LIFE AS WE KNOW IT

Our mission to understand our place in the universe
Big Picture

Big Picture’s first 21 issues have been firmly grounded on planet Earth. Now we’d like to look at an even bigger picture – the universe.

Space biology looks at life in space from several perspectives: how it began, where it might be, and the effects of space as a rather extreme habitat. Space exploration has many unique constraints, but has brought numerous benefits back home.

Join us on our journey to explore the past, present and future of life in space.

INSIDE

UNIVERSE IN A NUTSHELL
Getting to grips with astronomical numbers

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ONLINE
All of the resources for this issue – and plenty more – can be found online at bigpictureeducation.com

Cover: Tardigrade, also known as a water bear. See page 7. © Science Picture Co./Corbis
Making this diagram together, we found that different sources give different numbers for the same thing. Why don’t they match?

Well, data can be interpreted in different ways, and estimates can be made using different methods and different baseline data. Definitions matter, too – different sources might define ‘size’ or ‘orbit’ differently.

Which should you choose? The source itself is important – is it from a primary or a secondary source? Is it reliable? Is it recent? Is it from an organisation with an agenda or from an impartial source?

For sources and discussion questions, see bigpictureeducation.com/space-infographic
BEGINNINGS
How did our planet – and the life on it – get started?

What we know is that planets are a by-product of star formation. Gravity can cause massive collections of gas in space – molecular clouds – to collapse over hundreds of millions of years. As gravity pulls material within the collapsing cloud together, the centre of the cloud becomes more compressed and hotter. This dense, hot core becomes the centre of a new Star.

Not all of the material makes it into the stars, however. The Hubble Space Telescope has seen newly forming stars surrounded by flat, dark rings. It is thought these ‘proto-planetary discs’ are the leftovers from star formation that gravity will continue to sculpt into planets.

It is believed that our solar system formed in a very similar way, and the ingredients for life were probably already built in. As far back as 2003, astronomers found glycine – the smallest amino acid – in molecular clouds where star formation was active, though this discovery is contentious. In 2013, cyanomethanimine was found too. It is a precursor involved in the reaction to form adenine, one of the nucleotide bases from which DNA is constructed.

It seems that the early solar system – including the early Earth – was laced with some of the basic chemicals from which life is built. But what turned an inanimate, prehistoric ‘soup’ of chemicals into the first organisms we would classify as alive?

The most famous experiment into the origin of life on our planet was performed by Stanley Miller and Harold Urey in 1953. They tried to replicate the conditions of the early Earth in the lab, mixing water vapour with the gases that were thought to have been present in the atmosphere at the time (such as methane and ammonia). Next, they subjected the mixture to electrical sparks to represent lightning.

After a day, Miller and Urey found evidence of two amino acids: glycine and alanine. Their results showed that it is possible for simple chemistry to become more complex under specific conditions. But their results were far from conclusive – the question of life’s origins is still one of the biggest mysteries in modern science.

PLANETARY PUZZLES
Why is Earth habitable while other planets aren’t?

In science, a sample size of one is never good. The larger the sample, the greater the reliability. Modern astronomy gives us the ability to peer into other solar systems, see what they are like, and compare and contrast them with our own. Around 2,000 exoplanets – planets in orbit around other stars – have been spotted so far.

As water plays such a crucial role as a solvent for life here on Earth, of particular interest are exoplanets that might also have water in liquid form. They are most likely to reside in the habitable zones of stars – the region where the liquid water is stable (usually where the temperature sits between 0 and 100ºC, though pressure can affect this). Estimates suggest that there could be as many as 60 billion such ‘habitable’ planets in our Milky Way galaxy.

Liquid water is not just limited to the habitable zone, however. Some of the moons of the outer solar system – like Enceladus around Saturn, and Europa around Jupiter – have liquid water too. It is kept warm by the energy released in the tidal distortion of the rocks caused by the gravitational interaction between the moons and the giant planets.

Exploration of comets and asteroids, too, has shown that both contain water ice. An outstanding mystery is how Earth came to have so much water; one theory is that it was delivered here by comets and asteroids when they collided with the early Earth. However, water found on comets is largely of a different isotopic composition – made with deuterium, an isotope of hydrogen – so asteroids are more likely.
BIOSIGNATURES
Signs of life on other bodies

A planet may have the right conditions for life, but it is another thing to prove that life has developed to take advantage of those conditions. One way astrobiologists look to confirm the presence of life elsewhere is by peering into the atmosphere, where living organisms are likely to leave their mark.

