Spring 2012 Issue 22

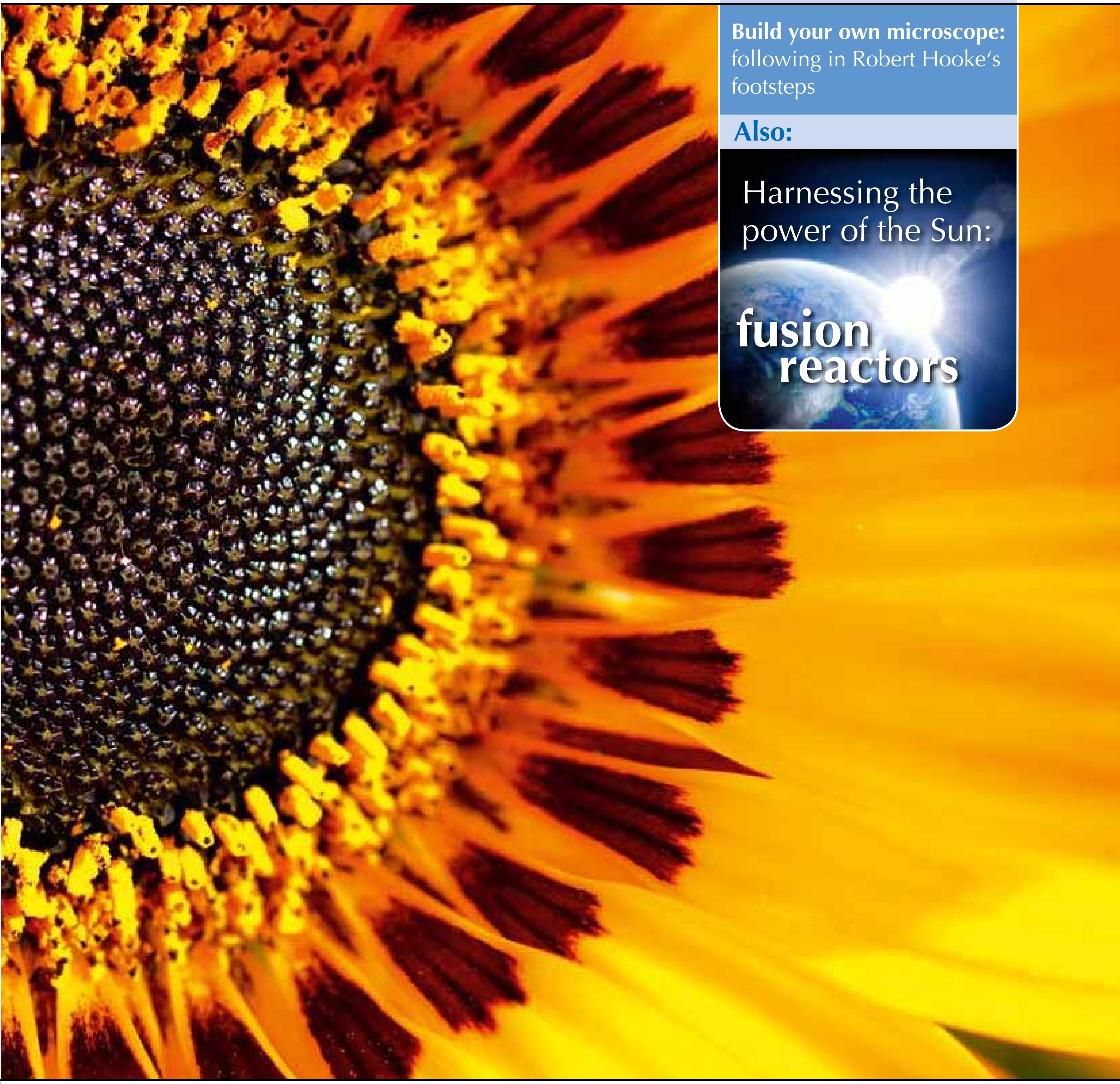
SCIENCE in SCHOOL

The European journal for science teachers

In this issue:

Build your own microscope: following in Robert Hooke's footsteps

Also:



Published and funded by EIROforum

Editorial

TV detectives often rely on genetic fingerprinting to track down criminals, but what is the science behind the technique? Find out in this issue of *Science in School* and learn how to do genetic fingerprinting at school (page 49). One of the marvels of forensic science is that it requires only very small samples – and the same is true of microscopy. Did you know that you can easily build your own microscope, following in the footsteps of 17th century scientist Robert Hooke (page 29)? If this inspires you to build more equipment, you could construct a paper rocket, launch it and analyse its flight (page 36).

Another person casting their eyes to the heavens is space scientist Maggie Aderin-Pocock, who regularly shares her love of astronomy with young people (page 6). During her frequent school visits, Maggie finds that "the main challenge is trying to get people to realise that science is for everybody." One group that needs no convincing are the participants in the European Union Contest for Young Scientists (online article), the winners of which receive generous prizes from EIROforum, the publisher of *Science in School*. In October 2011, EIROforum also demonstrated its commitment to science education by giving hands-on experience of scientific research to 30 European school teachers (see online article). To learn more about recent research and education activities at the EIROforum members, see page 2.

