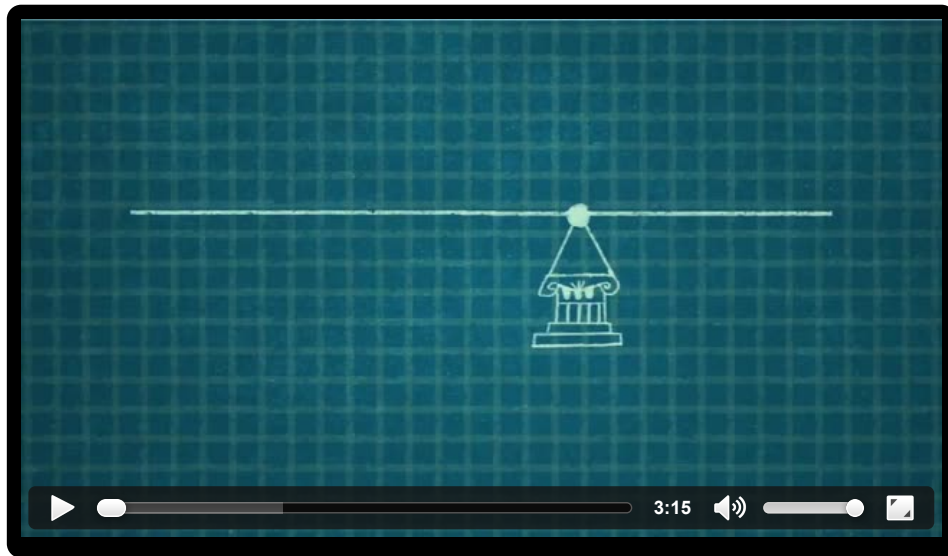


Making life easier

Building the ancient pyramids obviously involved a huge amount of work. When scientists talk about *work*, they don't have in mind homework or jobs. One of the things they mean is motion caused by a force. This includes forces of nature, such as gravity causing a leaf to fall from a tree. But it also includes forces that people apply to make objects move – these are known as *effort forces*.

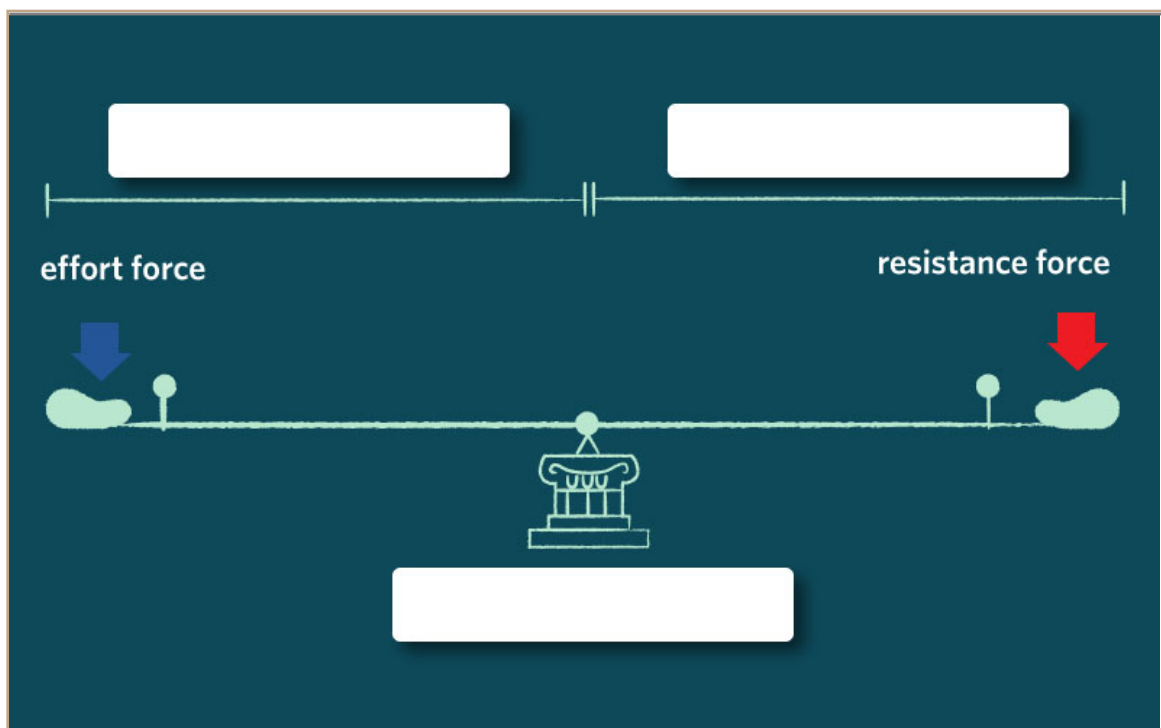
If you try to open a tin of drinking chocolate with your bare fingers then you're likely to just get sore fingers. But when you wedge a teaspoon under the lid and push down on the handle, the lid opens easily. Why is this?

