Catalyst

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Rat in a maze

The making of memories

SEP
Science Enhancement Programme

Catalyst

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The front cover shows a rat in a laboratory maze. Rats learn to navigate complex mazes and this has taught us how spatial memories are built up in the brain. See the article on pages 18-20. (photo: Patrick Landmann / Science Photo Library)

Contents

World-changing science

Science is often interesting in itself, but much of the scientific research carried out today has a specific purpose. Its aim is to make the world a better place. In this issue, we highlight some of the ways in which scientists are trying to make our lives better.

On pages 1-3, Sarah Mackintosh describes the latest efforts to devise ways of storing the carbon dioxide which is produced when fossil fuels are burned. This may at least delay the effects of global warming.

On pages 12-14, Eimear O'Carroll describes her studies which help people suffering from tinnitus, a disabling hearing problem. It's a business which grew out of a school project, and it's very modern – it delivers therapy over the internet.

On pages 15-17, Ginny Page describes how plant scientists are working to develop new strains of crop plants which can help to provide a sustainable food supply in the future.

But before we get carried away with man's influence over nature, Christopher Lloyd has a few words of warning (pages 21-22). In his view, *Homo sapiens* does not occupy top spot in the league table of life.

Editorial team

David Sang	**Vicky Wong**	**Gary Skinner**
Physics	*Chemistry*	*Biology*
Bognor Regis	*Didcot*	*Halifax*

Editorial contact:
01243 827136 or catalyst@sep.org.uk

SEP

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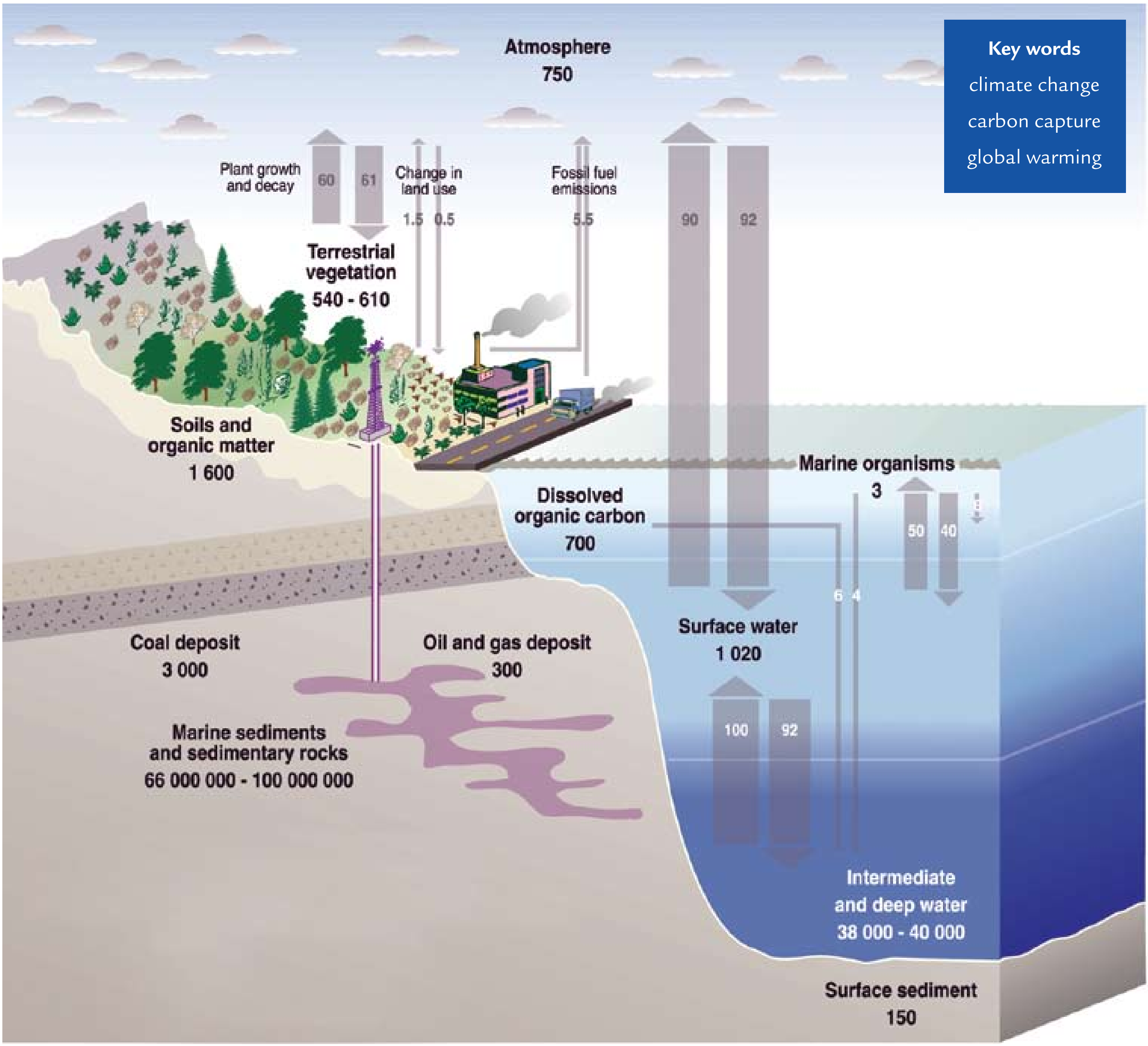
Carbon capture

Tackling climate change

Sarah Mackintosh



Key words
climate change
carbon capture
global warming

Burning fossil fuels releases carbon dioxide into the atmosphere. This is a major contributor to climate change. Can we capture and store that CO_2 as it is produced? Sarah Mackintosh of Nottingham University describes progress in the science and technology of carbon capture.

Carbon dioxide, released by human activities such as burning fossil fuels and deforestation, is the major greenhouse gas to cause manmade global warming. The current concentration of CO_2 in the atmosphere is 379 parts per million (ppm) compared with a pre-industrial level of 270 ppm. It is estimated that the level of CO_2 is currently rising by 2 ppm annually. Annual emissions of CO_2 grew by approximately 80% between 1970 and 2004. The current global emission from fossil fuels is 5.5 gigatonnes of carbon per year (GtC/yr) (see figure 1).

However, with the war on how to tackle future sustainable fuel demands still raging, it has become clear that a relatively short term 'band-aid' solution is urgently required to slow the current and potential effects of global warming.

Figure 1: *The carbon cycle explains the exchange pathways of carbon and shows CO_2 is increasing in the atmosphere. The figures give amounts of carbon in gigatonnes of carbon; a gigatonne is a billion tonnes.*

Phasing out fossil fuels

Can you imagine trying to phase out the world's current fuel supply? It will take the UK a few years just to phase out the traditional filament light bulb!

Carbon Capture and Storage (CCS)

A viable option currently being explored to counteract rising atmospheric CO_2 levels is CO_2 capture and storage. In this process CO_2 is separated from industrial and energy-related sources, transported to a storage location and stored in a way which isolates it from the atmosphere for a long time. Figure 2 demonstrates the potential effect on levels in the atmosphere of storing the CO_2 over a number of years.

Oil out, carbon in, what's the problem?

Although in principle the idea of storing CO_2 in ready made geological structures seems relatively straightforward, the reality is very different. There are many different aspects and implications to storing CO_2; for example, how do we remove other gases associated with fossil fuel burning from the CO_2, and how do we transport the CO_2 to the storage site? Is it possible that the storage site could leak and, if so, what are the consequences? CO_2 is not toxic at normal levels, but it is heavier than air and at high concentrations it can cause suffocation. How much extra energy will CCS processes cost? These are just some of the science questions – just imagine how complicated it becomes when lawyers, land owners and governments become involved! Despite the many hurdles that have had to be addressed, we are now at the stage where some demonstration carbon storage sites have already been or are due to be set up.

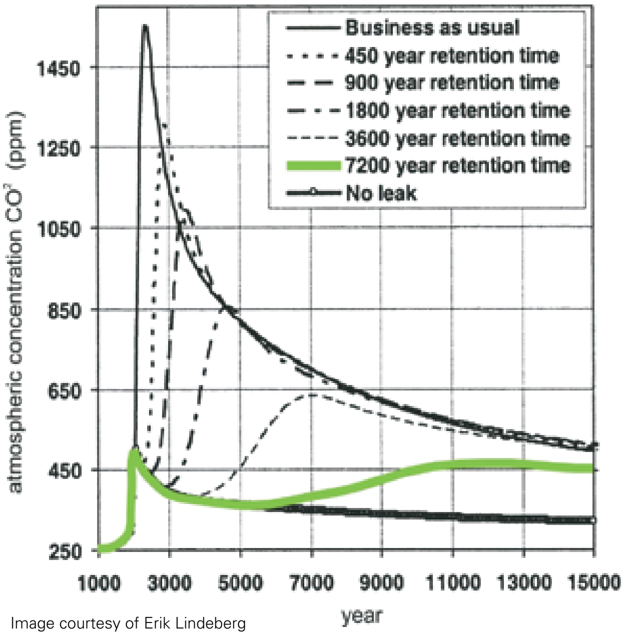


Image courtesy of Erik Lindeberg

***Figure 2:** Acceptable 'retention' times of CO_2 stored. Even storing CO_2 for just 450 years has a positive effect on the atmosphere.*

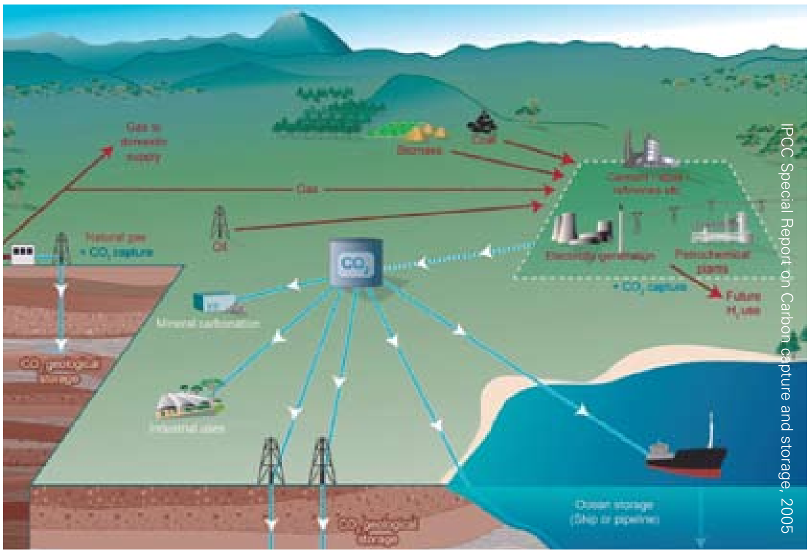


***Figure 3:** Carbon capture and storage processes*

Where can we store captured carbon?