The research institutes that constitute EIROforum cover a wide range of science areas, from molecular biology to astronomy, from particle physics to materials science. One such topic is fusion energy, a promising source of energy being investigated at EFDA. Christine Rüth from EFDA explains how a fusion reactor works and what the technical challenges are (page 42).

Another promising source of energy is hydrogen – indeed, hydrogen-powered cars are already on the market. Did you know that one potential source of hydrogen is an anaerobic bacterium (page 12)? One advantage of hydrogen as an energy carrier is that it can be synthesised in remote areas, but given this bacterium's preference for high temperatures, this could be a challenge in places like the remote Antarctic. In fact, just staying alive there is a challenge, although that has not deterred an intrepid group of Spanish researchers from returning every year to study permafrost and global warming (page 17).

From the far south, we jump to the far north to learn about Denmark's most innovative school, where science is taught not in laboratories but in open spaces (see online article). If that is good science, does bad science also have a place at school? And how do you tell the difference on the basis of media reports? Find out on page 23.

Finally, we are making every effort to continue the print version of *Science in School*, but we still need your help. Donating via the Paypal button on our website is simple, and every cent we receive goes towards printing and distribution. See: www.scienceinschool.org/donation

Eleanor Hayes
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To learn how to use this code, see page 57.

About *Science in School*

The European journal for science teachers

Science in School is the **only** teaching journal to cover all sciences and target the whole of Europe and beyond. Contents include cutting-edge science, teaching materials and much more.

Brought to you by Europe's top scientific research institutes

Science in School is published and funded by EIROforum (www.eiroforum.org), a partnership between eight of Europe's largest intergovernmental scientific research organisations.

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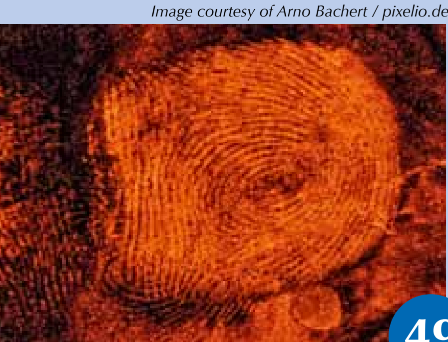

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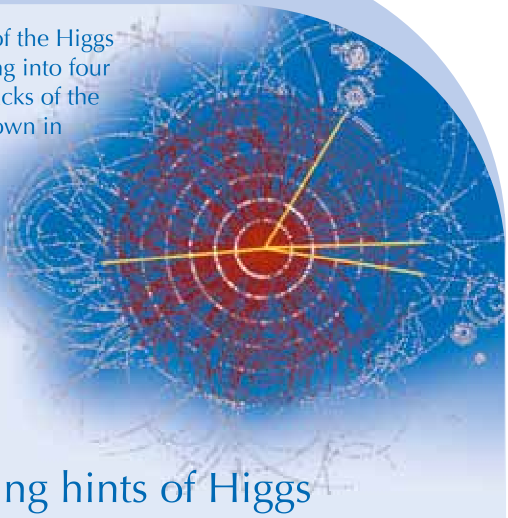
Forthcoming events for schools: **www.scienceinschool.org/events**

To read the whole issue, see: **www.scienceinschool.org/2012/issue22**

To learn how to use this code, see page 57.

Black holes, magnetism and cancer

Image courtesy of CERN



A simulation of the Higgs boson decaying into four muons; the tracks of the muons are shown in yellow

CERN:
Tantalising hints of Higgs

The hunt for the Higgs boson has entered its decisive phase, as announced in a seminar on 13 December 2011. If they exist, Higgs bosons are short-lived and decay in many different ways. Both ATLAS and CMS, the two largest experiments at CERN's Large Hadron Collider (LHC), have observed an excess of gamma rays (highly energetic photons) in the mass region where the Higgs boson would be expected to register.

However, even the 500 trillion proton–proton collisions observed in each experiment – thanks to a brilliant performance of the LHC during 2011 – are not enough. With a statistical significance between two and three standard deviations, the signals do not yet allow the scientists to claim that they have finally discovered the long sought-after particle.

About four times more collisions will be needed to finally conclude whether the Higgs boson exists. If all goes well, the LHC will provide these data by the end of 2012, when it will become clear if the standard model of particle physics can be considered complete.

To learn more, see the press release:

http://press.web.cern.ch/press/PressReleases/Releases2011/PR25.11E.html

To find out more about the LHC, see:

Landua R, Rau M (2008) The LHC: a step closer to the Big Bang. *Science in School* **10**: 26-33. www.scienceinschool.org/2008/issue10/lhcwhy

Landua, R (2008) The LHC: a look inside. *Science in School* **10**: 34-45. www.scienceinschool.org/2008/issue10/lhchow

Based in Geneva, Switzerland, CERN is the world's largest particle physics laboratory. To learn more, see: www.cern.ch

For a list of CERN-related articles in *Science in School*, see: www.scienceinschool.org/cern

EFDA-JET:
A snowball in hell

During the recommissioning of the Joint European Torus (JET) after an 18-month refurbishment period, scientists have injected the proverbial snowball into hell. The snowball in question is a 3 millimetre pellet of frozen deuterium, at approximately -260 degrees Celsius. Hell is the plasma inside JET, ionised deuterium gas at about 100 million degrees Celsius. These experiments are part of the quest for nuclear fusion, an energy source based on nuclei colliding and coalescing into heavier elements.