Take Earth's atmosphere as an example. The air we breathe contains 21 per cent oxygen, but it shouldn't. Molecules of oxygen above our heads react with sunlight and break apart. They then react with other molecules to make new compounds. The fact that Earth's oxygen levels don't drop is because something is constantly replacing the spent oxygen: life. Photosynthetic BACTERIA -- known as cyanobacteria -- produce 50 per cent of the oxygen we breathe. Plants release most of the rest. If we found similar levels of oxygen in the atmosphere of another planet it would strongly suggest the presence of some form of oxygen-producing biology.

Methane is another possible biosignature gas, particularly when it's present with another gas like oxygen. It is thought to be unstable in atmospheres for any length of time, so if it persists, it is being replenished somehow. In December 2014, NASA's Curiosity rover became the latest mission to detect methane on Mars. The source of the Martian methane remains a mystery. Although its origins are more likely to be geological, a small chance remains that it has a biological source.

The 2018 ExoMars rover mission will search for organic signs of life on the Mars surface and subsurface. Its drill will be able to go 2 metres under the surface.

Source: University of Leicester press release

LIFE AS WE KNOW IT
Do we know what we're looking for?

The more we explore life on Earth, the more we realise just how widespread and adaptable it is. Microorganisms called OBLIGATE ANAEROBES live in environments where there is no oxygen, such as deep-sea hydrothermal vents and the human gut. Exposure to small amounts of oxygen would actually kill them -- they are 'obligated' to avoid oxygen.

One thing that all Earth's life has in common, however, is water. Carbon is another -- about 18 per cent of the mass of a human body is made of it. In plants it can reach 50 per cent. Carbon is extremely abundant in living matter and is chemically versatile. It bonds easily with other elements to build the complex molecules found inside living things.

Yet some astrobiologists speculate that alien life need not be carbon-based, suggesting that silicon, which has some similar chemical properties, might be used in biochemical systems. So we need to be careful when searching for extraterrestrial life that we don't ignore other possibilities.

One of the first scientists to think about searching for alien life was radio astronomer Frank Drake. In 1961, he devised a way to estimate the number of intelligent civilisations that might exist in our Milky Way galaxy.

The 'Drake equation' acts as a giant sieve. First, take all the stars in the galaxy. Then, sieve out the ones that don't have any planets. Next, remove the ones without Earth-like planets, followed by ones that have Earth-like planets but the wrong conditions for life. Go on sieving a few more times until you end up with what's left.

Drake originally came up with an answer of over 10,000 intelligent civilisations in our galaxy alone. Modern, sceptical versions of the equation put that number down into single digits.

Want to know more about carbon? Or what silicon-based life might look like? See online: bigpictureeducation.com/space
STAYING STRONG
The challenge of keeping fit in space

Our bodies have changed through years of natural selection to cope with the stresses and strains of life on Earth. Remove our fragile frames from the place they have adapted to thrive in and very quickly we start to face significant challenges.

One of the main problems is the microgravity associated with life in orbit around Earth. Loss of bone density and muscle mass are real concerns. In the earlier days of spaceflight, astronauts lost up to 2 per cent of their bone density for every month they spent in space. That means carefully planned diet and exercise regimes are crucial. Making sure the astronauts consume enough vitamin D and calories, as well as limiting their sodium intake from salt consumption, has helped. Studies have also shown that the Advanced Resistive Exercise Device, launched to the International Space Station (ISS) in 2008, has made a difference too. It is a sort of weightlifting device that allows astronauts to ‘lift’ twice as much as previous exercise machines. These factors combined mean that ISS crew members can stay on board for six months at a time and not lose bone (though there are still questions about fracture risk).

Returning to Earth after an extended stay in space also has its own challenges. When Canadian astronaut Chris Hadfield touched back down, he realised that he had become accustomed to a weightless tongue. Once his tongue weighed something again he had to relearn to talk.

Read more about bone structure and compare real data on bone density and muscle mass loss online: bigpictureeducation.com/space

Other common physiological changes:
- Short-term fluid redistribution (facial/chest puffiness)
- Neurovestibular problems (space sickness)
- Intraoptic pressure (vision problems)
- Orthostatic intolerance (inability to stand up)

RADIATION
A critical limiting factor for life in space

We are fortunate to live under the protective cocoon of the Earth’s thick atmosphere and sprawling magnetic field. This prevents us from being dosed by some of the intense ionising radiation found in space. This radiation can take the form of charged subatomic particles or high-energy electromagnetic radiation such as X-rays coming from the Sun and the wider galaxy.