Biological Sequestration – CO_2 stored in forests and soils.

Biological sequestration has many limiting factors as its storage form is often volatile and subject to subsequent release through changes of land use, harvesting, fires, or other disturbances.

Ocean Sequestration

The ocean already stores a great deal of CO_2 (see figure 1), but it has been proposed that we could accelerate this process by fertilising the ocean with iron to promote growth of carbon fixing plankton – an unpopular choice with most people. An alternative is to inject CO_2 into the ocean at depths greater than 1000m at which depth it should form an impermeable hydrate seal which would prevent it escaping. This idea is being further researched in Japan where other types of storage are limited.

Geological Storage

Injection of CO_2 into stable geological structures such as oil and gas fields, unminable coal beds and deep saline formations (see figure 3). These structures are already well-researched and understood as we have been using them to extract fossil fuel for over 100 years, so it makes understanding the processes involved in storing the CO_2 easier. Depleted oil and gas reservoirs are estimated to have a storage capacity of 675–900 $GtCO_2$. Deep saline formations are very likely to have a storage capacity of at least 1000 $GtCO_2$.

The In Salah CO_2 project is in Algeria. Since 2004, 1.2 million tonnes CO_2 per year has been captured and stored there. Compare this with world annual production of 5500 million tonnes.

CCS – the current status

There are a number of different projects being carried out across the world (see figure 4), some projects are focused on CO_2 capture and some are more focused on CO_2 injection and storage. Current capture projects include Boundary Dam and CASTOR. Boundary Dam is a power station in Canada which has a centre that has been set up to develop new capture technology and perform long term tests on a semi-industrial scale. They are experimenting on the waste gas from the Boundary Dam power plant. The CASTOR project is based at a coal-fired power plant in Denmark. Its specific goals involve: halving the cost of capturing and separating CO_2; developing storage efficiency, safety and security while limiting its environmental impact; and testing in real-life, industrial-scale facilities.

Figure 4: *A variety of storage projects have been set up across the world.*

The Sleipner field is in the North Sea (see figure 5). It produces natural gas and light oil from sandstone which is about 2 500 m below sea level. Here, CO_2 is injected into a 200m-thick sandstone layer about 800 m beneath the bottom of the North Sea. Like most rocks deep underground, this sandstone is filled with salt water. It is very porous and permeable, so the CO_2 moves rapidly sideways and upward through the rock layer, replacing the water between the sand grains.

Figure 5: *The Sleipner oil field, where CO_2 is pumped into underground rocks.*

Teapot Dome is an experimental facility in Wyoming USA run by the US Department of Energy. Many universities and industrial partners carry out experimental work there to try to develop techniques to monitor the stored CO_2 and gain a greater understanding of what happens to the CO_2 underground (see figure 5).

The UK

In 2007 the government launched a competition for companies to compete to win funding to develop the UK's first full scale CCS demonstration. The winner is due to be announced this year (2010) and it is expected that the demonstration plant will be up and running in 2014.

Figure 6: *Experimental work being carried out at Teapot Dome.*

Research at the Centre of Innovation in Carbon Capture and Storage

Here at the University of Nottingham there is a great deal of exciting and novel research. Just some of the projects being done here at the moment include:

- A number of projects using minerals (rocks) to store CO_2 in a permanent, solid and stable form. Experiments are carried out in high pressure rigs shown in figure 7. Ground minerals are placed in the rig and heated. High pressure CO_2 is then passed into the rig. Experiments continue to optimise the process.

Figure 7: *Mineral carbonation experiments at Nottingham.*

- Studies into how other reactive gases (impurities) change the properties of carbon dioxide during capture, transport and storage.
- Establishing reliable monitoring of environmental impacts by testing gases released by the soil.
- Research into artificial photosynthesis: using light and catalysts to turn CO_2 into fuels or chemicals.

Dr Sarah Mackintosh is a research fellow in the Centre for Innovation in Carbon Capture and Storage at The University of Nottingham. She has a degree in Environmental Science

Look here!

Find out more about CCS research in Nottingham at: *http://tinyurl.com/yzs5joq*

Global 'Warming'?

Although, as you would expect, the planet will get warmer if CO_2 continues to increase in the atmosphere, it is possible that Europe will in fact get colder. This is because Europe is currently warmed by the Gulf Stream which is diverted past Europe by global ocean circulation (warm, less dense waters flowing in one direction at the sea surface and cold, dense waters flowing in the opposite direction in the deep ocean). More CO_2 in the atmosphere could slow down or even stop this circulation, reducing or slightly redirecting the Gulf Stream and making Europe a colder place to live!

Vicky Wong

Biomimetics

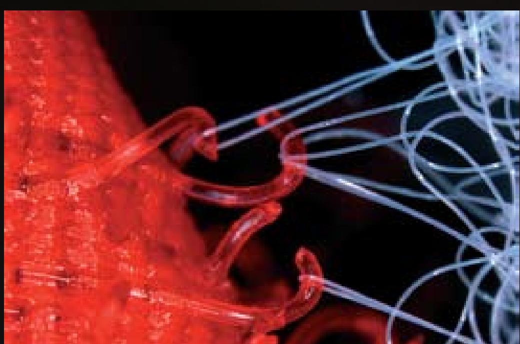
What do burrs on a dog's back, a pinecone, the skin of a shark and a water lily have in common? They have all provided the stimulus for the design of useful products by biomimetics.

Biomimetics is 'design inspired by nature.' It looks for inspiration in the natural world for solutions to a variety of problems.

Velcro

One of the earliest modern examples of biomimetics began over 60 years ago when George Mestral examined the burrs which stuck to the fur of his dog under the microscope. He saw hundreds of tiny hooks which latched into the soft fur of the dog. He discussed this with weaving experts and eventually a pair of cloth tapes were produced which, when pressed together, fastened in a similar way to a teasel and fur. The idea was patented by Velcro in 1952.

The hooks on the fruit of the burdock were the inspiration for Velcro.



Velcro consists of two fabrics, one with hooks and the other with loops.

Military fabric

Pinecones are a more recent example of an inspiring plant. When the cones are hanging on a tree they are firmly closed but, as they ripen and fall to the ground, they open in order to release the seeds. The cones respond to levels of moisture in the air and open as the scales dry out. This happens because the scales are made of two materials which react differently to humidity. As the cone dries out, one side expands more than the other and so the scales bend.

Scientists used this idea but reversed it, creating a fabric which contains lots of little flaps which open in high humidity. If a person wearing such a fabric gets very hot and sweats then the flaps will open and cool them down. As the level of sweat reduces, the flaps will close again. The military are particularly interested in this type of product for soldiers serving in desert locations which can be very hot during the day but cold at night.

As the scales of a pine cone dry out, they open to release the seeds.

Swimmers in shark skin

Shark skin is so rough that when dried it can be used as sand paper. It is covered with little v-shaped bumps which are made from the same material as the sharks' teeth. This rough surface reduces friction as the shark swims through the water and makes the shark a far more efficient swimmer than would be expected. After studying the shark skin, scientists tried covering boats and aircraft with little perpendicular ridges and found that they significantly reduced drag. Fabrics have also been produced which mimic shark skin and these have been used to make swimwear for competitions. The idea is so successful that 27 out of 33 medals at the Sydney Olympics were won by swimmers wearing the new shark skin style swimsuits.

Shark skin has pointed scales which reduce drag as the shark moves through the water

Swimsuit fabric designed to mimic shark skin

Michael Phelps of the USA was one of the successful swimmers at the Sydney Olympics – he wore a 'sharkskin' racing swimsuit.

Lotus leaves

The lotus plant (or water lily) lives in muddy water but manages to remain clean. This remarkable ability has been known about for many years, but recently scientists have looked more closely at the structure to find out why. The surface is superhydrophobic which means that it is extremely good at repelling water. You might expect that such a surface would have to be particularly smooth, but in fact it is made of a hydrophobic (water repelling) wax which is arranged in little ridges. This repels water effectively.

The rough surface also reduces the area for both dirt and water to be in contact with the leaf which significantly reduces how well they stick to the leaf. When water droplets fall on the leaf, they roll off the water-repellent surface, taking with them any dirt particles which are on it. This means that the lotus effectively has a self-cleaning surface.

