COSMOS LESSONS

## Physics

# Gravity: A home for the Milky Way

Laniakea – immeasurable heaven in Hawaiian – is the name given by astronomers to the enormous cluster of galaxies that the Milky Way belongs to. The motion of galaxies in this supercluster is determined by gravitational forces.

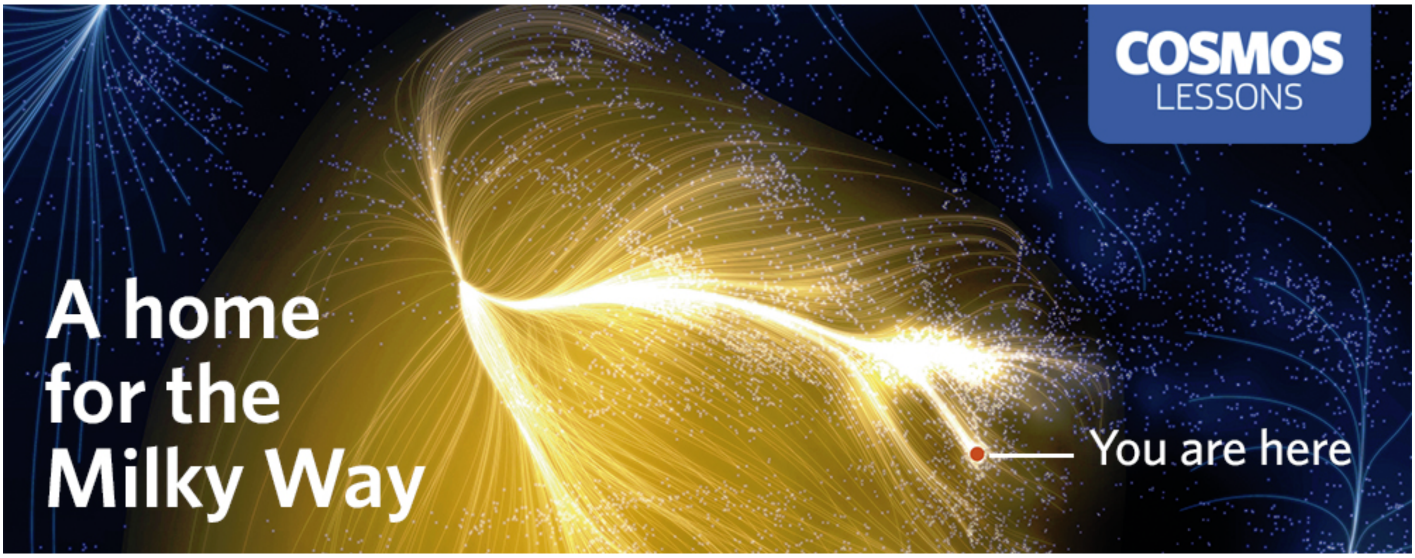
In this lesson you will investigate the following:

- What is gravity?
- Are astronauts in space really weightless?
- What was Galileo's experiment?

Prepare for a stellar journey as we travel from the Earth's surface to the International Space Station and beyond.

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: Gravity




Earth,
Solar System,
Milky Way,
The Universe.

**Making sure your letter finds its way by adding this to the address** is an old children's joke. But maybe it hasn't helped! Scientists have just discovered that it's missing a line!

Our galaxy, the Milky Way, is vast, with over a hundred billion stars. But now astronomers from Hawaii and France have plotted the even vaster *supercluster* of galaxies that the Milky Way belongs to. Called Laniakea, its hundred thousand galaxies form a heart-like shape that spans five hundred million light years.