In the unprotected arena of space, radiation can destroy cells, by damaging cellular molecules such as DNA, and cause genetic mutations, which can lead to diseases like cancer. Astronauts aboard the International Space Station (ISS) are, for the most part, safe because they still orbit within Earth’s magnetic field. If an intense eruption of charged particles bursts out of the Sun, astronauts can seek shelter in the parts of the ISS that offer greatest protection.

The longer you are outside Earth’s magnetic field, however, the more likely you are to be affected. So for missions to the Moon and other planets, radiation is the greatest limiting factor. The Apollo astronauts on their short return trips to the Moon were lucky that they didn’t suffer any significant effects. But it takes six months just for a one-way trip to Mars, so the chances of radiation problems are higher, unless we can come up with a suitable way to protect the astronauts.

For an in-depth look at radiation and its effect on DNA, go online: bigpictureeducation.com/space

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Potential ways radiation can damage DNA.
Life, it seems, comes in all shapes and sizes. Discoveries made in the past few decades have revealed that living things can make a home just about anywhere on Earth. **Extremophiles**, organisms that love extreme environments, help to shape our thinking about what could survive in other parts of the universe.

- **Thermophiles** (extreme heat): The single-celled *Pyrococcus furiosus*, first found near a volcano in Italy, can withstand temperatures of 100°C. Its enzymes contain tungsten, which is unusual for biological molecules, and function optimally at this high heat.

- **Halophiles** (extreme saltiness): *Wallemia ichthyophaga*, the most halophilic fungus known to exist, cannot grow without salt. High levels of salt allow the fungus to grow much bigger and to thicken its cell walls.

- **Radioresistant** (extreme radiation): First discovered in a submarine hydrothermal vent, the microbe *Thermococcus gammatolerans* can rebuild its damaged chromosomes following exposure.

You may have noticed that these extremophiles are mostly bacteria (from the Archaea division). But animals can be extremophiles too. Arguably the hardiest is the tardigrade (also known as the ‘water bear’, which is pictured on the cover). It can cope with low or high pressure, hot or cold temperatures, very little water and huge amounts of radiation. It does this by going into a hibernation mode. In 2007 it became the first living organism to survive in the vacuum of space without any protection.

For a full list of the different types of extremophiles, go online: bigpictureeducation.com/space

**MIND GAMES**

*Much is discussed about space’s physical effects, but what about its mental effects?*

It is not just the body that’s affected by long stays in space, but the mind too. Astronauts have been cut off from human contact, sight of Earth and radio contact with anyone back home. Russian cosmonaut Sergei Krikalev was stranded in space for 313 days when the Soviet Union broke up in 1992, thanks to budget cuts. His hometown even changed its name during his mission.

If we are ever to put humans on Mars, the problems are only likely to be compounded by the huge distances and timescales involved. Very quickly the Earth will become a tiny blue dot. It can take up to 21 minutes for radio signals to travel between us and Mars, so you might need to wait more than half an hour for any reply from home. To research the possible effects of such isolation, several international space agencies ran the Mars-500 mission. Six astronauts spent 520 days inside a container designed to simulate the journey to the Red Planet. Happily, no major problems were encountered.

To look at some psychological data from space, see this article online: bigpictureeducation.com/space

**DOUBLE DUTY**

*Twin studies in space*

TWIN STUDIES are often used in biology because twins’ shared GENES allow researchers to see whether changes or effects are the result of inheritance or environment: the classic nature–nurture question. Only one set of identical twins has been to space so far – Americans Scott and Mark Kelly (although they went separately).

But, in a ground-breaking experiment, the brothers have now agreed to undertake arguably the most ambitious twin study in history. From March 2015, Scott (above, right) is spending an entire year on the International Space Station – more than any American has clocked up before. His brother Mark (above, left) is staying on the ground, matching parts of his brother’s regime and undergoing medical tests throughout Scott’s time in orbit.

NASA selected ten experimental proposals to research during the unprecedented study, covering physiological, psychological and molecular factors. They include looking at gut bacteria, atherosclerosis (the hardening of arteries) and the effects of MICROGRAVITY on the IMMUNE SYSTEM. The lessons we learn could help us prepare for the long trek to Mars as well as provide insights into diseases here on Earth (see pages 8–9 for more).