This idea has led to the development of new paints and coatings which are self-cleaning. The photo shows a wate droplet on a self-cleaning coating. This contains tiny nanoparticles which make the water droplet form a near-spherical shape which collects dirt as it rolls off the surface. This self-cleaning and waterproof property is known as the 'lotus effect' after the same properties found on the lotus leaf. Materials covered with this coating are able to withstand corrosion and stay clean.

A lotus leaf, showing its superhydrophobic property.

A water droplet resting on a water-repellent coated surface

Look here!

For a video explaining what happens to water on very hydrophobic leaves: *http://tinyurl.com/ykw4dt7*

Elaine Greaney

Mission to Mercury

One of the most exciting projects that spacecraft engineers in the UK are working on at the moment is BepiColombo. This international project, which plans to send a spacecraft to the planet Mercury, will combine revolutionary new rocket engine technology with exciting scientific goals - exploring the inner solar system in a way that has never been done before. Elaine Greaney describes how the spacecraft's ion propulsion motors will contribute to this mission.

Key words
spacecraft
Newton's laws of motion
Mercury
propulsion

BepiColombo

BepiColombo is a joint mission to the planet Mercury (see Box) by the European Space Agency (ESA) and the Japan Aerospace Exploration Agency (JAXA). It is due to launch in 2014 on an Ariane 5 rocket from French Guiana, and it will then travel for six years until it reaches Mercury.

The European part of the spacecraft (the Mercury Planetary Orbiter) will be equipped with eleven scientific instruments to study the surface and internal composition of Mercury, whilst the Japanese part (the Mercury Magnetospheric Orbiter) will study Mercury's magnetic field.

The mission is named after Giuseppe ('Bepi') Colombo, an Italian scientist who was best known for studying the planet Mercury, and who worked out how to get a spacecraft into orbit around Mercury by first using a **slingshot manoeuvre** around Venus. The BepiColombo spacecraft will be propelled by an **ion propulsion** system and will use gravity assists from the Moon, Earth and Venus, before eventually being captured by the gravity of Mercury.

An artist's impression of BepiColombo as it approaches Mercury.

Mercury

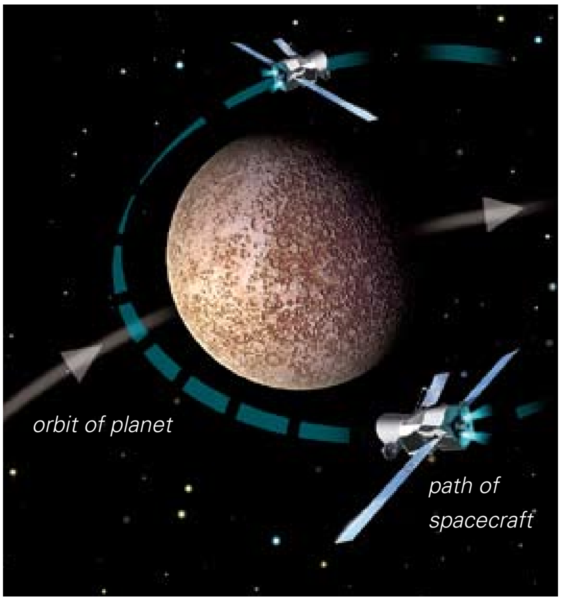
Mercury is the planet in our solar system which is closest to the Sun. It is 1/19th of the volume of the Earth and is similar in appearance to our Moon. It is unusual because of its suspected iron core and magnetic field.

Mercury's closeness to the Sun makes it difficult for a spacecraft to travel there due to the extreme temperatures involved, but scientists are keen to send a probe there for the valuable clues that such a mission can provide in understanding both the planet itself and the formation of our solar system; clues which cannot be obtained with observations from Earth.

A photograph of Mercury's surface, taken by an earlier mission.

Slingshot manoeuvre

A 'gravitational slingshot' or 'gravity assist' manoeuvre is when the gravity of a nearby planet or other celestial body is used to alter the path and speed of a spacecraft, in order to save fuel and journey time. The Mariner 10 probe was the first spacecraft to use a gravitational slingshot manoeuvre. It visited Venus and Mercury in 1974.



The path of a spacecraft as it performs a slingshot manoeuvre around a planet.

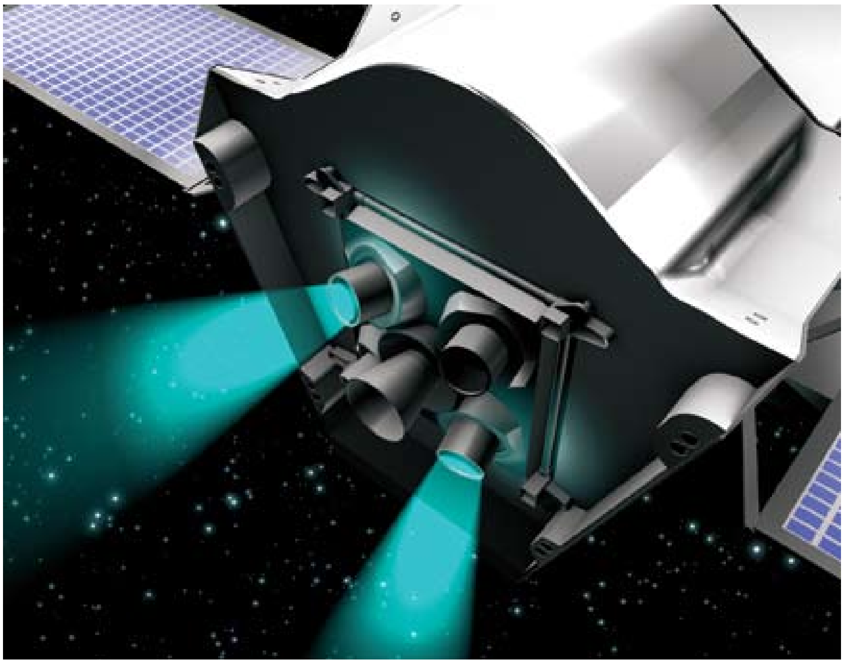
The main limit to using slingshot manoeuvres is that planets are not always in the right place at the right time in order to help a mission to a particular destination. This means that any missions planning to use this type of manoeuvre to speed up or slow down their spacecraft during its journey have to make sure that the manufacture and launch of the spacecraft is carefully timed to coincide with the planets being in the right place.

Note that, if a spacecraft is accelerated during a slingshot manoeuvre, the planet will be slightly slowed down – both energy and momentum must be conserved.

BepiColombo's engines

BepiColombo is a very high profile mission for the European Space Agency, and it is only possible because it will use ion propulsion technology. The ion engines which will carry the BepiColombo spacecraft to Mercury are being built at QinetiQ in Farnborough, Hampshire, where a group of scientists and engineers have been developing ion propulsion technology for decades.

The ion engines being built for BepiColombo work by creating a plasma made of ions from xenon gas, and then accelerating these ions out of the engine, generating thrust which pushes the spacecraft forwards. Xenon is used as a propellant because it is easy to ionise, and relatively safe to use. However, xenon is globally in short supply and very expensive.



BepiColombo's propulsion system – the solar panels use sunlight to generate the electricity required to power the ion propulsion engines.

Ion propulsion

Ion engines use beams of ions (charged atoms or molecules) to create thrust in accordance with Newton's 3rd Law. Unlike a chemical rocket which burns fuel very quickly, an ion engine produces much less thrust but can keep running for a long time. This allows a spacecraft to slowly build up speed and travel long distances. Ion propulsion is characterised by the high velocity with which the propellant is accelerated out of the engine – at about 50 km/s. This is 16 times faster than conventional chemical thrusters. This means that the amount of fuel that has to be used is much lower, so the spacecraft is much lighter and easier to launch away from the Earth's gravity.

Advantages of propulsion technology which uses less fuel than traditional chemical systems:

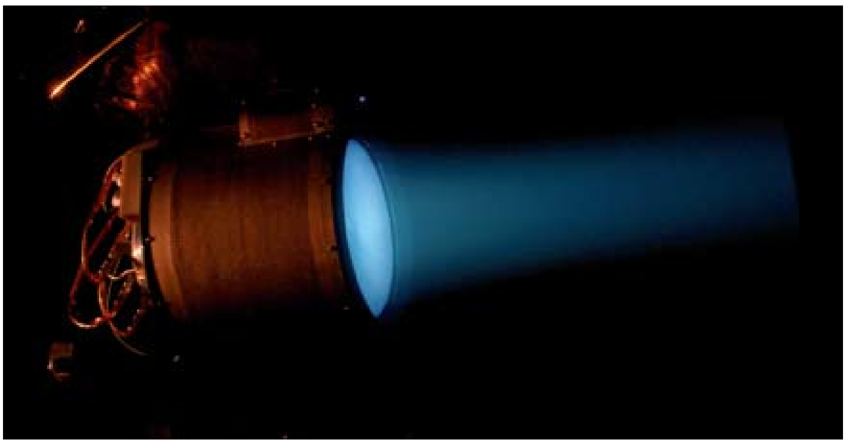
- Longer spacecraft lifetimes for the same amount of fuel
- Larger final spacecraft velocities
- More room on the spacecraft for scientific instruments
- Reduced cost of launching the spacecraft from Earth
- The amount of fuel which can be carried is enough to propel a spacecraft right across the solar system

Uses of ion propulsion:

- Keeping communications satellites in geostationary orbits around the Earth
- Carrying probes large distances to other planets or asteroids
- Maintaining the orbits of scientific missions close to the Earth (e.g GOCE which is measuring the Earth's gravitational field)

One of QinetiQ's T6 ion propulsion engines ready for tests …

the test chamber at Farnborough …



a T6 engine generating 200 mN of thrust on a test balance.