The answer lies in a simple mechanical principle discovered 2000 years ago by the Greek mathematician, Archimedes.



Question 1

Label: Use the information in the video to label the three basic components of a lever.



Question 2

Complete: Find the missing words to complete the following sentences and enter them into the right hand column.

| | |
|---|--|
| A force applied by a person to make something move is known as an _____ force. | |
| Every lever has three components: an effort arm, a resistance arm and a _____. | |
| A lever is balanced when: effort force x length of effort arm = resistance force x length of _____ arm. | |
| A lever gives you a trade-off: increase the distance and you can use less _____. | |

Multiplying force

Suppose your family is driving along a country road and the way is blocked by a large boulder. You try to lift the boulder but it's impossible to move!

If you had a long crowbar you could use a small rock as a fulcrum and then use the lever principle to shift the boulder with less effort. As shown in the diagram on the right, the amount of effort force you need depends on the length of the effort arm compared to the length of the resistance arm.

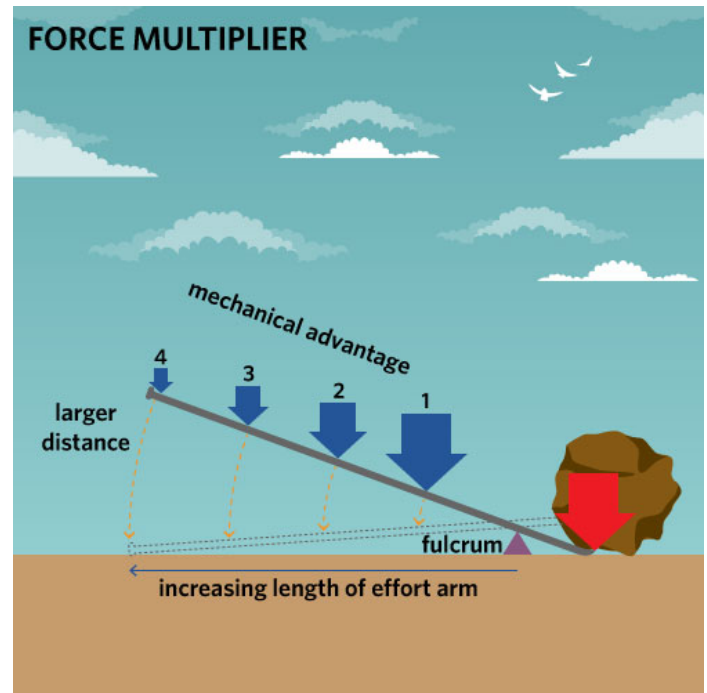
Mechanical advantage is a measure of how much the effort is reduced and it depends only on the lengths of the two arms:

$$\text{mechanical advantage} = \frac{\text{length of effort arm}}{\text{length of resistance arm}}$$

For example, if the length of the resistance arm is 0.5 m and the length of the effort arm is 2 m then:

$$\text{mechanical advantage} = \frac{2 \text{ m}}{0.5 \text{ m}} = 4$$

With this mechanical advantage you could use a quarter of the effort force needed to lift the boulder without a lever. The downside is that you need to apply the force over a larger distance, as shown in the diagram.