**THE UNUSUAL SUSPECTS**

*Extremophiles in the spotlight*

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**FAST FACT**

*Deinococcus radiodurans* is a radiation-resistant microbe and can survive extreme cold, dehydration, vacuum and acid conditions. It is in the Guinness Book of World Records as the most radiation-resistant life-form in the world.

Source: Guinness Book of World Records

Spores of *Wallemia sebi*, a xerophilic fungus that thrives in very dry conditions. SciMat/Science Photo Library
The exploration of space can have benefits for healthcare on the ground. We’ve already seen, for example, the effect of space travel on bone density and muscle. But weakened and fragile bones are a problem on Earth too, in osteoporosis – which affects around three million people in the UK. Work to minimise degradation of astronauts’ bones on the International Space Station (ISS) can improve ways to treat the condition here on Earth.

The ISS is also equipped with dexterous robotic arms designed to undertake complicated repairs. That technology has been adapted for operating theatres, where it is used in procedures including knee replacements.

Even our search for life on other planets has benefited life at home. In the 1970s the Viking lander touched down on the surface of Mars, equipped with an experiment to sniff out life in the Martian soil. The same technology was later adapted into an insulin pump for people with diabetes.

One of the most exciting areas of space research is vaccines. Bacteria often become more potent in microgravity – they spread more quickly and grow stronger, developing thicker membranes – and the stresses and strains of space travel take their toll on astronauts’ immune systems. Space is a particularly good place to research how we combat these microbes.

Take Salmonella (above) as an example. One of the most common causes of food poisoning, it is known to become more virulent in space. This is particularly concerning for future long-duration trips to Mars and beyond. But studies have already mapped out the entire gene expression response of the bacterium to the conditions of spaceflight. It is hoped that understanding this in more detail will help both astronauts and us on the ground. If a vaccine can be developed to combat this more virulent strain, it could be used to combat Salmonella on Earth too.

Similar studies are being conducted into an effective response to so-called superbug MRSA. Space can be an excellent place to study pathogens because they often behave in ways that they simply don’t on Earth. These insights could be the key to unlocking the medicines of tomorrow.

To understand how a particular protein functions, biologists look at it in its crystalline form and use X-ray crystallography to map out its molecular structure. (See Big Picture: Proteins for more.)

Creating these crystals for certain proteins can prove incredibly tricky on Earth – some, for example, are far too fragile. Under the conditions of microgravity in space, however, they can often form far more easily and then can be returned to Earth for X-ray analysis. It is hoped that by making protein crystals in space we can learn about a range of diseases back on Earth.

A good example is Huntington’s disease, a hereditary condition that damages nerve cells in the brain. We all have a Huntington’s gene, but there is a dominant variant allele that leads to disease. There is currently no cure, and researchers on Earth have been unable to synthesise the crystalline form of the huntingtin protein that causes the condition. In 2014, an experiment was taken to the International Space Station with the aim of producing those crystals. Bringing them back to the ground and studying them in the laboratory should lead to greater insights into the condition. (Find out more on Huntington’s online in Big Picture: Genes, Genomes and Health.)

Crystalline structures are also a key part of drug design. By building larger and more perfect crystals in the less restricted environment of space, new combinations of crystals might lead to a wider range of medicines on the ground.
WATCHFUL EYES
Space satellites monitor Earth

Satellites observe large swaths of the planet in one go, allowing us to see the big picture and learn things we simply couldn’t from ground level.

Satellites help us detect forest fires, track migrating endangered species and manage water supplies. They help us monitor retreating ice sheets, expanding urban sprawl and shrinking rainforests. Air pollution levels over our cities are being measured, and high-resolution 3D satellite maps of the Great Barrier Reef are being used to decide the best way to preserve this dwindling natural spectacle.

In the wake of natural disasters, satellite images are crucial for medical aid workers to deploy their resources to the right areas.

In a recent response to the Ebola crisis in West Africa, volunteers used satellite images to draw maps so that epidemiologists could chart the spread of the disease. When it comes to combating climate change, satellites have a vital role to play too. They can measure a range of things from carbon dioxide levels to ocean circulation and acidification.

FAST FACT

Arabidopsis thaliana (a type of cress) has been grown from seed on the International Space Station, and turnips and basil are to be grown on the Moon in 2015.
Source: NASA press releases

PROTEINS. When astronomers applied their technique for spotting galaxies to automatically detect these tumour changes, they matched the accuracy of a doctor in a much faster time.