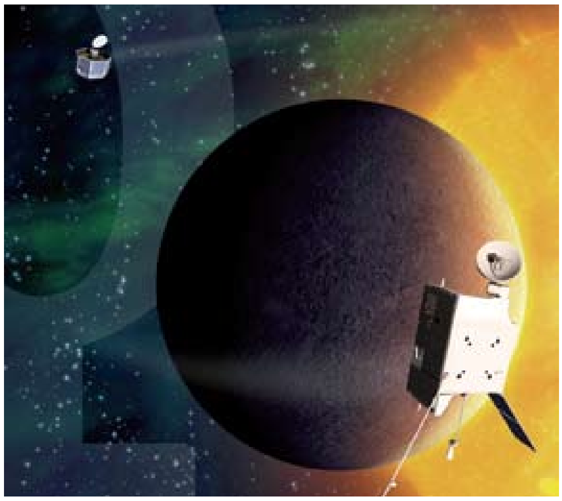
Build and test

The BepiColombo spacecraft will have a mass of 3000 kg and a solar panel wingspan of 26 m, but each of the 4 ion engines that will carry it to Mercury has a mass of just 8 kg and is only 30 cm wide. Each engine is assembled from over 1400 parts, by engineers in clean rooms wearing protective clothing to ensure that the engines are kept clean and don't cross-contaminate the sensitive spacecraft instruments.

Before launch, the engines will be tested in chambers that simulate the vacuum and temperatures of space. They will also be subjected to vibration testing to prove that they will be able to survive being launched on a rocket from Earth. After the spacecraft separates from the launch rocket, the engines will have to work non-stop for 26 000 hours to deliver the spacecraft to Mercury, so there is redundancy in the system in case a problem occurs.

To safely deliver the spacecraft to its destination, the engines will first be used to accelerate the spacecraft away from the Earth, then to position BepiColombo for its gravitational slingshot manoeuvres and then finally to brake and stop the spacecraft from crashing into Mercury. The spacecraft will be positioned safely in orbit around the planet, and then the job of the ion engines will be done; but the work of the scientific instruments and the scientists back on Earth will have only just begun!

Elaine Greaney is an ion propulsion engineer at QinetiQ.



An artist's impression of the two parts of BepiColombo after each has entered its own orbit around Mercury.

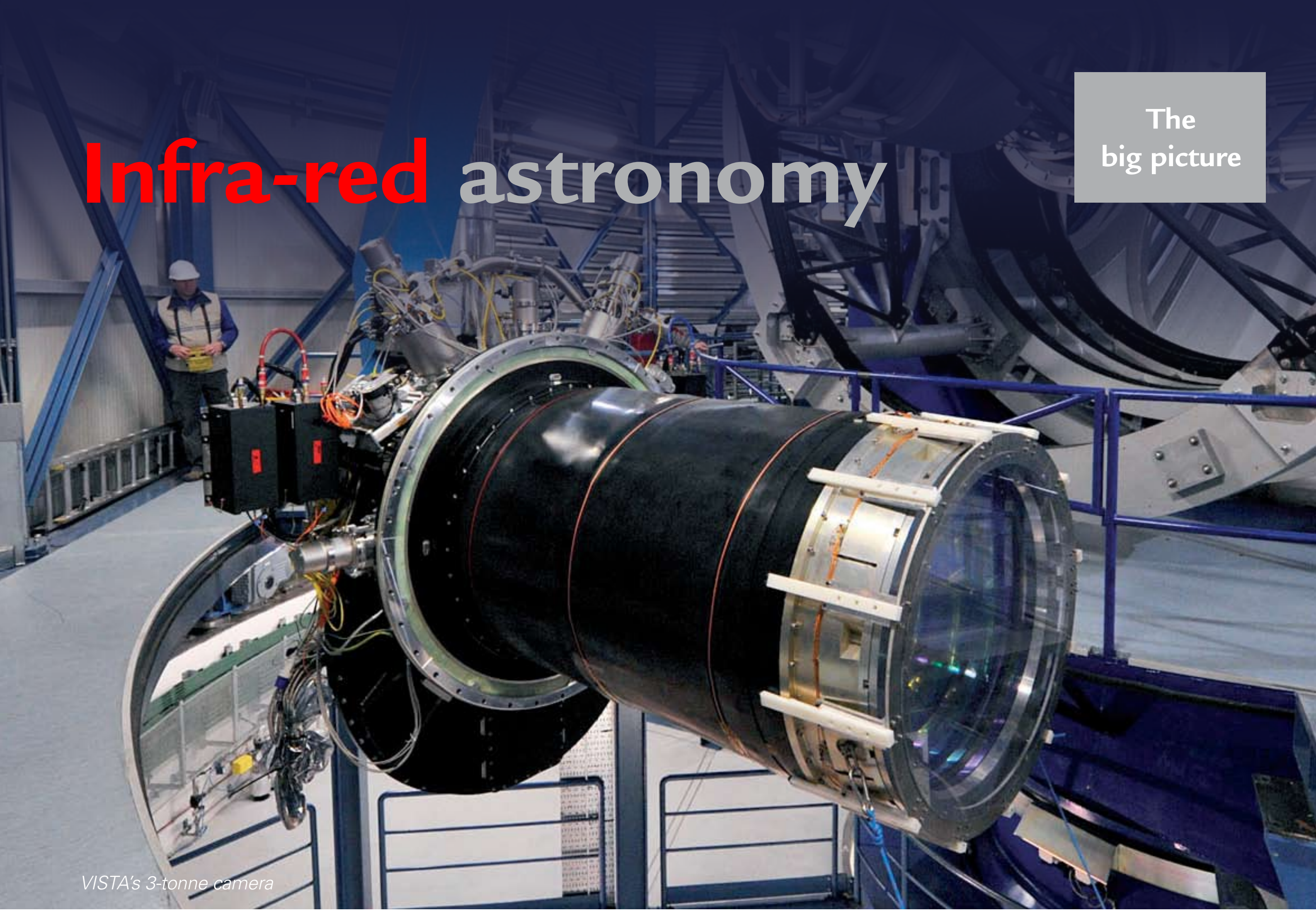
Look here!

The European Space Agency's page about BepiColombo: *http://www.esa.int/SPECIALS/Operations/SEMYRMQJNVE_0.html*

QinetiQ's page about rocket propulsion: *http://www.qinetiq.com/home/markets/related_markets/space/electric_propulsion.htm*

More about how space rockets work: *http://www.sep.org.uk/catalyst/articles/catalyst_13_2_145.pdf*

Infra-red astronomy



VISTA's 3-tonne camera

High on a mountain-top in Chile stands the VISTA telescope. Astronomers have recently released VISTA's first images – you can see one on the centre spread of this issue of CATALYST.

VISTA is no ordinary telescope. It can 'see' infra-red radiation – electromagnetic radiation beyond the red end of the spectrum.

ESO/Y. Beletsky

The VISTA telescope inside its dome.

ESO/J. Emerson/VISTA and Digitized Sky Survey 2.
Acknowledgement: Davide De Martin

On the left, the Flame Nebula as seen in visible light; the central area is blocked by a giant cloud of dust. VISTA's infrared view, on the right, sees through the dust.

This has two great benefits:

- The telescope can detect radiation from distant stars which are otherwise hidden behind clouds of dust which absorbs visible light.
- The telescope can see cool stars which emit little visible light.

VISTA's camera is impressive. It weighs 3 tonnes and has 16 detectors with a total of 67 million pixels.

Professor Jim Emerson of Queen Mary University of London leads the VISTA consortium. He says, "History has shown us that the most exciting things that come out of projects like VISTA are what you least expect — and I'm very excited to see what these will be!"

VISTA stands for Visible and Infra-red Survey Telescope for Astronomy.

ESO/J. Emerson/VISTA. Acknowledgment: Cambridge Astronomical Survey Unit

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The VISTA telescope's image of the Flame Nebula in the constellation of Orion, a region in which new stars are forming.

Eimear O'Carroll

Hearing trouble
Science versus business?

Eimear O'Carroll describes how a Young Scientist project led her and two fellow students to set up their own business before they left school.

Key words
hearing
sound waves
tinnitus
cochlea

When I first decided to do a Young Scientist project, I could not possibly have envisaged what was in store for me. Although I was always good at science and enjoyed its ability to answer so many phenomena questions, I didn't really think it was for me on a permanent basis. That was all about to change ...

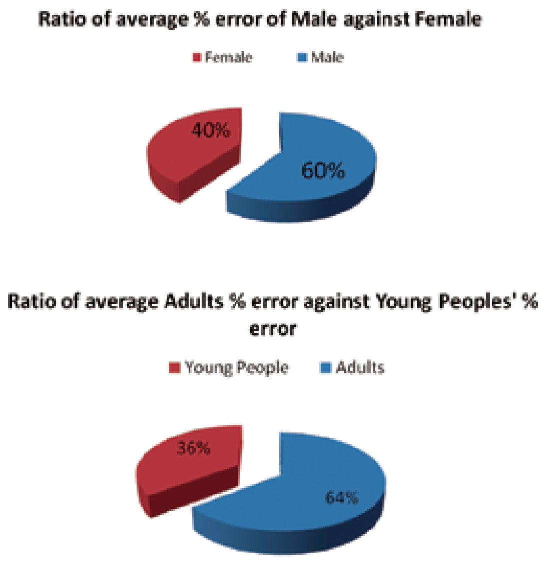
I joined forces with two other students, Rhona Togher and Niamh Chapman, and we set about thinking of a new and imaginative science project. From the very outset, our physics teacher, Mr. Carolan, was highly enthusiastic about our project and gave us guidance at every stage. He saw my profound interest in our work as well as my sometimes pathological dedication to perfection in planning and executing every stage of our project. I was extremely lucky to work with likeminded people at this time and it started me thinking about the possibilities of working in science in the future. What I originally thought would be a predictable job in a lab suddenly metamorphosed into endless possibilities and an ever changing career. *I could see the profound benefits of working at something you love and knowing that each day brings new challenges.*

Where's that sound?