Question 3

Calculate: Suppose you use a teaspoon to open a lid. The resistance arm is 1 cm long and the effort arm is 10 cm long.

Calculate the mechanical advantage and state what this means in terms of the reduction in the effort force you need.

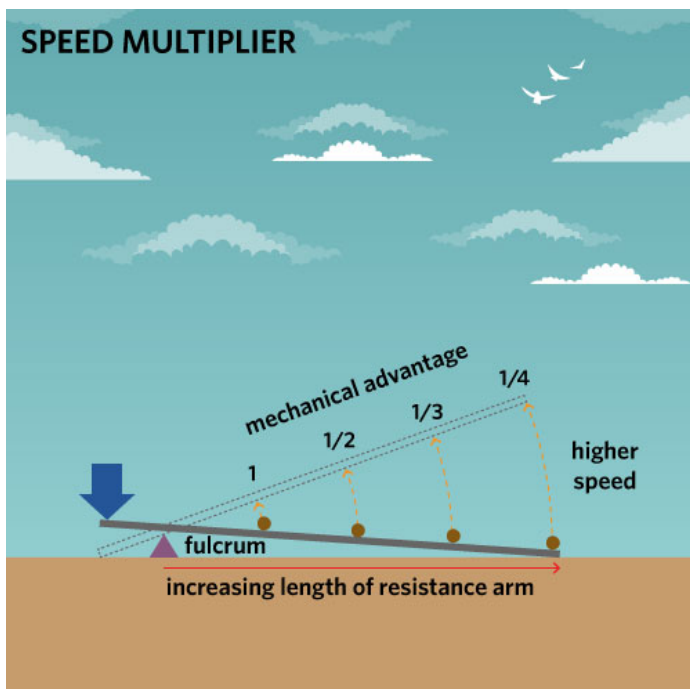
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Question 4

Calculate: You can use a hammer as a lever to remove nails, making a difficult task much easier.

If the resistance arm is 5 cm long then how long would the effort arm need to be to give you a mechanical advantage of 5?

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Multiplying speed

As well as shifting heavy loads, levers can be used to make things move quickly. For example, you might have played with a ruler placed across the edge of a desk, pushing down on the short overhang to shoot a small object placed on the other end – a *projectile* – into the air.

What matters here is the *speed* at which the projectile moves. The longer the resistance arm, the greater the distance that the projectile moves in the same amount of time that you apply your effort force, and so the higher its speed.

So there are two ways that levers can help you. They can:

- Multiply force – for these levers the effort arm is longer than the resistance arm, and the mechanical advantage is greater than 1.
- Multiply speed – for these levers the resistance arm is longer than the effort arm, and the mechanical advantage is less than 1.

Question 5

Calculate: A catapult has a 20 cm effort arm. How far from the fulcrum should the projectile be placed to provide a mechanical advantage of 0.25 or one quarter?

- ☐ 5 cm
- ☐ 20 cm
- ☐ 40 cm
- ☐ 80 cm

Question 6

Select: Suppose a particular lever has a mechanical advantage of 0.5. Which of the following statements about the lever are true?

- ☐ It is a speed multiplier.
- ☐ It is a force multiplier.
- ☐ Its effort arm is twice as long as its resistance arm.
- ☐ Its resistance arm is twice as long as its effort arm.

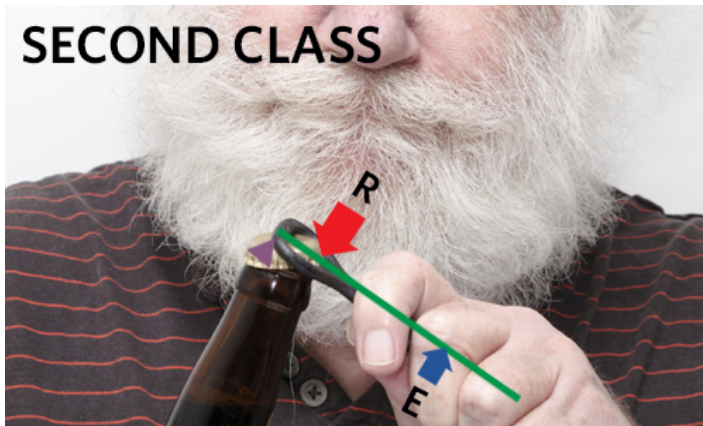
Types of levers

So far all of the levers we've looked at have had the fulcrum in the middle and the effort and resistance arms on opposite sides. These are known as *first-class levers*.