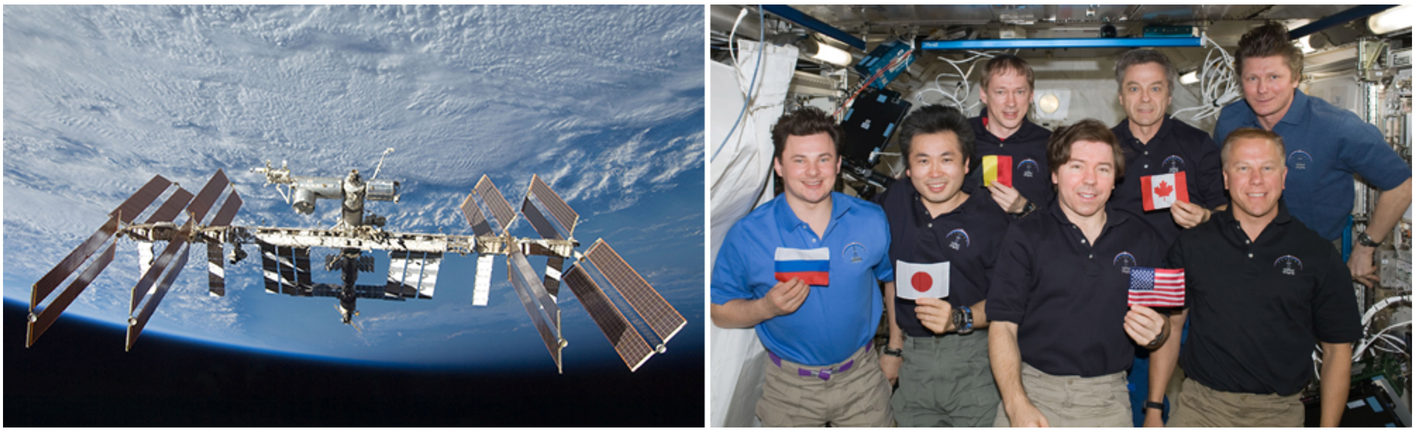
Actually, we've known for a while that we live in a supercluster, but couldn't tell where it started or finished – it's hard to see the edges from inside. The astronomers had to rely on new technology in telescopes and computing to be able to gather and then make sense of the vast amounts of data they needed.

And that data gave them more than just a static picture – it also told them how the galaxies are moving. This turns out to be crucial information because there are other superclusters nearby...relatively speaking. With the information about movement the scientists could see that all the galaxies in Laniakea are moving towards one central point. Galaxies just outside Laniakea are moving towards other points, so they belong to neighbouring superclusters.

So why are the galaxies converging? Gravity. The same force that keeps your pen on the desk is operating across enormous distances, pulling galaxies together at perhaps the largest scale we can imagine!

Meanwhile, at the cosmic post office, they're breathing a sigh of relief, "Oh, *that* Milky Way...in Laniakea". Expect some extra letters as they clear the backlog.

**Read or listen to the full *Cosmos* magazine article here.**



Left, the International Space Station (ISS) and right, representatives of the five ISS partner nations on the station. They are from Russia, Japan, Belgium (representing the European Union), the United States and Canada.

## Question 1

**Imagine:** Scientific research in the modern world is all about working in teams, often with members spread around the globe. For example, the team that discovered the boundaries of Laniakea had members in France and Hawaii and was helped by others in Australia, Puerto Rico and Chile.

Imagine you are a scientist in an international team, working with others from all continents. List some of the benefits and difficulties you might encounter working in such a team.

| Benefits | Difficulties |
| --- | --- |
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# Gather: Gravity

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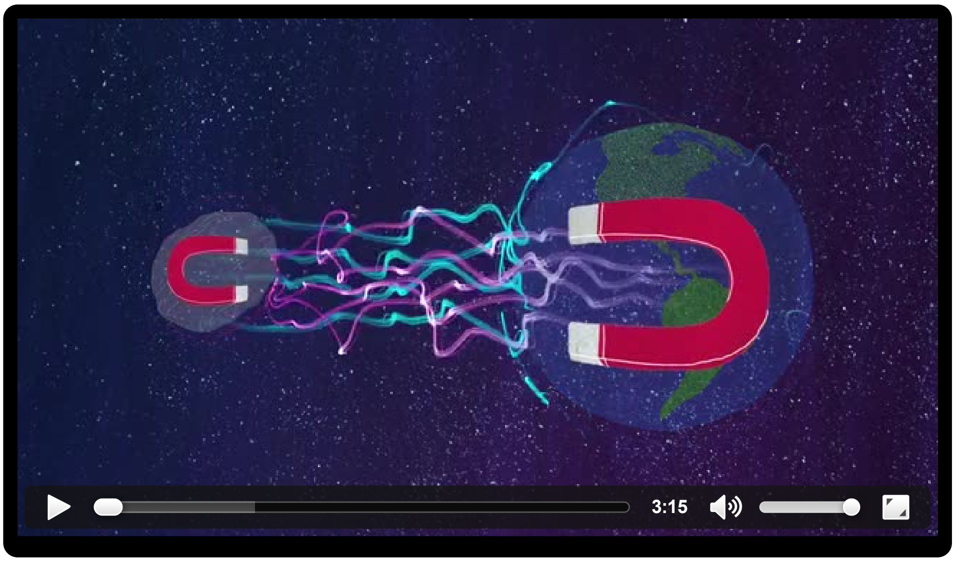
## What is gravity?

Laniakea and other superclusters demonstrate gravity at perhaps its most impressive, drawing together whole galaxies – each with billions of stars – across vast expanses of empty space. What is this mysterious force, and how can we describe it?