We originally studied the localisation abilities of humans in relation to pure tones. We used an older study as our foundation and extended it to include a wider breadth of candidates and a more precise level of technology. We designed and implemented a test that involved blindfolded candidates trying to locate the source of pure tone frequencies in the range 2000 – 4000 Hz. By measuring the angles within the circular testing system that the candidate indicated as the source relative to the actual source location we could analyse the localisation ability of the candidates.

Our study concluded that girls were better able to localise pure resonant frequencies than their male counterparts. The project earned us 1st place in the senior group category of the 2008 Young Scientist and Technology Exhibition. We were all in 5th year and still had time to get back into a normal routine to prepare for our Leaving Certificate in June 2009.

But never presume plans will run smoothly. Mr. Carolan was always the first to tell us what we could achieve if we kept going with this research. And our display and presentation were considered so impressive that the judges encouraged us to enter another sound-related project the next year. And so the madness started all over again.



Our results summarised. Girls are better than boys at judging where sounds are coming from, and young people are better than older people.

This time we decided that if we were going to do another project we would submit the best we possibly could. This would be our last chance to enter a project, and we now knew what was expected and we felt we could improve on our previous level of work. We had devised a new idea that we felt could have a profound effect on science.

A new project – temporary tinnitus

In deciding on our new project, we considered the old idea of looking around you and seeing common problems and then trying to come up with solutions. Given our background, we focussed in on sound theory. The problem that came up ahead of all others was the annoying sound evident after a disco, club, gig or mp3 player use.

The big sound of a rock band can be exhilarating – but it can also damage your hearing.

It was only on isolating the problem of temporary **tinnitus** that we realised how prevalent it really was. We surveyed 1000 people of all ages and discovered a 92% incidence rate. The sheer number of people who have experienced tinnitus (ringing in the ears) was staggering. When you take on board that temporary tinnitus can be an indicator of permanent damage to the **cochlea**, it should be alarming to realise how much damage is being done and how close we could be to a deaf generation in a couple of decades.

One part of our project was to identify a problem but the harder part was to devise a solution. Again, we worked closely with Mr. Carolan and we hypothesised as best we could, based on our knowledge of sound and how the ear works Eventually, we hit on the core of the problem and the essence of the solution. The temporary tinnitus in many cases was being caused by bent or broken cochlear hairs and the hairs hitting off each other were creating phantom sounds being sent to the brain. If we could straighten those bent hairs, we could reduce interference and hence lessen the tinnitus. This is what we achieved.

further when we were given overall runner up in the competition. Our work had paid off and we were ecstatic at have achieved so much. It could have been the end of the research but fate had other things in store.

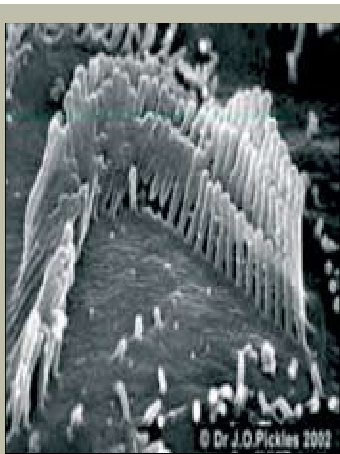
We hadn't been back in school for more than a week when we felt that familiar tug of wanting to do more research. All the time we had been working on this project we had still wanted to know if our therapy would work for permanent tinnitus. Obviously we had to concentrate on our Leaving Certificate which was approaching fast but we wondered could we do more.

Finding funding

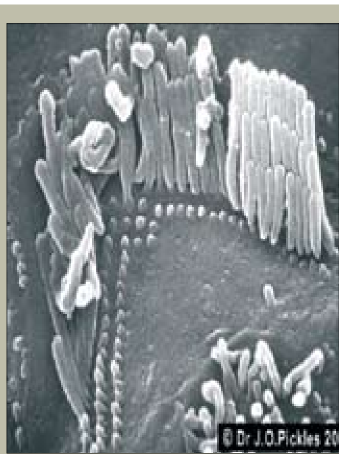
It was at this point that things changed drastically. One of our team, Niamh, decided to exit as she felt that she needed a summer off after exams. Mr. Carolan approached a number of companies and organisations to see if we could gain funding to do further research after our exams. There was very little interest until he talked to the county enterprise board. They suggested that the best way to protect our research data and, at the same

These electron microscope images show the damage done to cochlear hairs by loud noise.

Normal cochlear hairs



Moderate sound damage to cochlear hairs



Serious sound damage to cochlear hairs

Therapy

We succeeded in developing a therapy that manages to re-straighten some of those hairs in one minute. Our therapy combats sound damage by using sound to stimulate the inner ear and allowing it to vibrate maximally. By doing this we soothe the ear and allow the cochlear hairs to re-straighten. As the interference between bent cochlear hairs is no longer present the tinnitus is similarly gone. People have described our therapy as like listening to a low hum.

Our project went into overdrive and we produced a work of scientific research that I am still immensely proud of. We knew we had done well but when they called out our names for the special award of Health Innovation Award from the Health Research Board, we were in shock. This surprise was compounded

Ana Blazic/bigstockphoto.com

Restored Hearing's therapeutic sounds are delivered over the internet to the sufferer's computer; they then listen using headphones.

time, gain funding was to incorporate our group into a limited company. And so, on the 1st May 2009, Restored Hearing Ltd. was born with Rhona Togher, Anthony Carolan and me as directors. Anthony took over the initial running of it so as to allow Rhona and myself to study and sit our exams but as soon as the exams were over (that evening in fact), we got fully involved and we began a summer long study travelling around the country meeting and testing permanent tinnitus candidates and compiling our data.

Restored Hearing's homepage

What has happened since then has been like a rollercoaster. We officially launched in August with the co-founder of the Young Scientist, Dr Tony Scott, as guest of honour. We secured a business loan and were welcomed into the Nova UCD innovation centre to operate from.

We have gained worldwide insurance cover and to date have secured business from every continent. Over the last number of months we have achieved media exposure in a number of countries from print to TV.

Just lately, we won the regional finals of the Ulster Bank Business Awards, putting us through to the 2010 national finals.

Where are they now?

Rhona Togher is studying for a degree in Physics in UCD Dublin; she lives a few yards from the Restored Hearing office in Nova UCD.

Anthony still teaches in Ursuline College, Sligo, and is keeping the Young Scientist flag flying.

Eimear O'Carroll has started a physics degree in University of Edinburgh and is loving it.

The team, together with Dr Tony Scott (right).

How we work now

Things have not quietened. Our company is thriving. We conference call every day. We meet in our own respective locations and we work just as hard on our private company as we do in our day jobs. We scarcely believe the changes that have occurred in less than a few years – we are now directors, entrepreneurs, an scientists, but most of all, close friends. The hours we have worked, the challenges we have faced and the successes we have shared have only helped to strengthen the bonds and make our company stronger. We have great hopes for the future and many goals to fulfil but we are optimistic and enthused.

I once thought science was restricted to a lab and a test tube. But I would like to think that I have found what science really is. It is profound interest and discovery in an area which is in constant flux. How can you get bored with something which is never the same? I am delighted to be studying physics and I am thrilled to be a director of a fun cutting edge company. I could not have done any of this if I had not followed my heart and my instincts. Today, I now realise how simple almost imperceptible decisions in school can cause a ripple effect that will intensely change your future. I guess the chaos effect may have a point after all!!

My one piece of advice to any students at a crossroads in their career decision is choose what interests you. There are days I get a few hours sleep because a presentation for the company has to be finished, a lab report has to be submitted and a flight has to be caught for our next meeting but I don't regret one bit of it because I love every minute of it. If you can find something this interesting to work at, be thankful.

Starting a greener revolution
Working towards a sustainable food supply

Ginny Page

How can we produce more food using less water, fewer chemicals and no more land? Ginny Page investigates.

A farmer plants a new crop in his fields, Vietnam.

Global food fights

Most of us in the UK can't imagine lasting more than a few hours without eating something tasty and don't expect we would ever have to. Plenty of affordable food pours into our shops from all over the world – but will it always be this way?

In 2008 food scarcity led to riots in some countries, and increases in food prices sent shocks around the globe. The world was reminded that producing enough food for our growing population was a challenge we cannot ignore.

Food security is a big issue on the international agenda. It refers to a situation where everyone has continuous access to safe, healthy food. Any major threat to crop production could be a global issue of food security.

As countries develop economically, people increasingly adopt western-style diets with more fast foods, including meat.

Key words
food security
green revolution
sustainability
GM crops

A big challenge

The United Nations predicts there will be about 9 billion people on Earth by 2050. That's 50% more than today's population and millions already go hungry. Also, as some countries become wealthier, more people are expected to adopt a Western diet full of dairy products and meat. It seems the richer we get, the more protein we want on our plate. More animals being farmed means more grain needed to feed them. These changes mean that in the lifetime of today's teenagers the world is probably going to have to increase its grain production by a massive 100% from current levels.