But it's also possible to have the fulcrum at one end and the two forces on the same side so that the effort and resistance arms overlap.

- In *second-class levers*, the effort arm is longer than the resistance arm. Examples include wheelbarrows, bottle openers, nutcrackers and even doors.
- In *third-class levers*, the effort arm is shorter than the resistance arm. Examples include brooms, tweezers, tongs, cricket bats and tennis racquets.

The equation for mechanical advantage still applies, so all second-class levers are force multipliers and all third-class levers are speed multipliers.




Question 7


Complete: The sketchpad below shows the three classes of levers. A handy way of remembering them is to say "FRE: 123."


- If the fulcrum (F) is in the middle it is a first class lever.
 - If the resistance force (R) is in the middle it is a second class lever.
 - If the effort force (E) is in the middle it is a third class lever.
1. Remember that the **mechanical advantage (MA)** is the length of the effort arm divided by the length of the resistance arm. Use the diagrams to work out whether MA is *greater than* ($>$) or *less than* ($<$) 1 in each case and insert the correct symbol into the space provided.
 2. Classify each type of lever as a force or speed multiplier by typing either *force* or *speed* into the space provided.

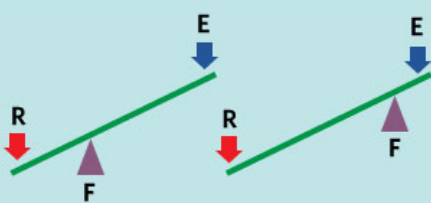
WHICH IS IN THE MIDDLE?

| | | |
|-----------|-----------|-----------|
| F | R | E |
| 1 | 2 | 3 |
| 1st class | 2nd class | 3rd class |