### Question 1

**Recall:** What phrase is used to explain gravity in the video?

### Question 2

**Think:** Gravitational attraction is a force that can make objects move towards one another.

- ○ True
- ○ False

### Question 3

**Consider:** Is a bird on a branch in South America gravitationally attracted to a pen in the pocket of an office worker in New Delhi?

- ☐ Yes
- ☐ No

## Question 4

**Remember:** You lift a rock and then release it.

Which of the following is true.

- ☐ The Earth and rock both move towards each other, but the Earth moves further.
- ☐ The rock falls towards the Earth, and the Earth does not move.
- ☐ The Earth and rock both move towards each other, but the rock moves further.

## Question 5

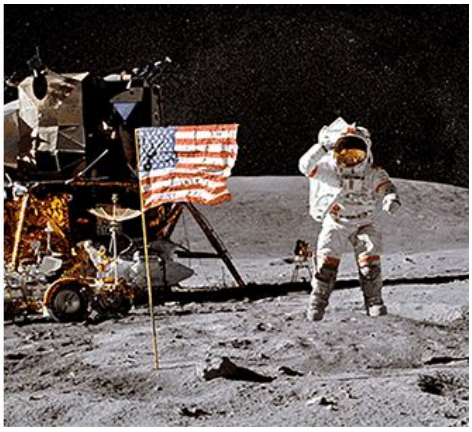
**Consider:** In the video, gravity and magnetism are compared in the following way:

- ☐ Gravity and magnetism are not the same, but behave in a similar way.
- ☐ Gravity is a form of magnetism.
- ☐ Magnetism is a form of gravity.
- ☐ Gravity and magnetism are opposing forces.

## Question 6

**Select:** Which words in the square brackets make the sentences true?

| | |
|---|---|
| The closer two objects are to each other, the [stronger] [weaker] the gravitational attraction between them. | |
| The more mass two objects have, the [stronger] [weaker] the gravitational attraction between them. | |



# Gravitational fields

As it says in the video, people weigh less on the Moon than on Earth, and you've probably heard too that deep in outer space – far, far away from any other objects – you'd be pretty much weightless.

A helpful way to think about such effects is in terms of a *gravitational field*. This refers to the gravitational pull of an object in the space surrounding it, even if there are no objects in the space for the force to act on.

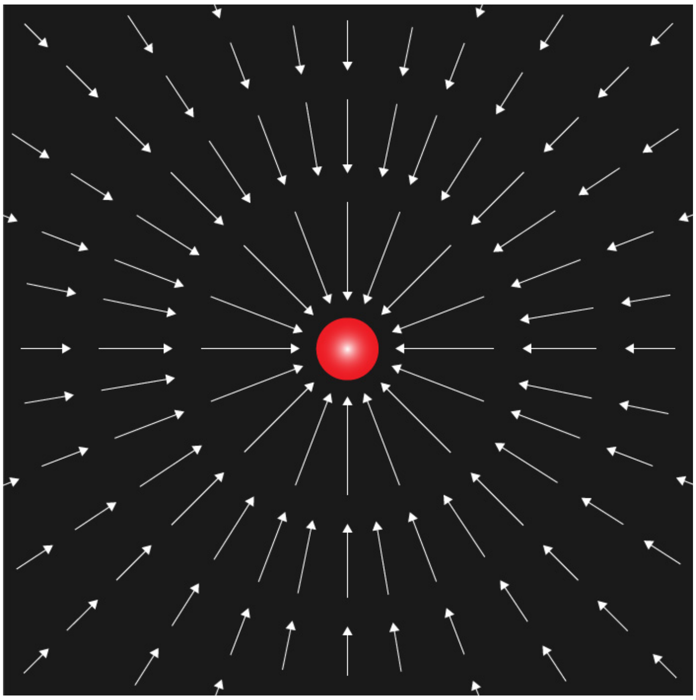
Gravitational attraction increases or decreases depending on the mass of objects and how far apart they are. So, for gravitational fields:

- the more massive an object is the greater the strength of its gravitational field, and
- the further away you are from the object the weaker the gravitational field at that point.

We can represent a gravitational field using arrows, where:

- the direction of the arrows represents the direction of the force, and
- the length of the arrows represents the strength of the force.

This is shown for a spherical object in the diagram to the right. Remember, in reality a gravitational field is 3D, not 2D.