Surprisingly, contrary to popular legend, the 'snowball' has a significant effect on 'hell'. The pellet injection system is designed to prevent plasma instabilities in which the hot gas momentarily escapes its magnetic cage, diffusing a lot of energy and many of its constituent particles. The injection of a cold pellet actually triggers instabilities as well, but if pellets are injected at regular intervals, scientists have found that the many small instabilities produced reduce the number of large instabilities, thereby allowing the plasma pulses to operate for longer.

The way is now clear to begin the process of slowly turning up the new heating systems to test the many other new components.

To find out more, see:

Rüth C (2012) Harnessing the power of the Sun: fusion reactors. *Science in School* **22**: 42-48. www.scienceinschool.org/2012/issue22/fusion

Situated in Culham, UK, JET is Europe's fusion device. Scientific exploitation of JET is undertaken through the European Fusion Development Agreement (EFDA). To learn more, see: www.efda.org

For a list of EFDA-JET-related articles in *Science in School*, see: www.scienceinschool.org/efdajet

Image courtesy of EFDA-JET

Essentially, this equipment is a gas-powered machine gun capable of firing up to 50 small frozen pellets of deuterium fuel per second into the hot plasma

Science in School is published by EIROforum, a collaboration between eight of Europe's largest inter-governmental scientific research organisations. This article reviews some of the latest news from the EIROforum members (EIROs).

Image courtesy of André-Pierre Olivier

EMBL:
Cancer research for schools

On 9 December 2011, more than 200 enthusiastic pupils and teachers gathered at the European Molecular Biology Laboratory (EMBL) for the EMBL Insight Lecture 2011. To celebrate the International Year of Chemistry, Maja Köhn, who works in the highly interdisciplinary field of chemical biology, gave a lecture on 'Chemistry and biology – strong allies in the fight against cancer'.

Her cross-disciplinary team of organic chemists and molecular biologists works on designing molecules that inhibit proteins involved in disease mechanisms. The scientists want to understand the role of phosphatases in cancer metastasis, the molecular mechanisms leading to disease and how the activity of these proteins can be modulated. During her lecture, Maja demonstrated how inhibitors of phosphatases are designed by combining molecular biology, biochemistry and synthetic chemistry.

The EMBL Insight Lectures series is produced by EMBL's European Learning Laboratory for the Life Sciences (ELLS) to inform young people about current trends in life-science research and how this research influences our everyday lives. Maja's lecture is one of a growing list of EMBL Insight Lectures available at: www.embl.org/ells/insightlectures

EMBL is Europe's leading laboratory for basic research in molecular biology, with its headquarters in Heidelberg, Germany. To learn more, see: www.embl.org

For a list of EMBL-related articles in *Science in School*, see: www.scienceinschool.org/embl

ESA:
Take your classroom into space

PromISSe is the fourth European long-duration mission to the International Space Station (ISS), which began on 23 December 2011 with the arrival at the ISS of the European Space Agency's astronaut André Kuipers and his Russian-American colleagues. André and his colleagues will remain in space until mid-May 2012.

During this 148-day mission André is taking part in experiments on human research, fluid physics, materials science, radiation and solar research, mostly in the European space laboratory Columbus. School students can join in too, taking part in many science activities being transmitted from space to classrooms across Europe.

André is also encouraging a new generation of space explorers to stay fit and 'Train Like an Astronaut', with a NASA-led educational programme for 8- to 12-year-olds. Thousands of pupils are invited to perform physical exercises and classroom lessons, competing with teams from around the world.

To learn more about the Columbus laboratory, see:

Wegener A-L (2008) Laboratory in space: interview with Bernardo Patti. *Science in School* **8**: 8-12. www.scienceinschool.org/2008/issue8/bernardopatti

For more details of the in-orbit demonstration for children, see: www.esa.int/SPECIALS/PromISSe/SEMU1FJ37SG_0.html or use the direct link: http://tinyurl.com/7y7ahy9

To find out more about the 'Train Like an Astronaut' project, see: www.esa.int/SPECIALS/PromISSe/SEMK0FJ37SG_0.html or use the direct link: http://tinyurl.com/76hk2vy

ESA is Europe's gateway to space, with its headquarters in Paris, France. For more information, see: www.esa.int

For a list of ESA-related articles in *Science in School*, see: www.scienceinschool.org/esa

ESA astronaut André Kuipers with an experiment to demonstrate properties and behaviour of wet foams in space

Image courtesy of ESA

Image courtesy of ESO / MPE / Marc Schartmann

A simulation of how the gas cloud approaching the supermassive black hole may break apart over the next few years. The remains of the gas cloud are shown in red and yellow, with the cloud's orbit marked in red. The stars orbiting the black hole are also shown along with blue lines marking their orbits. This view simulates the expected positions of the stars and gas cloud in the year 2021

ESO:
Doomed cloud approaches black hole

Astronomers using the European Southern Observatory's Very Large Telescope have discovered a gas cloud with several times the mass of Earth accelerating fast towards the black hole at the centre of the Milky Way. This is the first time ever that the approach of such a doomed cloud to a supermassive black hole has been observed.