Surely the answer is simply to use more land and grow more crops? Back in the 1960s, a 'green revolution' in the use of industrial fertiliser and pesticides on specially selected crops caused a boom in food production. But in 2010 we are much more aware of how changes in agriculture can risk damaging the environment (see Box). We need a 'greener revolution' for the 21st century.

Food *v.* environment

Plants need nitrogen to grow and its availability is a major factor in growing nutritious crops. Although about 80% of the air around us is nitrogen, most plants can't use it directly and need it in the form of nitrate or ammonium. Farmers have been adding these compounds to soil in the form of manure for centuries, but it wasn't until the discovery of the Haber-Bosch process in 1908 that it became possible for industrial chemists to synthesise nitrogen fertiliser on a grand scale. It may have helped us grow more crops over the last century, but this process demands a lot of energy, using more fossil fuel than any other agricultural practice. Nitrogen fertilisers also cause dangerous pollution when they leach into groundwater, and lead to the release of the greenhouse gas nitrous oxide into the atmosphere. Clearly we need to limit their use.

So how can science help?

Plants are our ultimate source of food because of photosynthesis – the process by which plants convert energy from the sun into a form that animals can eat and use. As with other plants, crops are affected by water availability, soil quality, pests, disease and weed competition. Add in the effects of climate change increasing stresses such as heat, drought, salinity and flooding, and we have a lot of plants under pressure.

We need to identify crop plants that have the capacity to withstand these pressures, and can be grown using sustainable agricultural practices. Do these 'superhero' plants already exist? If they don't, what are the alternatives? Science and technology have important parts to play in the development of a sustainable food supply, but we must not forget the importance of social, economic and environmental factors – see Figure 1.

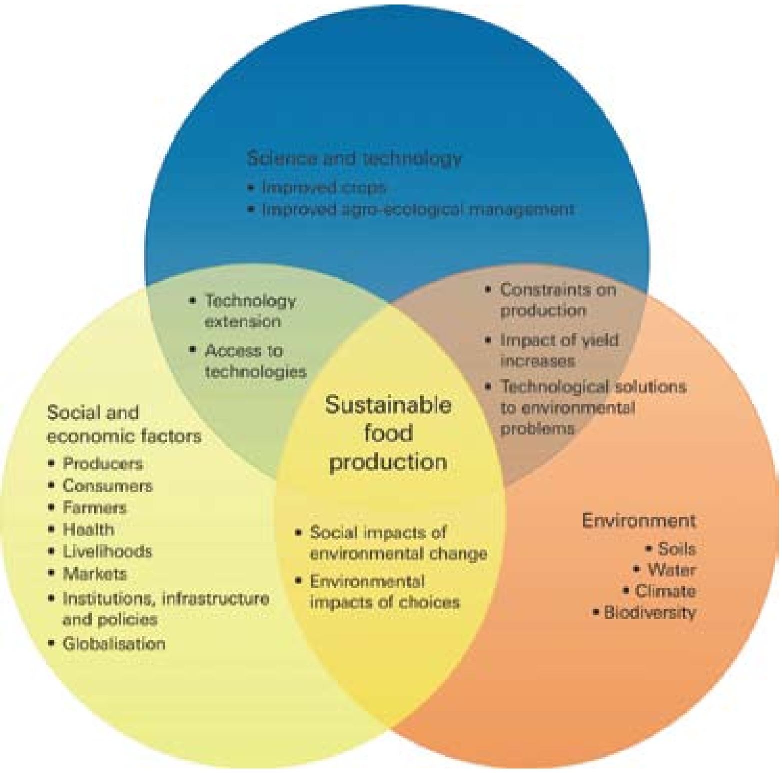


Figure 1 *The factors involved in sustainable food production*

Genetic treasure hunts

Before the days of gene technologies the only way plant breeders could tell whether a plant had a particularly useful gene was to grow it and find out. Much of the time the answer was 'no', or 'not sure', and many months could be wasted. Today we can search for genes by looking at thousands of plants in a single experiment. Once we have found genes for, say, resistance to a fungus in wheat, we can try targeting them in breeding programmes or transferring them into crops using genetic modification (GM).

Wheat blotch, a fungal disease, affects the yield of this important crop.

Current GM technologies involve inserting novel genes into a crop plant of the same species (cisgenic) or another species (transgenic). But the application of GM techniques has been controversial. The only GM crop being grown commercially in Europe is *Bt* maize – the latest version of which contains six genes transferred from the bacterium *Bacillus thuringiensis*. These *Bt* genes produce proteins which are toxic to a range of pests who feed on the maize plants. Some people are concerned that *Bt* maize may pose a threat to the environment or food safety. But as yet there is no scientific evidence to suggest that these threats are any greater than those from using lots of insecticides.

Sometimes we can find useful genes from old varieties of crops that farmers abandoned years ago, or from wild plants. UK scientists have identified a gene from a wild relative of potato that provides resistance against a really nasty strain of potato late blight – one of the most damaging crop diseases in recent history.

Partners in pest control

Millions of hectares of crops are lost to pests and diseases every year. Scientists are exploring ways to manage pests without the need to make genetic changes to crops. In East Africa, life can depend on good maize crops but farmers can lose up to 40% due to moths whose larvae bore into the plant stems.

A collaboration between African and UK scientists has resulted in a 'push-pull' system of pest management making use of other plants which have evolved a range of effective defence mechanisms against the moths. When grown round the edge of the maize field, Napier grass 'pulls' the moths away from the crop because the chemicals it produces are more attractive. It also exudes a substance deadly to the moth larvae if they burrow into its stem. If moths do make it past the border, they can be 'pushed' away from the maize plants by the repellent properties of the silverleaf plant grown in rows between the crop. Silverleaf is a legume so can also enrich the soil by fixing nitrogen.

No single solution

Scientists are working on lots of new ideas at the moment: enabling more plants to form symbiotic relationships with nitrogen-fixing bacteria; developing perennial crops; growing drought-resistant wheat; and computer-designing plants able to thrive in a high CO_2 world. We may not know for another 10 years or more which of these ideas will work best, but we do know none of them will guarantee food security on their own.

A plant scientist at work at the John Innes Research Centre, Norwich, UK.

Difficult decisions, big opportunities

When deciding which technologies we should use, we must compare what costs and benefits they bring to human health, the environment, society, and both local and global economies. Two big questions we need to ask:

- Will the new technology or practice limit risks to the environment and human health?

Even Darwin noticed that his cabbage seed stocks could be contaminated by pollen from purple kale grown nearly half a mile away. Genes move in this way all the time. But what might happen if genes from transgenic crops were transferred into other plants nearby? Whilst there is no evidence to date of GM crops causing environmental damage or harm to human health, existing regulation says that scientists must assess all theoretical risks before releasing any GM plant into the environment.

- Will the new technology or practice bring real benefits to farmers and their families?

More harm than good can result from imposing new technologies on people who are not ready to use them. Scientists need to work alongside farmers to understand their ways of working and learn from their experience so that the research will be of maximum benefit.

There are also concerns about the impacts of businesses in protecting their research investments. By using patents to protect their 'intellectual property', companies may prevent others from understanding their ideas enough to make products more cheaply, or adapt technologies to meet local needs. Where research could lead to benefits for poor people, there are good arguments for it to be funded by organisations not seeking large profits.

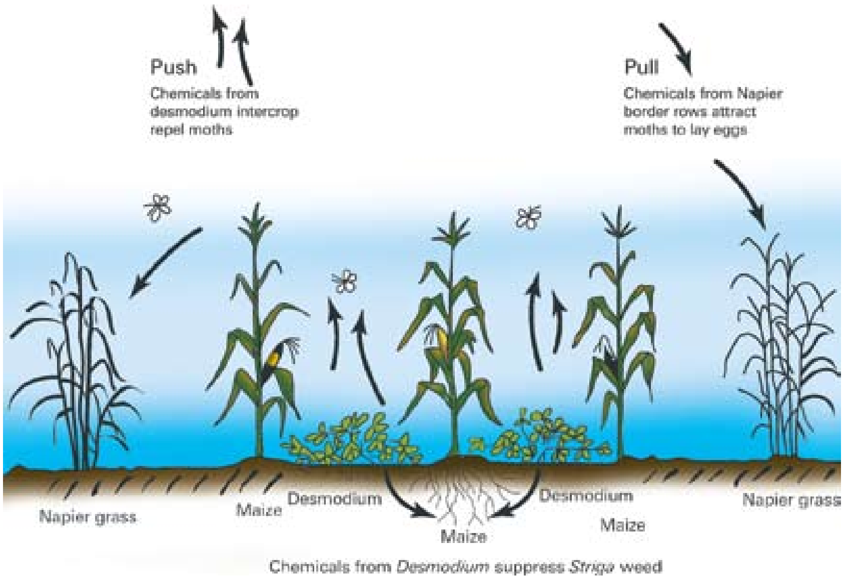


Figure 2 *The push-pull system use in Africa to manage maize pests. Source: The Gatsby Charitable Foundation*

Can we feed the world?

Of course just growing food isn't enough to ensure that hungry people get to eat it. The food has to be harvested, stored and transported from where it is grown to where it is to be eaten or processed without losing its nutritional value. Sometimes that involves many days and thousands of miles. In the case of food aid going to people in countries made desperate by earthquakes or droughts, food can travel across the world only to be stuck on a runway because there are not the roads or trucks to get it to the people who need it.