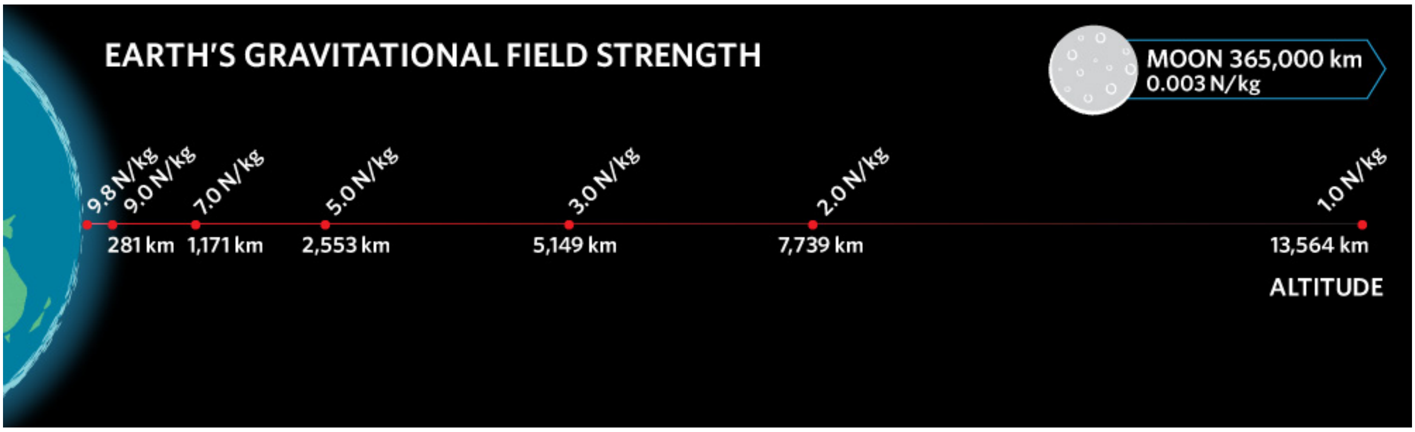


## Gravitational field strength: g

The strength of a gravitational field, at any particular position, is how much gravitational force would act on a mass of 1 kg if it was placed at that position. Force is measured in newtons (N), so gravitational field strength is measured in newtons per kilogram (N/kg). It is represented by the letter **g**.

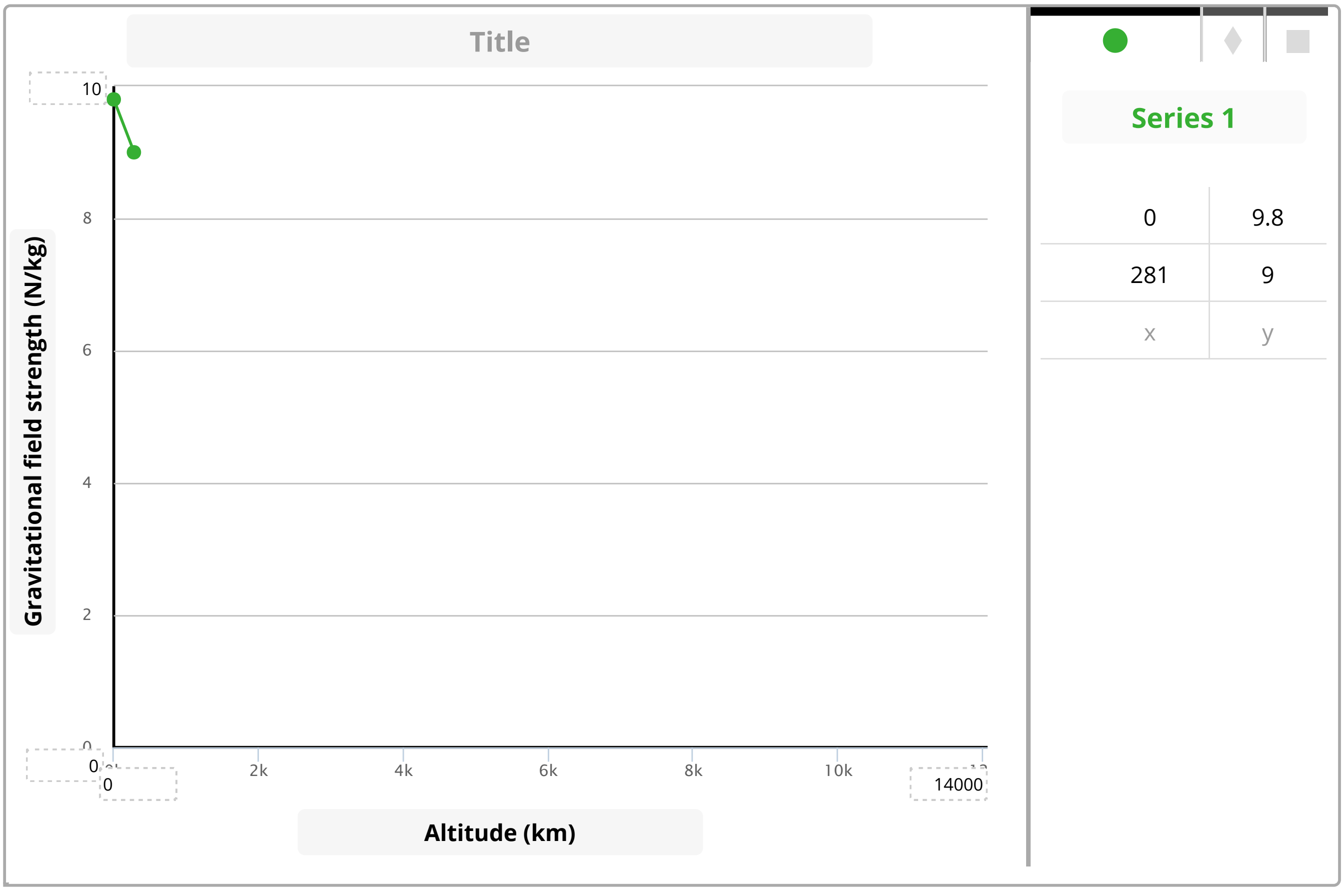
The diagram below shows g for the Earth's gravitational field as you leave its surface and travel out towards the Moon.