 fulcrum

 resistance

 effort

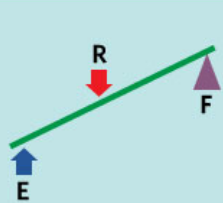


MA **1**

multiplier

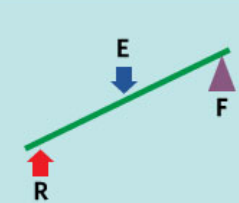
MA **1**

multiplier



MA **1**

multiplier



MA **1**

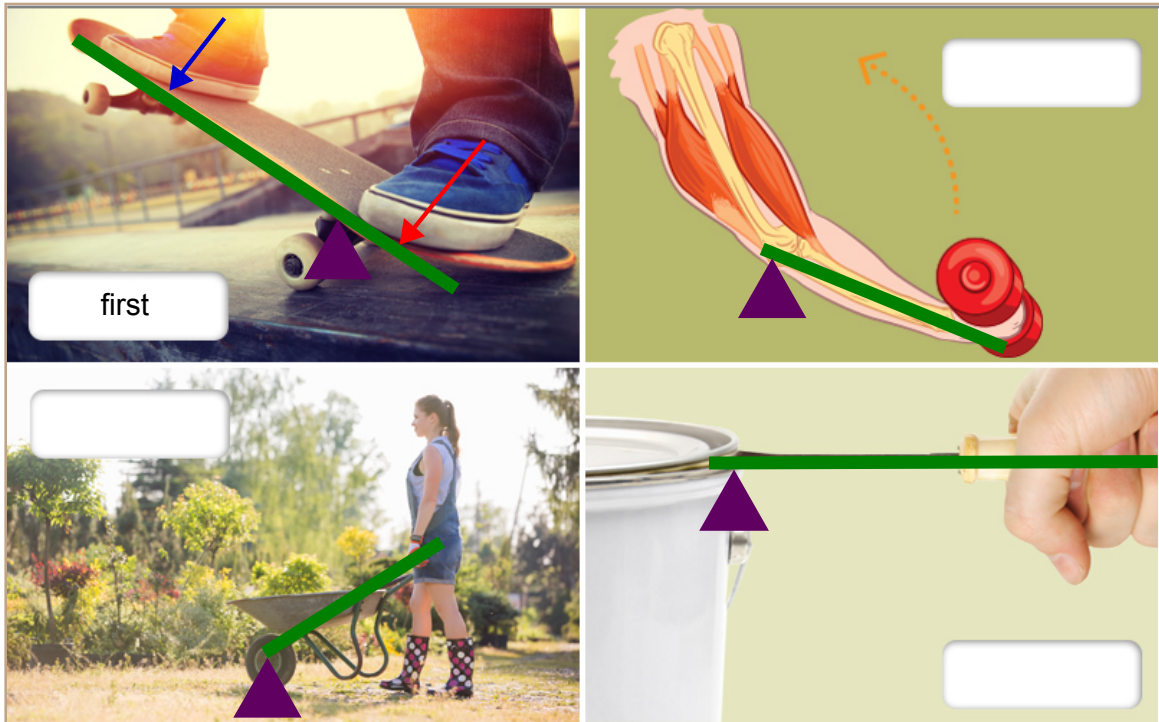
multiplier

Question 8

Classify: In each of the images below, the lever is shown as a green line and the fulcrum as a purple triangle.

1. Draw a **blue arrow** to show the position and direction of the effort force.
2. Draw a **red arrow** to show the position and direction of the resistance force.
3. Classify each lever as either first, second or third class.

The first one has been done for you as an example.



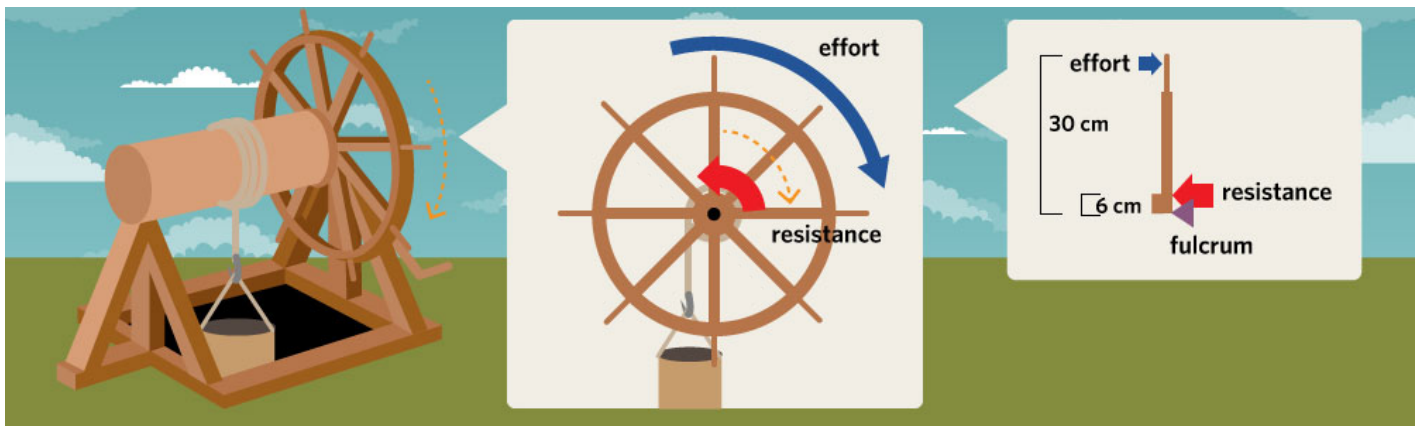
Process: Levers and Gears

COSMOS
LESSONS



Wheels

A wheel works as a special kind of lever. This is easiest to see in old-fashioned wooden wheels like those used to raise water in a well. Each of the spokes is a lever arm and the centre of the wheel acts as a fulcrum. The rod attached to the centre is known as an *axle*, which spins at the same rate as the wheel.



Question 1

Classify: Which class of lever is each spoke of the wheel shown above?

Hint: Remember FRE:123.