To really achieve food security as part of a greener revolution we need to involve not just scientists, but many others, from politicians to aid workers, from farmers to business people.

Ginny Page is Director of the Science and Plants for Schools (SAPS) programme and is based in the Cambridge University Botanic Garden. She thanks the Royal Society and the John Innes Centre (JIC) for their help with this article.

Try this!

Look for changes in prices of foods in your local supermarket and see if you can find out why.

Read *The Death of Grass* by John Christopher – a science fiction novel set in a world where a terrible virus is killing off all forms of grass.

Discuss who you think should fund research on new crops, what regulation needs to be in place, if more people should be vegetarian, and whether the only solution to food security is to slow down population growth.

Look here!

Find out more about developments in crop science:

http://royalsociety.org/Reapingthebenefits/
http://www.foodsecurity.ac.uk/
http://www.ukfg.org.uk/

Cristian Bodo

Memories are made of this?

Key words
memory
hippocampus
neuron
laboratory animals

When we think about memory, we tend to assume that ours is not particularly good (if it were, it would not have been that difficult to study for that last exam!). But the fact is that we all have a great memory, and that we use it all the time, to the point that we become unaware of it. Cristian Bodo explains.

When you find your way home after school without even having to think about it, when you recognise other members of your family and when you consider if it is best to stay at home doing homework or to go out with your friends, you are always using bits of information stored somewhere inside your brain that guide your actions and help you make decisions.

Can you imagine what it would be like if they were not there? This is precisely what happened to a man called Henry Molaison who, after a particularly difficult surgical operation in his brain, lost the ability to create new memories (Box 1). Henry would find himself lost all the time, because he could no longer remember how he had arrived at a particular place or recognise where it was. After being introduced to someone, he would start a lively conversation with his new acquaintance, but if the person left the room for a few minutes and then returned, Henry would start to introduce himself all over again. He could not work any more, because he did not remember how to get to his office.

Henry Molaison, whose damaged brain gave scientists insights into how memories are stored.

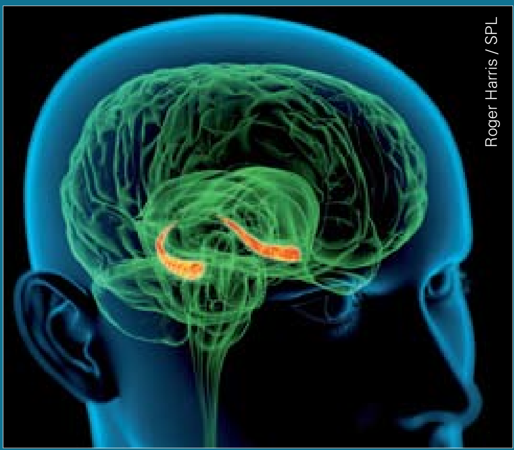
Searching for memories in the brain

Henry's story became famous among scientists who were trying to figure out how memory works. They all agreed that *something* had to change inside our brain every time that we commit something to memory, even when we do it unconsciously. This 'memory trace' has to remain there so that we can retrieve that particular piece of information when we need it. This can happen after just a few hours or after years, or even decades. However, what is it that changes exactly, and where in our brain are these memory traces stored?

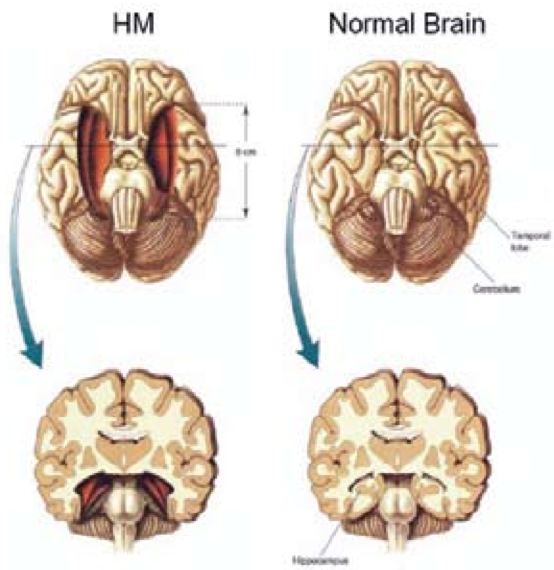
Although brain scientists have been working on this for a long time, we still don't have definite answers to these questions. We think that the **hippocampus** (Greek for seahorse, because its discoverer thought that it looked like one of those

Box 1 The hippocampus

The hippocampus is a brain structure belonging to the limbic system, present in humans and other mammals. It is a 'paired' structure, meaning that it is composed of two mirror-image halves in the left and right sides of the brain. Scientists have found that it works as a memory recorder, allowing us to store memory traces of what we see, hear, taste or feel, that we can later use to remember our past experiences. But no one knows for sure yet what these memory traces look like, or where in the brain they are being stored.



creatures) (Box 1) is essential for storing new memories. In fact, the hippocampus was precisely the part of the brain that got damaged the most during Henry's brain surgery, and so he provided an important clue to the people that were trying to understand memory. He had little problem remembering things that he had committed to memory before the operation, so it looked as if the hippocampus was essential to store new memory traces, but it was not the place of storage itself.



Henry Molaison's brain (on the left), showing the damage he suffered as a result of an operation, compared with a normal brain.

Non-human animal models in memory research

One problem with studying how memories are created in humans is that we have limited access to our own brain: the procedures that are required to obtain tissue samples are likely to cause permanent damage to our brain structures. That is why lab animals have proved to be so useful in memory research. Non-human animals use their memory for their survival in the wild: they need to remember how to get to their lairs, where to find food, what is good to eat and what is poisonous, who are their relatives or members of their group and what their predators look like.

This natural ability to remember things that are important to them can be used by scientists in the lab. If an animal is offered a reward such as a piece of candy each time it performs a task, it will quickly memorise how to complete the task. By comparing the brains of rodents (rats and mice) before and after they have learned a particular task, the scientists have looked at differences in structure, in the pattern of connection between neurons and in electrical activity.

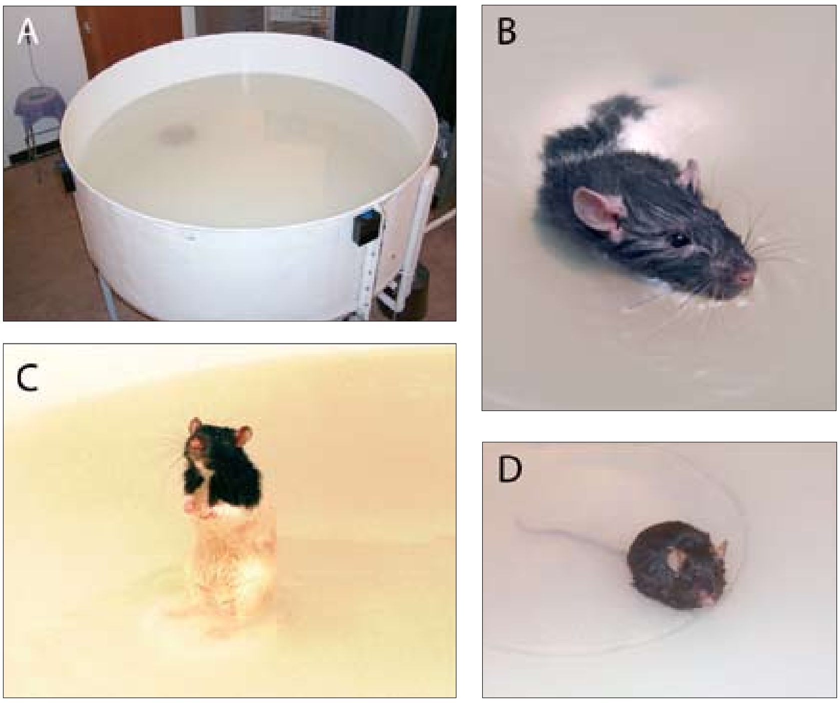
One common task that lab animals will perform is the 'water maze'. This consists of a big circular pool, filled with cloudy water and with a small platform hidden somewhere under the surface. Rodents don't like to swim, and so they want to find the platform to stand on when you put them in the pool. Since they cannot see it, at first they search at random, but they gradually learn how to locate it using cues in the environment.

This test is useful to measure 'spatial memory', the kind that helps you to find your bearings on a familiar environment. After some time the animal is put back in the tank without the platform but it will look for it where it originally was. Animals with experimentally impaired memory simply search at random, having no memory of the earlier training.

Using this method it was discovered that a substance called glutamate, produced by neurons, is essential for creating new memories. When glutamate was blocked in the brains of experimental animals, they became incapable of

A water maze; the mouse learns to swim to the platform using the surrounding objects to orient itself; the overhead camera records its route.

storing simple memories and learning new tasks, while those in the control group had no problem doing this. Furthermore, by looking closely at the brain circuits in the two groups, scientists discovered that glutamate helped to store new memories by strengthening the connections between the neurons. This in turn suggested to them that the strength of the connections between individual neurons may be a good indicator of how vivid a memory is, or how hard it is to lose it.