**Remember:** Objects at any position in the diagram are not just in Earth's gravitational field – they're in the gravitational fields of all the objects in the Universe! But almost all of those other objects are so small or far away that they have virtually no effect. The exceptions are the Moon and Sun.



## Question 7

**Plot:** Use the information from the diagram above to complete the graph, plotting the strength of the Earth's gravitational field at increasing altitudes.




## Question 8

**Estimate:** The Earth's gravitational field strength at its surface is 9.8 N/kg. That means a 1 kg bunch of bananas has a force of 9.8 N acting on it.

Use the graph to estimate the force of the Earth's gravity on the banana bunch if it was taken 10,000 km (shown as "10k" on the graph) above the Earth's surface.

## Weight vs. mass

The last question illustrates the difference between *weight* and *mass.* The terms are used interchangeably in everyday language, but their scientific meanings are quite different.

- Mass: how much matter an object contains, measured in kilograms.
- Weight: the gravitational force on an object, measured in newtons.

The amount of matter in the bananas doesn't change – there's 1 kg of bananas on the Earth's surface and 1 kg of bananas 10,000 km up. They'd fill you up just as much wherever you ate them!

But the forces acting on them differ. The gravitational field is stronger on the Earth's surface than at 10,000 km, so the gravitational force on the bananas – that is, their weight – is different at the two locations.

We can summarize this in an equation:

**weight (N) = mass (kg) x gravitational field strength (N/kg)**

or

***W = m x g***

### Example

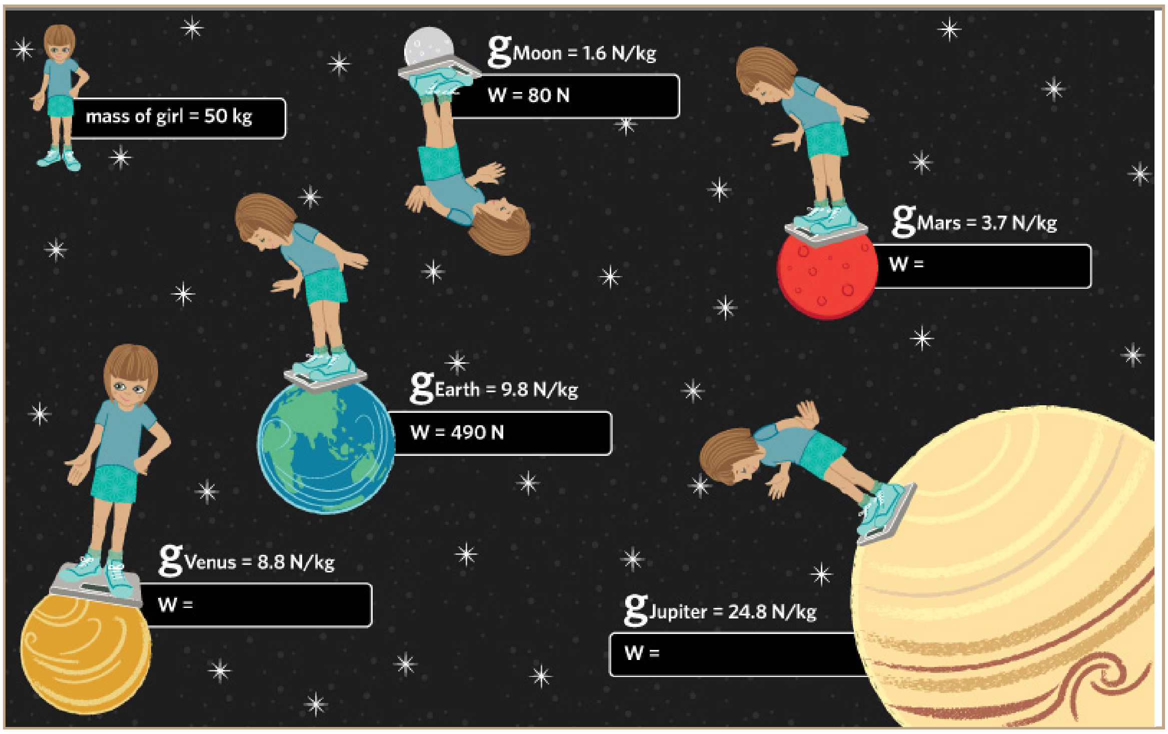
What is the weight of a 50 kg girl on the Earth's surface?