Over the past seven years, the speed of this gas cloud has nearly doubled, reaching more than 8 million kilometres per hour. In mid-2013 it will pass at a distance of only about 40 billion kilometres from the event horizon of the black hole. In astronomical terms, this is an extremely close encounter with a supermassive black hole. The cloud's edges are already starting to shred and disrupt and it is expected to break up completely over the next few years.

"The idea of an astronaut close to a black hole being stretched out to resemble spaghetti is familiar from science fiction. But we can now see this happening for real to the newly discovered cloud. It is not going to survive the experience," explains Stefan Gillessen of the Max-Planck Institute for Extraterrestrial Physics, the lead author of the paper describing the discovery.

To find out more, see the press release (www.eso.org/public/news/eso1151) or the research paper:

Gillessen S et al. (2012) A gas cloud on its way towards the supermassive black hole at the Galactic Centre. *Nature* **481**: 51-54. doi: 10.1038/nature10652

Download the article free of charge on the *Science in School* website (www.scienceinschool.org/2012/issue22/eiroforum#resources), or subscribe to *Nature* today: www.nature.com/subscribe

ESO is the world's most productive astronomical observatory, with its headquarters in Garching near Munich, Germany, and its telescopes in Chile. For more information, see: www.eso.org

For a list of ESO-related articles in *Science in School*, see: www.scienceinschool.org/eso

ESRF:
The chemistry of attraction: magnetism

A problem that has puzzled scientists for 70 years has finally been solved. Magnetite – the most magnetic of all minerals – stops conducting electric currents at low temperatures, a discovery made in 1939 by Dutchman Evert Verwey. The reasons remained controversial until a group of scientists working at the European Synchrotron Radiation Facility (ESRF) fired an intense X-ray beam at a tiny, perfect crystal of magnetite at very low temperature. They observed a subtle rearrangement of the mineral's chemical structure, trapping electrons within groups of three iron atoms, inhibiting them from transporting an electrical current.

Magnetite (Fe_3O_4) was discovered more than 2000 years ago. It gave rise to the original concept of magnetism and was used to build the first magnetic compass. When it crystallises from volcanic magma, magnetite conserves the direction of Earth's magnetic field, which was key to the discovery that this field had reversed direction in the past. Tiny crystals of magnetite are also found in insect and pigeon brains and are thought to play a role in these animals' ability to fly back home over long distances.

To find out more, see:

Attfield JP (2011) Condensed-matter physics: A fresh twist on shrinking materials. *Nature* **480**: 465–466. doi: 10.1038/480465a

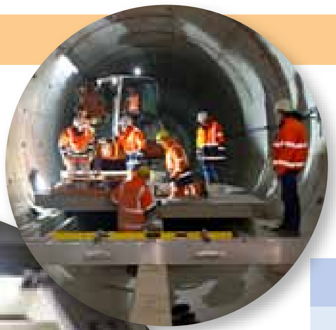
Download the article free of charge on the *Science in School* website (www.scienceinschool.org/2012/issue22/eiroforum#resources), or subscribe to *Nature* today: www.nature.com/subscribe

Situated in Grenoble, France, ESRF operates the most powerful synchrotron radiation source in Europe. To learn more, see: www.esrf.eu

For a list of ESRF-related articles in *Science in School*, see: www.scienceinschool.org/esrf

The scientists watching magnetite crystals

Image courtesy of Ana Wright



The ongoing tunnel floor installations

Images courtesy of European XFEL

European XFEL: Building the world's largest X-ray laser

The year 2011 has shown good progress on the construction and development of what will be the world's most brilliant source of ultra-short X-ray pulses. The European XFEL will offer new insights into the nanoworld, revealing the structures of biomolecules and allowing chemical reactions to be 'filmed'.

With most of the tunnel boring completed, tunnel builders have started to put in the concrete floor elements. All told, the facility is 3.4 kilometres long and has 5.7 kilometres of underground tunnels. The tunnel for the linear accelerator, which will speed electrons up to very high energies, is now ready for the installation of technical equipment.

At the far end of the accelerator, the tunnel splits into a number of smaller tunnels, where X-ray light flashes will be generated by forcing the electrons on a tight slalom course through a line of magnets called undulators. The first prototypes of the undulator segments have been delivered. Significant milestones have been reached in the development of the instruments that scientists will use to carry out their experiments and of other technical equipment. European XFEL expects to start operation in 2015.