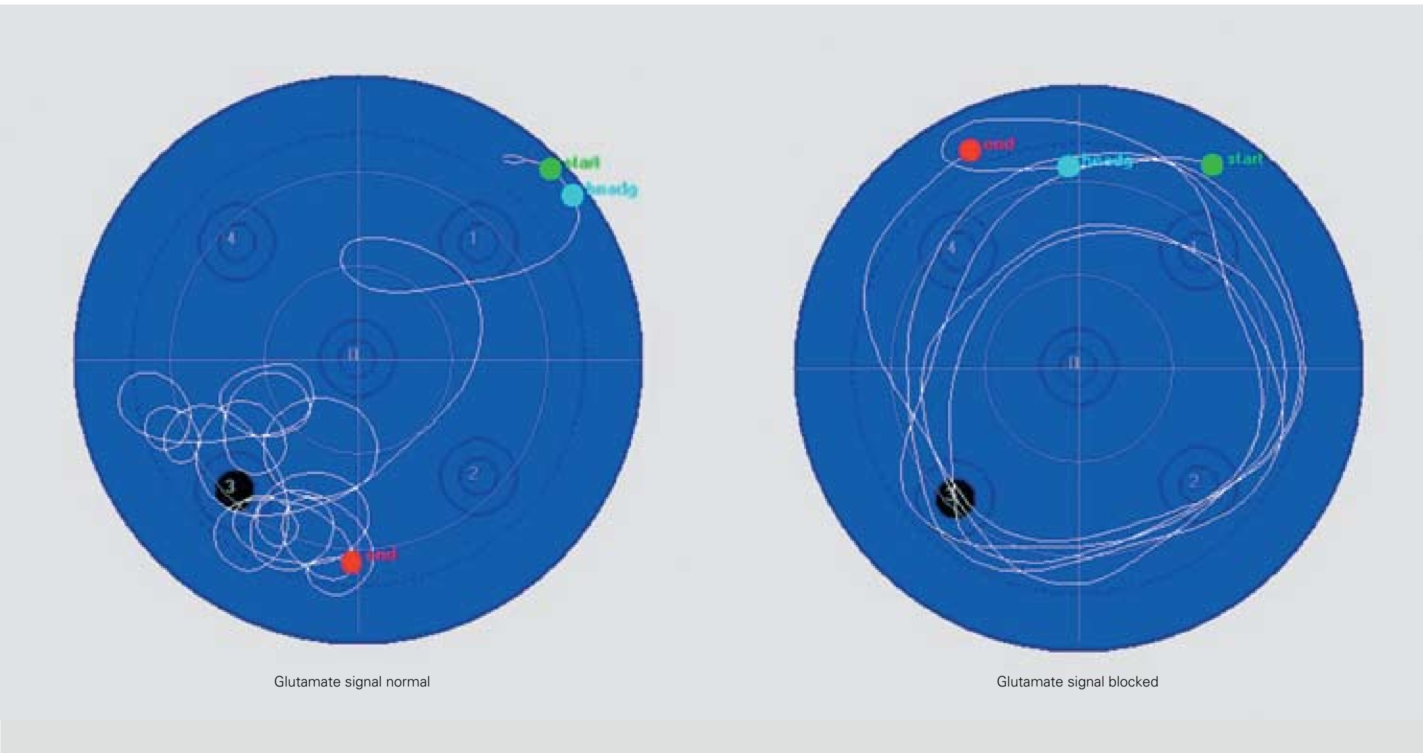
A *A typical water maze, 2 m diameter. The 'hidden' platform is visible from this angle but cannot be seen from water level.* ***B*** *A rat swimming in the pool.* ***C*** *A rat that has reached the platform and is looking around at external cues.* ***D*** *A mouse on the platform. The hidden platform is usually made bigger for mice so that they can find it more easily. The key point about the water maze is that the animals have to use 'spatial memory' to find the hidden platform.*

Why do we study memory?

The ability of the brain to create new memories based on our sensory perceptions is essential to live our lives and to function in a society. Imagine how terrifying it would be to suddenly find yourself in a place that you don't recognise, surrounded by complete strangers, without a clear idea of who you are, why you are there and what you are supposed to do next. And yet, this bleak scenario often becomes a reality for millions of people all over the world.

Our memory system is regularly targeted by several neurodegenerative (nerve destroying) diseases. Alzheimer's disease is the most famous and widespread of them. They leave patients in a state of great vulnerability as they progress. Since this disease becomes more common in old age, and people tend to live longer nowadays, the number of individuals affected is expected to increase in the future. That is why it is so important to find answers to our questions about memory. Therefore, not only is it interesting in itself, because it can potentially teach us something fundamental about how we function and who we are, but it can also help us to develop more effective therapies to fight these diseases.

Cristian Bodo works for the scientific journal Nature Reviews Neuroscience



Results of an experiment in which normal mice and those with the glutamate signal blocked were put in a water maze. The mice had already been trained to find the platform earlier but the glutamate blocked ones just forgot and swam around in circles!


dario diament/bigstockphoto.com

Christopher Lloyd

The species that changed the world

Are you special? Does knowing you are human make you feel superior to other forms of life on Earth? In a list of the world's most successful biological species, would Homo sapiens come top? Christopher Lloyd says it's time we took our place in the league table of life.

I suspect most of us think, at least sub-consciously, that being human makes us rather different from other living things. Just take a look at the world all around. What other species could build a city, repair a broken arm or walk on the Moon? While the evolutionary behaviour of non-human life may be very impressive when it comes to survival in the wild, nothing natural seems to compare with humanity for constructing a world that has truly transformed life on Earth.

What is history?

History is the study of the past only in so far as it concerns *people*. Traditionally, it begins with the earliest civilisations several thousand years ago, even though this represents just 1% of the actual time us hominids have walked the Earth. The planet and other life seldom get a look in.

The challenge of presenting a different view of life drove me to write a world history – one that surveys the history of life from the dawn of evolution to the present day as seen through the lens of 100 different life-forms.

The first half of *What on Earth Evolved? 100 Species that Changed the World* surveys the mechanics of life before mankind, from its earliest replicating molecules in bacteria to the rapid radiation of mammals following the death of the dinosaurs, culminating with the rise of man. Along the way it profiles 50 of the most successful species that emerged as a result of **natural selection** up to the time when prehistoric humans roamed the earth. Fascinating stories affecting planet, life and people abound in species such as influenza, cyanobacteria, slime, sponge, corals, sharks, earthworms, tyrannosaurus, mosquitoes, ants, elephants, rats and humans – to name just a few.


Scott Robert Anselmo

Tyrannosaurus rex – not so dangerous today.

The second part tells the story of how from about 12 000 years ago people introduced new evolutionary forces that were tailored to the creation of human civilisations and societies. From then on the success of many species was based on their ability to impress and accommodate the many needs of humans – from high yielding crops (e.g. wheat, rice, maize) and tame farm animals (e.g. cows, sheep, pigs) to mind-blowing drugs (e.g. cannabis, coca, ergot and poppies), to species that appeal to our senses of sight, taste and smell (e.g. roses, vanilla and lavender). The second part therefore profiles 50 of the most successful species that have thrived in the more modern environment of **artificial selection** up to the present day.

Christopher Lloyd has had a varied career as a historian, a science journalist and a manager of a software company.

Key words

evolution

natural selection

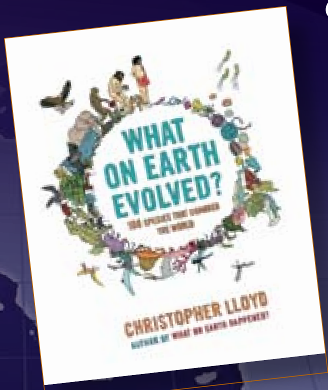
artificial selection

On the next page you can see how Christopher ranked the top 100 species – the species which have had most impact on Earth.

The **league table** of life

Christopher Lloyd's top ten – you can find the complete list at whatonearthevolved.com.

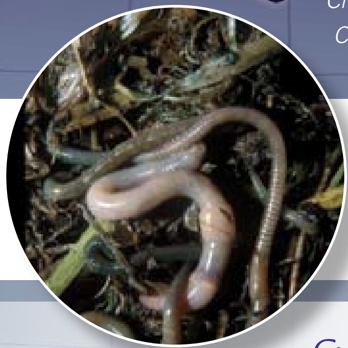
1 Earthworm
2 Algae
3 Cyanobacteria
4 Rhizobia
5 Lactobacillus
6 *Homo sapiens*
7 Stony corals
8 Yeast
9 Influenza
10 Penicillium



Christopher Lloyd's book What on Earth Evolved? 100 Species that Changed the World is published by Bloomsbury.

Christopher Lloyd has ranked the 'top 100 species' – the scores reflect each species' impact on evolution, the biosphere and humanity are considered alongside their global reach and longevity to give a total mark out of 500. He says: "This is not pretending to be science. Rather, it's a personal way of making the point that humans are not necessarily top of the ladder of life, as traditional history suggests."

1
431/500



Where would people be without the constant ploughing of the common earthworm?

3
403/500

Cyanobacteria (blue-green algae) photosynthesise, thus injecting oxygen into the atmosphere.

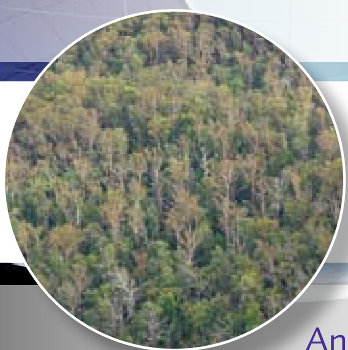
6
393/500

Homo sapiens, number 6 in the league table of life

7
391/500

Corals build vast underwater cities just as impressive as those constructed by man.

16
323/500



Eucalyptus trees dominate the landscape of the Blue Mountains in Australia.

25
291/500

Ants are almost everywhere – only Iceland, Greenland and a few Pacific Islands have none