- Mass of girl = 50 kg
- Value of g at Earth's surface = 9.8 N/kg

*W = m x g*
= 50 kg x 9.8 N/kg
= 490 N

## Question 9

**Compute:** Calculate the weight of the same 50 kg girl on Mars, Venus and Jupiter. Her weight on the Moon has already been calculated for you.



# Process: Gravity

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## Are astronauts weightless?

We've all seen footage of astronauts floating around in space, apparently weightless. We usually think that things have weight if they drop to the ground. The heavier something is, the harder it falls.

But are the floating astronauts we see really weightless?

## Question 1

**Decide:** Many people think that astronauts in the International Space Station are weightless because there's no gravity in space. But without gravity the space station couldn't remain in orbit.

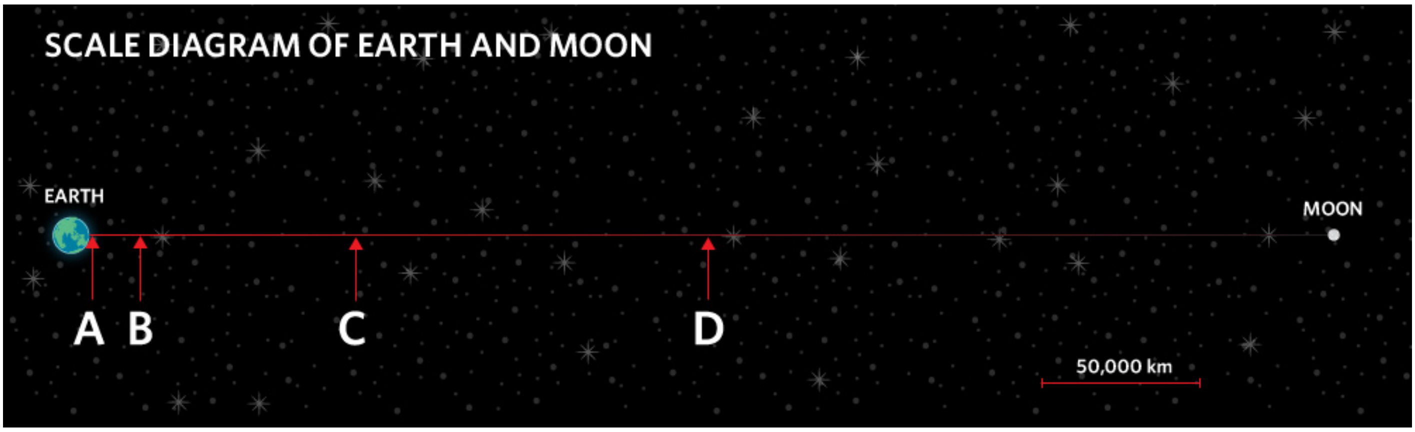
To be *really* weightless, an astronaut would need to be outside the gravitational fields of all planets, stars and other bodies.

- True
- False

## Question 2

**Select:** Which of the arrows in the diagram below best indicates the orbit of the International Space Station?

- A
- B
- C
- D




## Question 3

**Calculate:** Remember from earlier in the lesson that:

weight (N) = mass (kg) x gravitational field strength (N/kg)

The International Space Station orbits at an altitude of 370 km where the Earth's gravitational field strength is 8.8 N/kg.