European XFEL is a research facility currently under construction in the Hamburg area in Germany. It will generate extremely intense X-ray flashes for use by researchers from all over the world. To learn more, see: www.xfel.eu

ILL: Symmetry in quasicrystals

Discovery of colloidal quasicrystals with small-angle neutron scattering: the 12-fold diffraction symmetry of a quasicrystalline micellar phase and the corresponding tiling pattern showing the position of the micelles

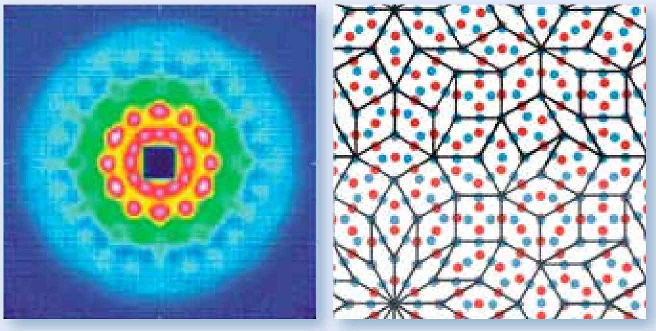


Image courtesy of instrument D11 / ILL and Stephan Förster / Universität Bayreuth

ILL is an international research centre at the leading edge of neutron science and technology, based in Grenoble, France. To learn more, see: www.ill.eu

For a list of ILL-related articles in *Science in School*, see: www.scienceinschool.org/ill

EIROforum

EIROforum combines the resources, facilities and expertise of its member organisations to support European science in reaching its full potential. To learn more, see: www.eiroforum.org

For a list of EIROforum-related articles in *Science in School*, see: www.scienceinschool.org/eiroforum

To browse the other EIRO news articles, see: www.scienceinschool.org/eironews

To learn how to use this code, see page 57.

Image courtesy of ESO / S Gillessen et al.

Maggie Aderin-Pocock: a career in space

Image courtesy of ESO / F Marchis, M Wong, E Marchetti, P Amico, S Tordo

Image courtesy of Paul Nathan

Maggie visiting a solar array

Saturn, as viewed in visible light

Image courtesy of ESO / University of Oxford / LN Fletcher / T Barry

As a child, Maggie Aderin-Pocock dreamed of going into space. She hasn't quite managed it yet, but she's got pretty close, as she tells **Eleanor Hayes**.

Are you ready for a tour of the Universe? Strap on your helmet and we'll dim the lights.

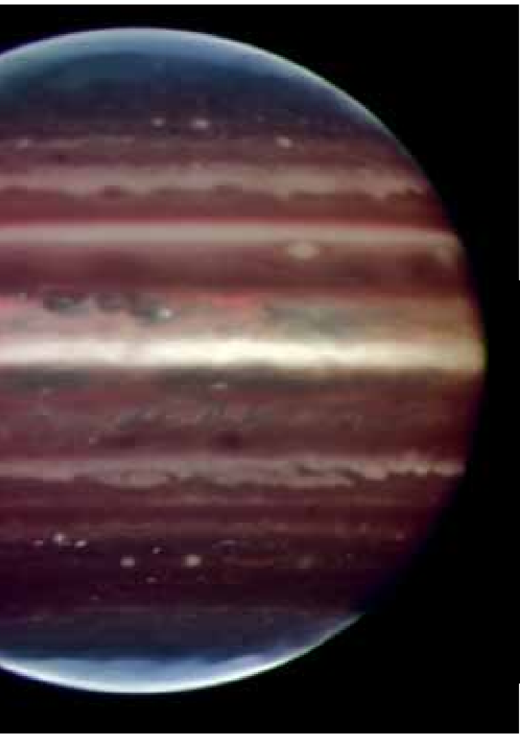
Over the course of the next hour, we'll be travelling far across the Solar System, across our galaxy and even beyond. As we leave Earth behind us, we'll look back and marvel at our own planet and its watery surface before whizzing off to orbit the Moon and see how very different it is. Then we'll take a trip to the centre of the Solar System and examine the Sun before visiting Venus, Mars and Jupiter. We'll take a close look at the rings of Saturn before ending up on Pluto. From there, we'll leave the Solar System behind us and visit some of the other stars in the night sky, until we reach the very edge of our galaxy. There, we'll use the latest technology on board the Hubble space telescope to see what's at the end of the Universe and try to calculate how many galaxies there are, and the probability of there being life out there.

All set for take-off? 3-2-1 and we're off!

This may sound like fantasy, like a once-in-a-lifetime dream, but Maggie Aderin-Pocock has taken this tour regularly over the past five years, guiding children as young as four years old through the wonders of our Universe. From the safety of their classroom, they are whirled away on a simulated journey through space and time, transported only by an interactive computer programme[w1] and Maggie's boundless enthusiasm.

Space scientist Maggie has many demands on her time – developing instruments for space satellites, filming with the BBC and, since March 2010, looking after her daughter Laurie. But she still makes time to visit schools around the UK.