This kind of collaboration is on the increase. At Harvard University’s Astronomical Medicine group, one success has been to use tricks learned from astronomical imaging to increase doctors’ accuracy at diagnosing heart disease from CT scans.

In a great example of interdisciplinary research and collaboration, astronomers at the University of Cambridge have teamed up with their colleagues in the oncology department to share their knowledge.

Doctors normally use a technique called immunohistochemistry to identify and confirm cancers as well as assess their aggressiveness. This involves staining a tumour sample, looking down a microscope and noting small changes in the stains as the tumour cells express different proteins.

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ASTRONOMY AND MEDICINE
How can looking at space benefit our health?

Our use of ground-based telescopes is making a difference in medicine too. Astronomers use these giant facilities to peer into the depths of the universe at objects like distant galaxies, taking pictures to analyse.

Specially designed software can automatically pick out the galaxies from the background of these images, full of fuzzy patches of light – not that dissimilar from the view a doctor sees of a tumour sample down a microscope.

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It’s difficult to prepare for the unexpected, so the first challenge is to make sure your experiment is as robust as possible – once you are in orbit there won’t be a lot of chance to tinker. Another major factor is mass. On Earth, sometimes experiments can fill an entire room. For space missions, ‘elbow room’ and mass are at a premium, so you need to work to miniaturise your equipment as much as possible.

Even routine procedures like taking blood samples, urine collections and body weight checks require a lot of thought. And remember, if your experiment needs human input then it will have to be operated by the astronauts aboard, who may not be experts in the field.

Depending on your experiment, it may be useful to have an identical control experiment on the ground. Say, for instance, that you want to investigate the effects of microgravity on plant growth. As always in science, you want every other variable to remain constant, and only the one you want to test is changed. Having a second experiment on the ground with all the same conditions, but with the addition of gravity, gives you a control. (Do also think about how many repeat experiments you might need – larger sets of data increase reliability.) You could be waiting quite a long time for your experiment to return to Earth, as resupply missions to the International Space Station don’t run all that often. Instead, you might want to think about ways your experiment can generate digital results that can be sent as messages back to Earth while your experiment is still in orbit.

**BIG AND SMALL**
Grappling with the numbers

Biology often deals with very small numbers, whereas in space and astronomy the numbers can literally be astronomically huge. For example, it is thought the visible universe is just under a billion billion billion metres across, whereas the width of one of our neurons is about 10 millionths of a metre.

Rather than write these numbers out by hand, scientists use the shorthand of standard form. The diameter of the universe becomes $8.8 \times 10^{26}$ metres; the width of a neuron becomes $1 \times 10^{-5}$ metres.

Powers of ten can also be used to represent data on a logarithmic scale if the values you are looking to chart vary widely. Take the pH scale. How much a substance is considered to be an acid or a base depends on how many hydrogen ions it contains. A strong acid can have one hundred million million times more hydrogen ions than a base. Imagine a pH scale that ran from 0 to one hundred million million. Instead, the pH scale is constructed by taking the negative logarithm of the number of hydrogen ions present. That yields a much simpler scale that runs from 0 to 14 – much more manageable!

A logarithmic scale lets you see concepts on one graph that wouldn’t be clear otherwise. The graph on the right demonstrates Kepler’s third law, which shows that there is a proportional relationship between a planet’s orbital period and its semi-major axis.
A SHORT HISTORY OF SPACE BIOLOGY
Each of the 44 expeditions to the ISS so far has taken biological experiments

Here’s a taster of what’s been done – to see biology experiments from each mission, go to bigpictureeducation.com/space

EXPEDITION 3: AUGUST 2001
Cardiovascular conditioning
This study, led by the European Space Agency, studied cardiac regulation and the balance between the parasympathetic (rest-and-digest) and sympathetic (fight-or-flight) nervous systems in weightless conditions.

EXPEDITION 8: OCTOBER 2003
Microbes
This study, led by the European Space Agency, looked at how we carry microbes into space, how they survive, adapt and multiply on the ISS, and where they grow most easily.

EXPEDITION 9: APRIL 2004
Seeds in space
This international experiment looked at the influence of gravity and light on germination and growth of plants. In space, plants in the dark grew in all directions, while those in the light all grew toward the light.