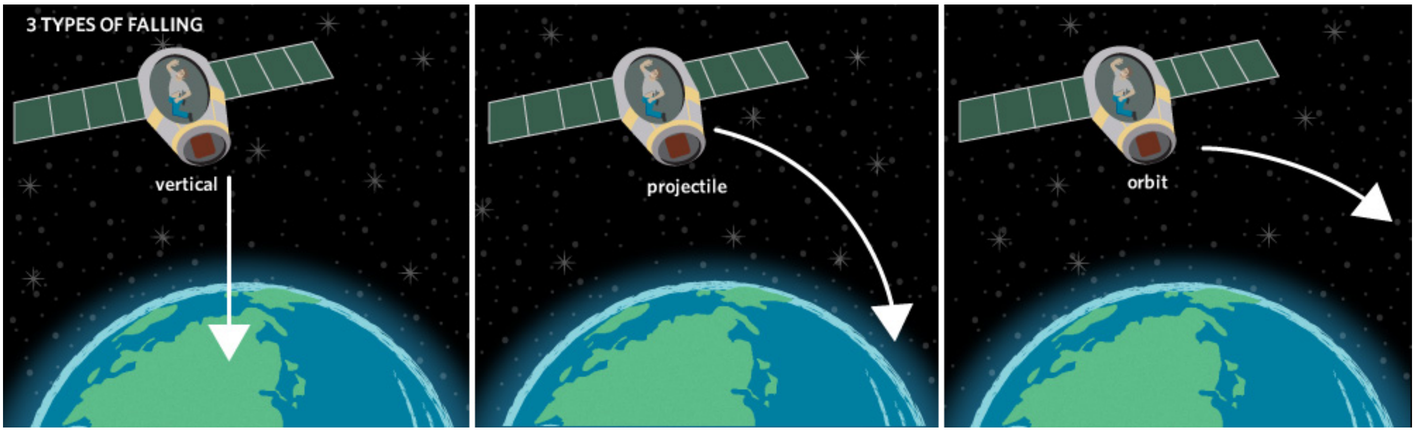
Calculate the weight of an 80 kg astronaut "floating" in the space station.

## Question 4

**Reflect:** In light of your answer to the previous question, explain why the terms "weightless" and "zero gravity" are misleading descriptions of astronauts in the space station.

The video explains that the astronauts in the space station aren't floating, they're falling. The reason they *appear* to be floating is that the space station is falling too. If you and the room you're in are falling at the same rate then you're never able to catch up to the floor to stand on it!

But of course the astronauts and the space station aren't falling straight down. They're moving sideways at 28,000 km/h – so fast that they follow the curvature of the planet and never fall vertically at all. This is just what it means for something to *orbit*.




## Question 5

Projectile motion is what you get when you throw a ball across a football field. Gravity causes the ball to fall back to the ground along a curved path.

If you were thrown at the same time as the ball so as to follow the same path (ignoring air resistance) then the ball would seem to float weightless before your eyes.

- True
- False

## Question 6

**Explain:** In all three types of falling the astronauts would appear and feel weightless – so long as they stay above the atmosphere. Suggest a reason why entering the atmosphere would spoil the feeling of weightlessness.

*Did you know?*

Because the International Space Station is travelling so fast – nearly 8 km per second – it only takes 90 minutes to circle the Earth.

Astronauts living and working in the space station get to see 16 sunrises and sunsets every day!


## Question 7

**Compare:** Although there's still gravity in the space station it doesn't have its usual effects. List two ways that water behaves differently in the "zero gravity" environment of the space station based on what you observe in the video.

## Question 8

**Predict:** If you started crying while in the space station what would happen to your tears?

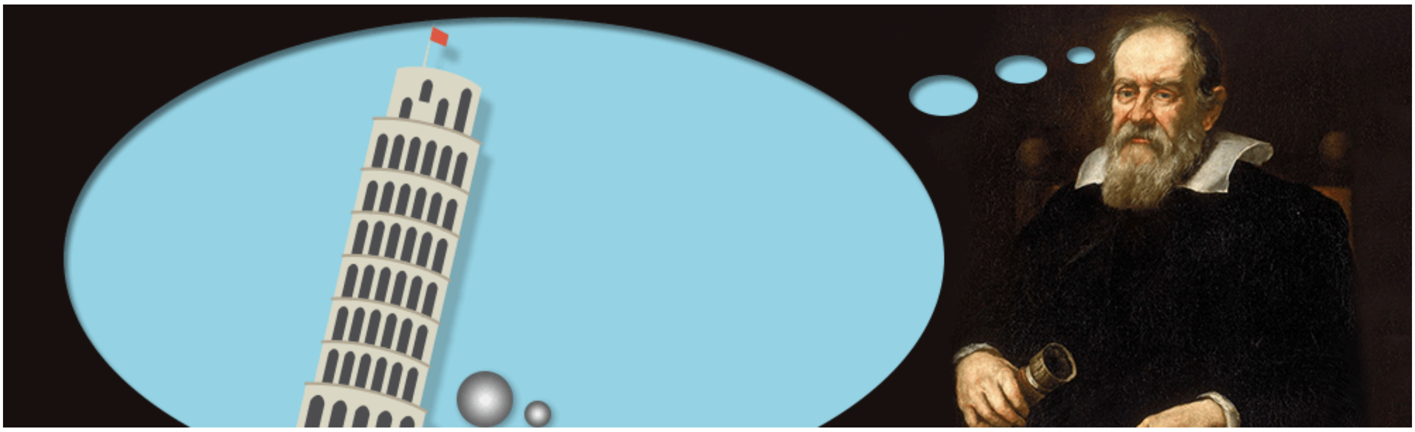
## Question 9

**Design:** If you could request an experiment to be conducted in the space station to answer a question about gravity, what would it be?