"I like to have aspects in my talk that will appeal to girls and aspects that will appeal to ethnic minorities, but the main challenge is trying to get people to realise that science is for



Jupiter, as imaged in infrared light with ESO's Very Large Telescope

A thermal-infrared image of Jupiter with its moon Io (left in this image), taken with ESO's Very Large Telescope

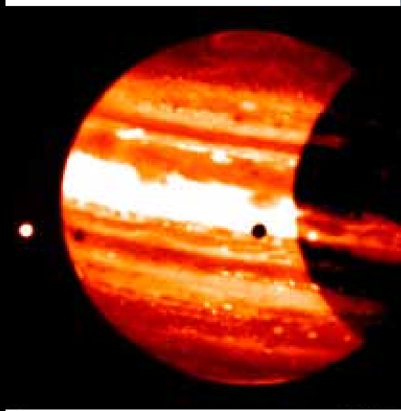


Image courtesy of ESO

Image courtesy of ESO / S Gillessen et al.

The centre of our Galaxy, the Milky Way, as observed in the near-infrared with the NACO instrument on ESO's Very Large Telescope

everybody. Anyone who's inquisitive is effectively a scientist – you don't have to have a bowtie or mad hair.

"I also try to show that if you look back in history, all cultures have been interested in astronomy. I talk about Stonehenge[w2] in the UK and about a stone circle in southern Egypt – Nabta Playa[w3], one of the oldest stone circles in the world, from about 6000 BC. Both are ancient astronomical constructions, which show that people across the world have looked up at the night sky and wondered what's out there[w4]."

What advice does Maggie offer the young scientists she meets on her school visits?

"My advice is to find out what you're really interested in and pursue that, but to be aware of other scientific areas, too. As scientists, we can be very linear, pursuing one course of research in great detail, but by looking around you may find other fields of science that can enhance your research. Some of the greatest insights and the greatest scientific discoveries will be made where the sciences overlap."

Nobody could accuse Maggie of having had a linear career. As a young child, she was captivated by a library book with an astronaut on the front cover and dreamed of being an astronaut too – but her route into space science was anything but direct.

"I suffer from dyslexia, so I wasn't very good at English or history at

REVIEW

- **Physics**
- **Space science**
- **Careers in science**
- **Women in science**
- **Science around us**
- **Ages 14+**

This is a very interesting article about the fabulous and dynamic life of a modern-day scientist. It may best be linked to the physical sciences, but it can also be used very easily in a multidisciplinary context.

It shows how important it is for us teachers to inspire our students to imagine and dream. I feel that as science teachers, we should provide a fertile environment for them to do so; we should provide situations and information that evoke students' interest while helping them to base their dreams on facts rather than fiction.

This article is very suitable for discussions, for example, on possible careers in science, on scientists as real people, on the characteristics and traits of scientists and on women in science. It can also be used to illustrate how scientific principles and concepts can be linked to countless applications around us.

I hope that Maggie will someday manage to go into space and that all our students fulfil their dreams.

Paul Xuereb, University Junior College, Malta

Image courtesy of ESO / S Gillessen et al.

Neptune, as imaged with the NASA / ESA Hubble Space Telescope

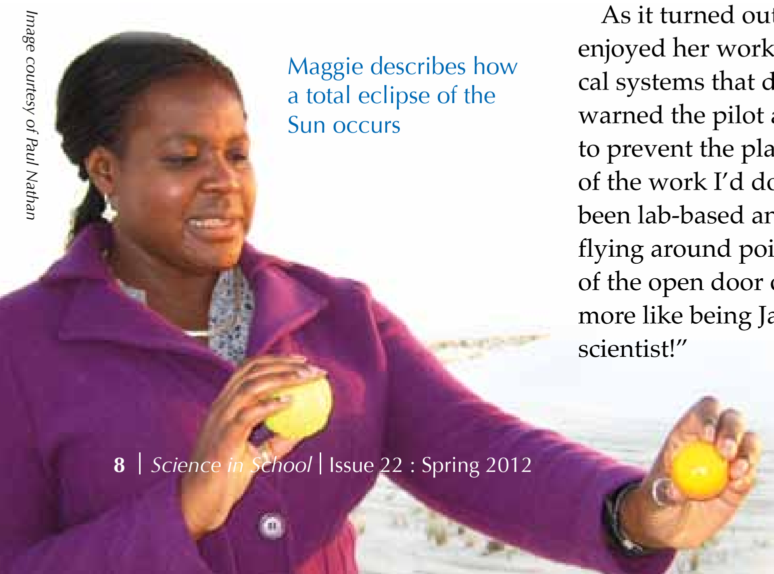
Image courtesy of NASA, ESA and the Hubble Heritage Team (STScI / AURA)

ESO's Paranal Observatory in Chile, where astronomers were observing the centre of the Milky Way using a laser beam

Image courtesy of G Hüdepohl

Image courtesy of ESO / Y Beletsky

school, but I did have an aptitude for science. My father was keen on my studying medicine and I found biology absolutely fascinating, but I decided in the end to study physics." As a student in London, UK, Maggie built her own telescope and began to specialise in optics. Sponsored by major oil companies, she then did a PhD, developing an optical system for looking at engine oils, to enable lubricants to be tested more effectively and cheaply – a system that is still used commercially, more than 15 years later.