EXPEDITION 17: APRIL 2008
HIV/AIDS vaccine
This study, led by the Russian Federal Space Agency, investigated a vaccine for HIV/AIDS. It grew crystals of a protein ‘candidate’ for the vaccine under microgravity conditions.

EXPEDITION 35: MARCH 2013
Radiation and reproduction
This experiment, led by the Japanese Space Agency, took freeze-dried mouse sperm to the ISS and exposed it to cosmic radiation, then returned it to Earth to fertilise eggs.

SPACE AWAY FROM SPACE
How can we re-create these conditions at home?

Space clearly has advantages when it comes to performing certain experiments, but that doesn’t come cheap. Launching something into orbit costs more than $22,000 a kilogram, so it’s vital that you are confident the mission is likely to work before launch. In some ways it is similar to the experiments done in the classroom or in a professional lab. Doing trial runs will help you to get used to the equipment before you start taking data and inform your final experimental protocol.

One way around this is to find or create places and environments on Earth that are as similar as possible to the space environment you want to explore. For example, Boulby International Subsurface Astrobiology Laboratory in Yorkshire, located in an old mine at a depth of 1.1 kilometres, is the UK’s deepest microbiology laboratory. As part of their Mine Analogue Research programme, they test technologies designed to explore other planetary bodies.

Airbus Defence and Space in Stevenage have mocked up the Martian surface in an outbuilding to test the ExoMars rover, which will directly search for life on the Red Planet.

We can also use places on Earth as analogue sites based on our knowledge of the conditions on other planets. The Dry Valleys of Antarctica, for example, are considered an ideal analogue for Mars. Astrobiologists have taken bacteria samples from the Dry Valleys and subjected them to the environmental conditions that would be similar to those found on the surface of Mars, such as high UV radiation, desiccation and low temperature. These Earthly experiments are important for understanding the survival of potential past or present life on Mars.

BIG PICTURE VIDEO EXPERIMENTS
Our short films show you ways that you can study space biology

1. Responding to extremes
Study the effect of global warming on the crustacean Daphnia by observing its heart rate when surrounded by different temperatures of water.

2. Is there life in there?
This introduction to astrobiology touches on the Viking space probes to Mars and involves a practical comparison of sand samples.

3. What’s your limit?
Explore the limits of life on Earth in a practical activity involving yeast exposed to different conditions. You’ll investigate temperature and discuss the results, linking to information on enzymes and osmosis.

Watch for yourself! bigpictureeducation.com/space

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ASTRONOMICAL QUESTIONS
THE ‘UNKNOWN’ WILL ALWAYS BE CONTENTIOUS. CONSIDER THESE QUESTIONS AND DISCUSS WITH OTHERS. DO YOU AGREE OR DISAGREE WITH EACH OTHER? WHY?

THE CASE FOR AND AGAINST HUMAN SPACEFLIGHT
SHOULD WE JUST CALL THE SHOTS FROM HOME?

Ever wondered why Britain has never launched its own astronauts into space? British people who have been to space before have gone on other countries’ spacecraft. Tim Peake, due to go to space in November 2015, will go on behalf of the European Space Agency rather than the UK Space Agency.

Many well-known figures in the field have argued against human spaceflight. They say it is more expensive and riskier than sending robots. If a robot crash-landed into Mars there would be disappointment and the loss of years of work, for sure, but that doesn’t compare to the loss of human life. And, they say, robots can do many of the jobs that humans can do plus many that they can’t.

The history books certainly show that space travel is dangerous: the Challenger and Columbia space shuttle disasters together claimed the lives of 14 astronauts. There have been other fatalities and close calls too, with Apollo 13 perhaps the most famous narrow escape. No one has ever died in space – the deaths have all occurred during launch and re-entry.

Is risk a good enough argument for not pushing the boundaries of what is possible? What if Columbus, Cook and Cabot had decided sailing out into uncharted waters was too much of a risk? What if we had never ventured out of our caves in the first place? Or out of Africa?

Sending humans into space has led to many technological developments. Would the same innovations have been made if we restricted ourselves to robots? Then there is the inspiration factor: many of the scientists of today were inspired by the daring accomplishments of the Apollo astronauts. Imagine the impact of seeing a fellow human set foot on Mars for the first time.

PROS
• Humans can make on-the-spot decisions – a robot can only follow its (admittedly sophisticated) programming or wait for significantly delayed instructions from Earth.
• Astronauts can currently cover a lot more ground on the surface of a planet or moon and can use more advanced equipment to explore.
• Some healthcare advancements have come directly from preparing the astronauts.