Use the project space below to design your experiment, beginning with a clear statement of the question you would like to answer or the hypothesis you would like to test. You can use images, diagrams, etc. to illustrate your ideas.

# Apply: Gravity

## Experiment: Recreate a famous experiment



### A short history of dropping things...

Aristotle was a Greek philosopher who lived in the 4th century BCE. He had many theories about the physical world and these, over time, came to be accepted as beyond challenge. Two that are relevant to this lesson were that the Earth is at the centre of the universe – not in the corner of a galaxy in the corner of a supercluster – and that heavier objects fall faster than lighter ones.

Almost 2,000 years later Galileo Galilei, in Pisa, Italy, was applying a new way of going about science. He didn't just believe everything that Aristotle had written, but actually conducted observations and experiments to find out!

According to legend Galileo decided to test the theory about falling objects. Fortunately, the perfect resource was right at hand – the Tower of Pisa, 54 metres tall. Galileo climbed the tower and dropped balls of varying mass from the top. And – so the story goes – they all landed at the same time.

Aristotle had got it wrong.

### Your task

Design and carry out an experiment to replicate Galileo's, and present a report of the experiment in the project space below.

It will be best to work in teams, but first, answer the questions below.

*Hint: you may be able to use some of the answers in your report.*

### Safety

Have your teacher check a plan of your experiment before carrying it out. This is especially important if you intend climbing anything in order to drop your objects. You also need to be sure the dropped objects do not bounce or shatter when they impact the ground, harming students recording their fall.

## Question 1

**Consider:** In choosing which objects to drop, what considerations will you have to take into account? How will you know what the masses of your objects are?

*Hint: would a feather be a suitable object? If not, why not?*

## Question 2

**Engineer:** For the experiment to work you have to be sure that you drop the objects at the same time. How will you ensure this? Is there any way you can check if the objects were released at the same time?

## Question 3

**Report:** Use this space to upload a report of your experiment, including a video of the results. Organize the report under the following titles:

Background

Aim

Hypothesis

Variables

Materials

Procedure

Results

Discussion

Conclusion

In the discussion section, make sure to identify factors that you would change if you could carry out the experiment again, but with better equipment. Why would you make these changes?

**Contrast:** Watch Brian Cox carrying out his version of Galileo's experiment below. Your school probably doesn't have equipment this good!

# Career: Gravity

Brought to you by Edith Cowan University

Megan Johnson is an astronomer with a special affinity for dwarf galaxies, the little galaxies that may have been the building blocks of our very own Milky Way.

Growing up in a small town in Connecticut, USA, Megan actually dreamt of becoming a ballerina and joining a dance troupe in New York. But when a broken leg put an end to her ballet career, Megan fell back on her other love – mathematics.

After studying and working in finance, Megan happened to read an interview with a young astronomer who had just discovered a whole new spiral arm of the Milky Way. Intrigued by how astronomy seemed to be an application of mathematics, she decided to study astronomy and has never looked back.

Now Megan works as an astronomer at CSIRO in Sydney, studying dwarf galaxies. She wants to know everything about them – from what they look like to how they evolve and form stars. One of the most interesting things Megan has learnt is that dwarf galaxies interact with each other more than previously thought. Being so small, dwarf galaxies are helpless against the gravitational pull of larger galaxies and are hurled around space until, occasionally, they slam into each other and merge. Some astronomers think this can lead to the formation of larger galaxies, like our own Milky Way.

In her quest to survey the small galaxies Megan spends most of her time at her computer, making sense of data from CSIRO's many telescopes or writing scientific papers. She also helps out visiting researchers who come from all over the world to use the telescopes at CSIRO's Australian Telescope National Facility.

Despite her astronomical workload, Megan always makes time for hanging out with her husband and three-year old daughter.

## Question 1

**Ponder:** There are many different types of object in space: stars, galaxies, black holes, pulsars, planets and moons, to name a few. If you were an astronomer, or any other sort of scientist studying things found in places other than on Earth, what would you want to study, and why?

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