Maggie describes how a total eclipse of the Sun occurs

Image courtesy of Paul Nathan

When Maggie entered the job market in 1994 after her PhD, Britain was in the middle of a recession and jobs were hard to find. With some qualms, she took a job at the UK Ministry of Defence. "As a child, I was a pacifist, but my ideas had evolved since then and I had realised that we need some defence. However, during the interview I was told 'we can't tell you what you'll be doing until you sign the Official Secrets Act'. So I turned up knowing that there might be some things I wasn't prepared to do, and that I might have to leave the job before I really started."

As it turned out, Maggie hugely enjoyed her work, developing optical systems that detected missiles, warned the pilot and sent out decoys to prevent the plane being hit. "Most of the work I'd done for my PhD had been lab-based and suddenly I was flying around pointing cameras out of the open door of an aircraft. It was more like being James Bond than a scientist!"

"It was more like being James Bond than a scientist!"

Her next project involved developing hand-held land-mine detectors, which relied on a metal detector, ground-penetrator radar (to trace the rough outline) and nuclear quadropole resonance (to detect explosives). "Land-mine detectors were a very topical subject in the late 1990s because of all the work Princess Diana was doing. For that reason, we got a lot of visits from politicians and I used to try to find interesting ways to tell them about the technology – and that's when I started to think about doing public engagement work."

At that point, though, Maggie's career took another turn. "I'd always wanted to work in space and astronomy and in 1999, a job came up at University College London, managing

The dome of the Gemini South Telescope, reflecting the Chilean sunset

Gemini Observatory / Keith Raybould

Image courtesy of Old Moonraker; image source: Wikimedia Commons

Stonehenge, a prehistoric stone circle that allowed celestial events to be predicted

Image courtesy of Raymbetz; image source: Wikimedia Commons

Nabta Playa, one of the world's earliest known archaeoastronomical devices

a project making bHROS[w5], an optical spectrograph for the Gemini Telescope in Chile." In fact, the job turned out to be a lot more than project management. "I like project management but I really love the hands-on stuff too. At the end of the project, we packed the instrument into 28 boxes and I flew out to Chile myself to construct it at the telescope. Chile is my favourite place on earth: because it's in the southern hemisphere, you can look up into the night sky, right into the heart of the Milky Way. I stayed out there for about nine months. In the end, my husband had to come out and bring me home!"

On her return to the UK in 2004, Maggie moved from building instruments for peering into space to building instruments that actually travel into space. As a project manager at Surrey Satellites[w6] (now part of Astrium), she was responsible for the development of a spectrographic instrument, one small component of the vast James Webb Space Telescope[w7]. A collaboration between NASA, the European Space Agency (ESA)[w8] and the Canadian Space Agency, the James Webb Space Telescope will replace the Hubble Space Telescope and is due to be launched in 2018.

"As a child, I wanted to be an astronaut. I haven't succeeded in doing that (yet!) but being a space scientist is the next best thing because I'm building instruments that go into space. When the telescope is launched, it's going to travel a million miles from Earth and look across the Universe, hopefully giving us a new understanding of what's out there. Being part of such an epic project fills me with joy."

Subsequently, Maggie worked for Astrium on several optical instrumentation projects for ESA and NASA and for ground-based telescopes. Her latest project involved detecting carbon dioxide, as part of a large NASA project. "It's quite challenging. We can detect the absorption characteristics of carbon dioxide, but what we really want to do is to localise the emission of carbon dioxide – to find out where it's coming from and how much there is, so that in future people who release carbon dioxide are taxed for it. Doing that from space makes a lot of sense, but you need to develop very high-resolution detectors."

It was while working for Astrium that Maggie became increasingly involved in science communication. In 2006, with funding from the UK's Science and Technology Facilities Council[w9], she started visiting schools and appearing on television – on a news programme. "I wanted to demonstrate parabolic flight by throwing an apple, but the news crew were a bit perturbed because you don't usually do live demonstrations on the news. In the end, they loved it and I've been asked to do other news programmes since – and I always bring a demonstration if I can[w10]."

Since the birth of her daughter Laurie, Maggie has been taking a break from space instrumentation, but she's still very involved in science communication. "Four days after Laurie was born, I got an email asking me to make a documentary for the BBC. My husband took time off work to look after her and we travelled the world making a documentary called 'Do we really need the Moon?'. Right now, we're filming a second documentary about why we need satellites, and Laurie's travelling with us."