- ☐ First
- ☐ Second
- ☐ Third

Question 2

Calculate: Use the measurements shown in the right hand diagram of the lever arm to calculate the mechanical advantage of the lever. Then state whether it acts as a force or a speed multiplier.

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Gears

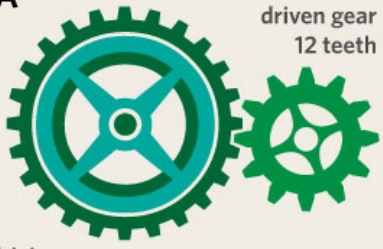
Gears are simply wheels with teeth around their rims. When two gears are arranged so that their teeth interlock, an effort force applied to one – the *driving* (or *drive*) *gear* – is passed on to the other – the *driven gear*.



Question 3

Work out: The sketchpad below shows two simple *gear trains* – sets of gears connected together – A and B. Work out how many rotations the driven gear makes for the given number of rotations of the driving gear. Complete the tables labelled **No. of rotations** for both A and B – you'll fill in the gear ratios in the next question.

A



driving gear
24 teeth

driven gear
12 teeth

NO. OF ROTATIONS

| | | | |
|--------------|---|---|---|
| driving gear | 1 | 2 | 3 |
| driven gear | | | |


GEAR RATIO

no. of teeth driving gear
 no. of teeth driven gear

=

=

B



driving gear
12 teeth

driven gear
24 teeth

NO. OF ROTATIONS

| | | | |
|--------------|---|---|---|
| driving gear | 1 | 2 | 3 |
| driven gear | | | |

GEAR RATIO

no. of teeth driving gear
 no. of teeth driven gear

=

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Question 4

Calculate: To measure the effects of gears, engineers use a value called the *gear ratio*:

$$\text{gear ratio} = \frac{\text{number of teeth on the driving gear}}{\text{number of teeth on the driven gear}}$$

Work out the gear ratios for gear trains A and B above and write them in the sketchpad.

How does the gear ratio relate to the number of rotations of the driving and driven gears?

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Question 5

Extend: We saw that levers are either force multipliers or speed multipliers. It is the same for gears.

Consider gear train A in the sketchpad above.

1. If the driving gear was moving at 95 *revolutions per minute* (rpm), what would the speed of the driven gear be, in rpm?
2. If gear train A was on your bike would you use it to ride up steep hills or on the flat? Why?
3. Is gear train A a force multiplier or speed multiplier?

Hint: if you're not sure the video might help.

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Question 6

Extend: Answer the questions below for gear train B.

1. If the driving gear was moving at 60 *revolutions per minute* (rpm), what would the speed of the driven gear be, in rpm?
2. If gear train B was on your bike would you use it to ride up steep hills or on the flat? Why?
3. Is gear train B a force multiplier or speed multiplier?


Question 7


Summarize: In the sketchpad below:


1. In the space provided above the number line draw an **orange line** over the range of gear ratios where the gear train is a force multiplier.
2. Draw a **green line** over the range of gear ratios where the gear train is a speed multiplier.
3. Draw an **orange circle** in the white box beside the image of the cyclist who would be using a gear ratio as a force multiplier.
4. Draw a **green circle** in the white box beside the image of the cyclist who would be using a gear ratio as a speed multiplier.


GEAR RATIO

0 1 2 3 4

force multiplier 

speed multiplier 







Egg beater challenge

Old-fashioned egg beaters are great little machines!

Look carefully at the picture to the left. Your task is to analyze and explain how it works in terms of the simple machines that you've been learning about.

Decide what types of machines are involved and how they work. Make sure you include at least one labelled diagram – you can use the sketchpad or draw your own on paper then upload it as a photo.

Some terms to think about might be: *lever, effort arm, resistance arm, effort force, resistance force, fulcrum, mechanical advantage, wheel, driving gear, driven gear, gear ratio, force multiplier, speed multiplier.*



Question 8

Analyze: Use the tools below to present your egg beater analysis.

Keeping time

Another place gears are used is in clocks and watches. The Antikythera Mechanism falls into this category. By building up complex gear trains the ancient Greeks were able to model the rotations of the Moon around the Earth and the Earth around the Sun extremely accurately.