CONS
• Humans need to be kept alive. This means bigger, more expensive missions carrying everything needed to sustain life (see page 6).
• It is risky. The consequences of a mission going wrong are much more serious.
• It’s too expensive – missions would cost less without humans.

Can you think of others?

LAND COVERED ON MISSIONS WITHOUT HUMANS

<table>
<thead>
<tr>
<th>System</th>
<th>Distance in km</th>
<th>Mission Date</th>
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<tbody>
<tr>
<td>Spirit rover (2004–10)</td>
<td>7.73 km (in 2,695 days)</td>
<td>2004</td>
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<tr>
<td>Opportunity rover (2004–present)</td>
<td>42.2 km (in 4,082 days)</td>
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LAND COVERED ON MISSIONS WITH HUMANS

<table>
<thead>
<tr>
<th>System</th>
<th>Distance in km</th>
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<tr>
<td>Apollo 15 rover (1971)</td>
<td>27.8 km (in 12 days)</td>
<td>1971</td>
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<tr>
<td>Apollo 17 rover (1972)</td>
<td>35.74 km (in 12 days)</td>
<td>1972</td>
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Can you think of others?

MORE ACTIVITIES ONLINE: bigpictureeducation.com/space  Ethical questions... Who owns space? Is space research worth the cost?... And
The mapping of the human genome is one of the greatest achievements in our scientific history. Now, many people are discussing ways in which we can benefit from having this information.

One of the first biologists to sequence the human genome – Craig Venter – has advocated the use of genetic selection in space exploration. What if you could look into someone’s genetic sequence and pick astronauts who have genes for strong bones? The effects of bone-density loss in microgravity could be minimised. Equally, if someone’s genetic analysis shows that their DNA repairs itself very quickly, that could help armour them against space radiation (and minimise cancer risk).

Is it ethical to select someone for a job based on their genetic information? Would it only apply to astronauts, or would it set a dangerous precedent for other professions too? Currently it is illegal in the US to pick someone for a job based on their genetic information. There is no similar law in the UK.

Would genetic selection be a step towards genetic modification of an astronaut? We can already modify foods to last longer, taste better and give astronauts more of the nutrients they need. We could also modify the bacteria in the gut to keep astronauts healthier in space – is that okay? Why not go a step further and actively alter the genome of the astronaut candidates most mentally suited to space exploration so that they are physically versatile too? Where would you say the line is? Why?

Looking way into the future, could we select or modify cyanobacteria to absorb Mars’s thin atmosphere of carbon dioxide and pump out oxygen so that we can eventually live there ourselves?

It works the other way too. There is a growing scientific appetite for sample return missions – those where robots (or people) go to planets, asteroids, comets and moons and bring back material to Earth for analysis. What if there is alien life resident on those objects and we inadvertently introduce it to our biosphere? It may thrive here, rapidly evolve and cause us no end of problems.

For these reasons we are currently extremely careful about quarantining anything brought back from beyond Earth orbit. When the Apollo 11 astronauts returned from the Moon, they had to wear special biological containment suits when on the deck of the aircraft carrier that rescued them from their ocean splashdown. They then spent three weeks in a quarantine trailer to make sure they hadn’t brought any biological material back from the Moon.

Is bringing material back to Earth worth the risk?

Are we doing enough to make sure we are safe?
REAL VOICES

Very few people get to visit space themselves, but many more work on space-related biology every day. Here, we meet a flight surgeon for an astronaut and two researchers who study extremophiles from astrobiological and biological perspectives.

PETER WOOLMAN
PhD researcher, Open University

What do you do?
I study a type of microorganism called halophiles (meaning salt-lovers) that live in a salt mine in Yorkshire.

What’s the aim of your research?
There may be similarities between halophiles and potential microorganisms that live or have gone extinct on Mars. Obviously, there aren’t any biologists on Mars and it’s difficult to carry out experiments remotely, so we’re looking at organisms that exist in Martian-like conditions on Earth.

If I could find a way of detecting organisms (a biomarker) that could be used on Mars, it could be used to prove the presence of Martian life. The biomarker could take many different forms, such as distinctive chemicals that remain after the organism dies or changes to rocks that could only be caused by life.

What did you study at A-level (and beyond)?
All four sciences at A-level: biology, chemistry, maths and physics. I did molecular biology and genetics as my undergraduate degree, then a Master’s in developmental biology. I then worked in the biotech industry before starting my PhD.