If you've finished this section, enjoy the following video.



Apply: Levers and Gears

COSMOS LESSONS

Make your own catapult



Materials

10 craft sticks, or icy pole sticks

4 rubber bands

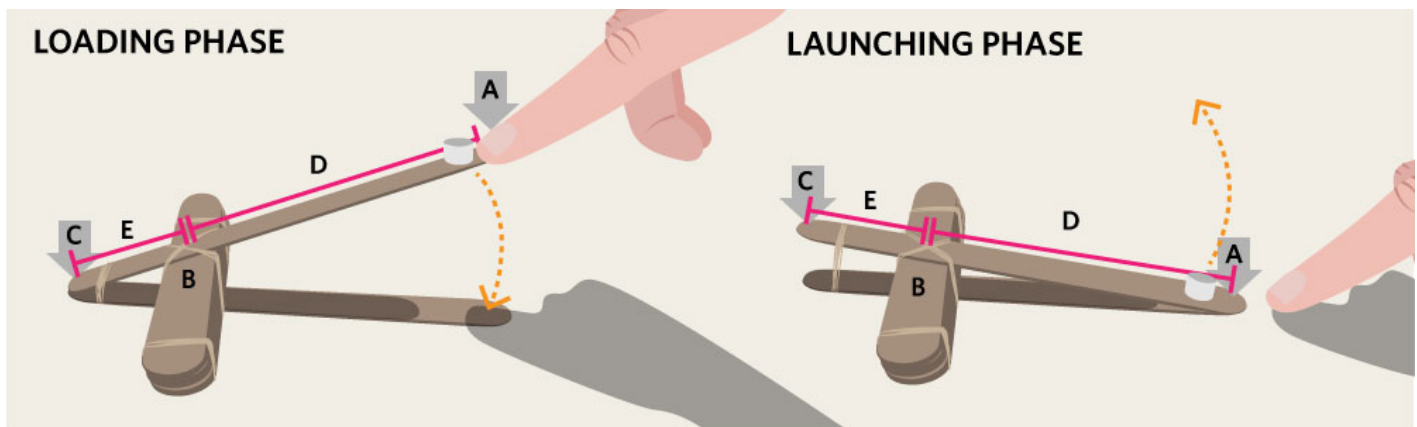
mini marshmallows

Method

1. Form a stack of 8 craft sticks and wrap a rubber band around each end to hold them together.
2. Stack the other two craft sticks and bind them together using another rubber band, close to one of the ends.
3. Separate the two craft sticks at the other end and slide the stack of eight in between so that the upper stick makes an angle of about 30 degrees with the horizontal.
4. Wrap another rubber band around the centre of the structure to hold it all together.
5. Place a mini marshmallow on the raised end of the sloping stick and launch it by pressing down and releasing. If you have trouble keeping the marshmallow sitting on the stick, you can wrap a rubber band around the stick to provide support. Otherwise, you can glue a plastic bottle cap to the end to create a more enclosed launching pad.



Discussion



Question 1

Analyze: Complete the table to analyze the lever action of the catapult during both the loading and launching phases. The effort force during launching is provided by the stretched rubber band, which stores the energy that you apply to the other end of the lever. Assume that the lever arm is perfectly rigid – if the lever on your catapult bends too much then loosen the rubber band holding it down at the front of the catapult. Use the following terms:

effort force | effort arm | fulcrum | resistance force | resistance arm

| Part of catapult | Loading phase | Launching phase |
|------------------|---------------|-----------------|
| A | | |
| B | | |
| C | | effort force |
| D | | |
| E | | |

Question 2

Calculate: Use a ruler to measure the lengths of the effort arm and the resistance arm of your catapult during the *loading* phase and then calculate the mechanical advantage. Does this setup multiply force or speed?

Hint: Remember that the mechanical advantage of a lever is equal to the length of the effort arm divided by the length of the resistance arm.

Question 3

Calculate: Using the same measurements as in the previous question, calculate the mechanical advantage during the *launching* phase. Does the lever act as a force or speed multiplier as you launch the catapult?



Question 4

Think: Describe two ways in which you could decrease the mechanical advantage and so increase the speed at which the marshmallows are launched, using the same basic structure and materials. Test your answers by experimenting with your own catapult.



Question 5

Design: Design your own catapult made out of craft sticks and rubber bands. You could start by thinking about how you would like to improve the simple catapult you've already made – perhaps to increase the height or the distance that the marshmallows reach. Then you might want to draw a couple of sketches or just get building!

If you have enough materials then try making the catapult you've designed and test its launching ability. Upload sketches, photos and any written plans into the project space.

Career: Levers and Gears



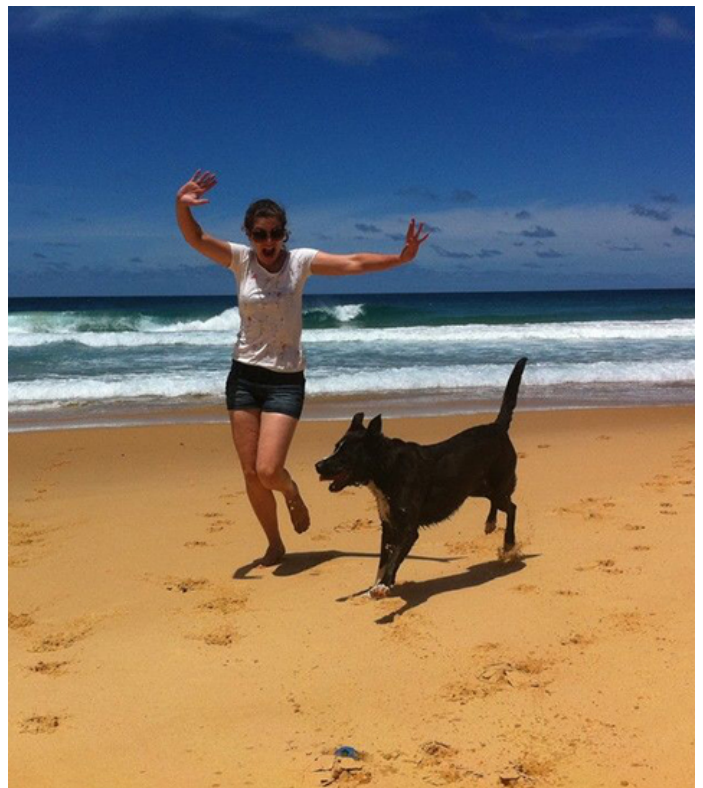
Brought to you by Edith Cowan University

Sarah Jane Keeling grew up in Wollongong, New South Wales, Australia, full of ambitions. There was no shortage of things she wanted to be when she grew up – an astronaut, astronomer, teacher, paediatrician or scientist, among other things. Sarah now works as a lab manager at the Plant Cell Biology Research Centre at the University of Melbourne. But before that she worked as everything from a cook to a research assistant and even a warehouse packer!

But of all her jobs, Sarah most fondly recalls her time as a science presenter at the Scienceworks museum in Melbourne. Every day she put on special shows in the hair-raising Lightning Room and Planetarium Theatre while also running smaller presentations and workshops for school groups. Her days could get rather hectic as she hurried from one show to another but it was well worth the joy of successfully explaining a scientific concept to a curious visitor. Watching their faces light up as they “get it” makes you feel like you’ve done a great job, she says.

Sarah always loved learning about space and the stars so spending so much time in the Planetarium was another incredible part of her job. She could see first-hand how the planets moved night after night and how the constellations changed through the seasons. Coming up with ideas for a new show or activity was always loads of fun too!

When she isn't working, Sarah is a huge fan of swing dancing. The infectious rhythm of the music makes her smile from ear to ear, she says. And when it comes to winding down after a hard day at work, there's nothing better than an evening walk with her husband and dog.



Question 1

Plan: Imagine you have a job at Scienceworks communicating science to visitors. Choose an everyday tool involving levers or gears and think of an interesting activity that shows how it makes our lives easier.

In the project space below, use a text box to write down what you would say to explain the science behind it. You can also draw a diagram of the setup using a sketchpad or upload a photo of a hand-drawn diagram.



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