What would your advice be for someone interested in studying astrobiology?
Try to acquire a range of scientific knowledge. That doesn’t just include biology, also geology and chemistry. No one will know everything, but it’s really good to know something about a few different areas.

Would you consider going to space yourself?
It’s probably my dearest wish. It would have to be on a mission planned by an organisation I could trust. Also, I think I’d like to be able to come home afterwards.

If you could go to any planet, which would it be and why?
Jupiter – to study its moons. If there is extraterrestrial life in our solar system, that’s probably the most likely location.

If you weren’t studying an astrobiology PhD, what would your dream job be?
A science fiction writer, but I’d also consider a career in IT.

To read a longer interview with Peter, including his thoughts on where organisms might live on Mars, go online: bigpictureeducation.com/space

BRIGITTE GODARD
Flight surgeon, European Space Agency

What does a flight surgeon do?
I act as general practitioner (GP) for astronauts.

What’s your average day like?
I have one main patient. Right now, it’s Samantha Cristoforetti, an Italian astronaut on the International Space Station ( pictured above with Brigitte).

Right now, it is a quiet time when all is going well from a medical perspective, but things can become more difficult. I talk with Samantha once a week for 15 minutes. I receive and review data from medical exams and do a lot of reporting.

When is it busiest?
Three months before launch and after return. There is a lot of travel, and dealing with medical issues can be stressful. Samantha will land in Kazakhstan, where I will pick her up with the other crew member, and will return directly to Houston, Texas, USA, where all post-flight medical and science exam has to be done (all preflight was collected in Houston).

What are the common medical issues?
Pain, usually the back or legs. Astronauts exercise a lot but it isn’t always enough. Sleep, either falling asleep or waking too early. Space motion sickness, usually at the beginning; luckily, it wasn’t a problem for Samantha.

What is your favourite part?
Launch is something very stressful but so beautiful when you see the rocket going in the sky.

What was your career path?
I wanted to be an astronaut but my eyes were not good enough. I studied to be a medical doctor, but looked out for any medical activities related to space.

In 2005, Centre National d’Etudes Spatiales – the French Space Agency – was looking for a physician to work in a bed-rest study for healthy volunteers. I then worked on European astronaut selection. Eventually I was offered a flight surgeon position. After one week, I knew it was right for me.

What advice would you give to others?
Do all of the space-related lessons you can. As well as being a doctor, you need knowledge of space. Look for short courses, diplomas and Master’s.

Do you still want to go to space?
A long time ago I did a parabolic flight and got really sick. I tried another recently and was really sick again. So maybe it’s not for me.

MORE ONLINE: bigpictureeducation.com/space
What do you do?
I study an ancient single-celled organism called *Haloferax* and the unusual way it replicates DNA. All cells have genetic information that they copy to make new cells, and this process starts at specific origins of replication in the DNA.

When I joined Thorsten Allers’s lab in January 2015, they had already found that deleting all the origins of replication in *Haloferax* made the cells grow faster. This was very unexpected and is a paradox: why would cells have evolved origins of replication if they slowed growth?

What’s an average day like?
I start by checking how my *Haloferax* cultures are growing. Their natural habitat is salt lakes like the Dead Sea, so they require high temperatures, 45°C, and high salt concentration, 2 to 3 molar (equivalent to two tablespoons of salt in a glass of water). If life on other planets resembled life on Earth, then extremophiles like *Haloferax* would be ideal candidates as they manage to live with less water.

Our experimental approach is to alter genes and see what happens. *Haloferax* has 4,000 genes but I have a shortlist of five that I’m particularly interested in – these genes encode proteins that interact with the origins of replication. By deleting them in different combinations, we can see how growth is affected and whether these proteins are necessary to initiate replication.

How did you get into research?
At school in Belarus, I was interested in biology, so I chose to study molecular biology at Edinburgh University. I wanted to do simple, elegant experiments that answered fundamental questions – like the experiments that discovered DNA.

After my PhD at Cambridge University, I came to Nottingham. *Haloferax* are certainly simple, but I was intrigued by the findings about replication and growth. You have to expect the unexpected with extremophiles!

What extreme conditions do you enjoy?
I’ve climbed the highest mountain in Europe, Mount Elbrus. The summit is 5,600 metres – it was extreme, but also very appealing and exciting.
GO FURTHER

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