When Laurie is a bit older, Maggie plans to return to space instrumenta-

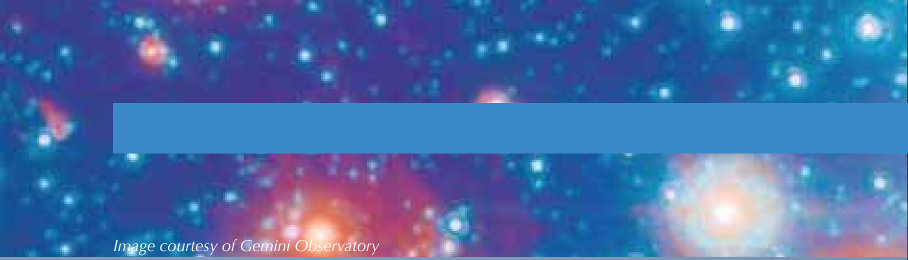
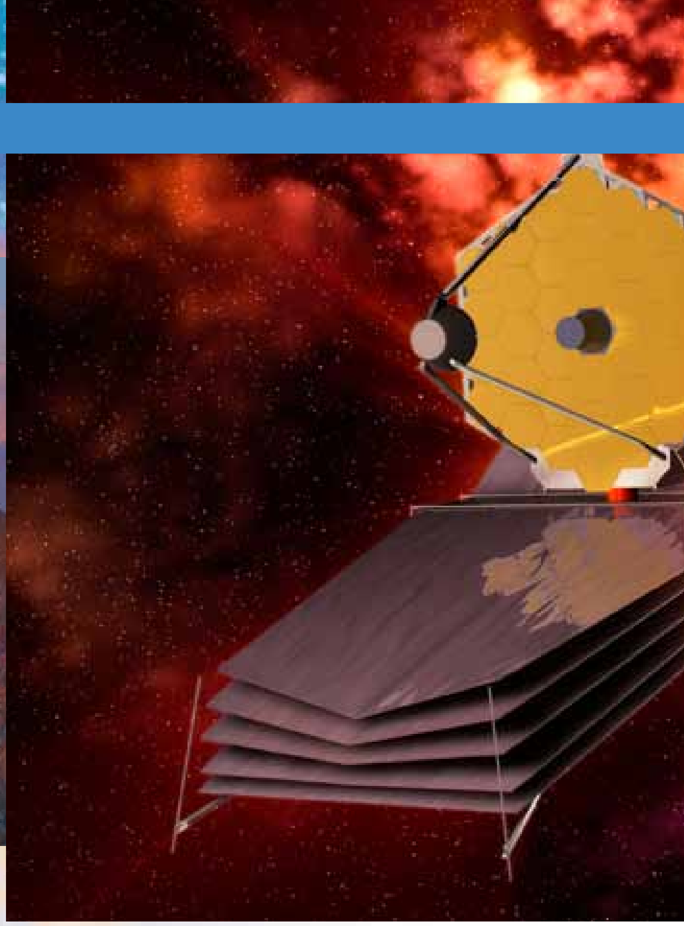


Image courtesy of Gemini Observatory

Sunset over the Gemini South Telescope



tion, but in the meantime she's hoping to be involved in a project for music and literary festivals, looking at the science in Shakespeare's plays. "For instance, in *Romeo and Juliet*, Juliet drinks a potion that makes her appear dead. What was the chemical composition of that potion? Does it really exist? Or when Shakespeare's characters navigate by the stars, which constellations were they using? We can use the plays to see how science has evolved since the 17th century."

Clearly, Maggie does not regret her choice of career. "I'm very lucky to have found work I enjoy so much and that is also so varied – not just building equipment that goes into space but also talking about it. I like to pass on my enthusiasm when I can."

Web references

w1 – Celestia is a free, interactive, 3D astronomy programme that allows you to travel throughout the Solar System, to any of more than 100 000 stars, and even beyond our galaxy. Devise your own tour of the Universe or take tours prepared by other users. See: www.shatters.net/celestia

w2 – Stonehenge near Salisbury, UK, is an enormous stone circle constructed between 3000 and 2000 BC. Archaeologists disagree about the religious significance of the monument, but its design appears to have allowed eclipses, solstices, equinoxes and other celestial events to be predicted. To learn more, see: www.stonehenge.co.uk

To find out more about the 2008 excavation of Stonehenge and for a 360° panorama of the stone circle, visit the BBC website (www.bbc.co.uk) or use the direct link: http://tinyurl.com/55qv67

w3 – To learn more about Late Neolithic astronomy at Nabta Playa, see: www.colorado.edu/APS/landscapes/nabta or use the shorter link: http://tinyurl.com/7pghhsu

w4 – Aimed at young children, *Stories of Stars* is a collection of myths about astronomy, each short story taken from a different culture. To download the illustrated stories (in English, Aragonese, French, Portuguese and Spanish), visit: http://sac.csic.es/unawe/cuentos_cuentos_de_estrellas_eng.html or use the shorter link: http://tinyurl.com/75z92gj

w5 – bHROS is an optical spectrograph, part of the Gemini South Observatory in Cerro Pachón, Chile. To learn more, see the Gemini Observatory website (www.gemini.edu) or use the direct link: http://tinyurl.com/7wwbj7w

w6 – Formed as a spin-off company by the University of Surrey, UK, Surrey Satellite Technology specialises in designing, building and launching small satellites. See: www.sstl.co.uk

w7 – The James Webb Space Telescope will be a large infrared telescope, examining every phase of cosmic history from the first glow after the Big Bang to the formation of galaxies, stars and planets, to the evolution of the Solar System. See: www.jwst.nasa.gov

w8 – ESA is Europe's gateway to space, organising programmes to find out more about Earth, its immediate space environment, our Solar System and the Universe, as well as to co-operate in the human exploration of space, develop satellite-based technologies and services, and to promote European industries. See: www.esa.int

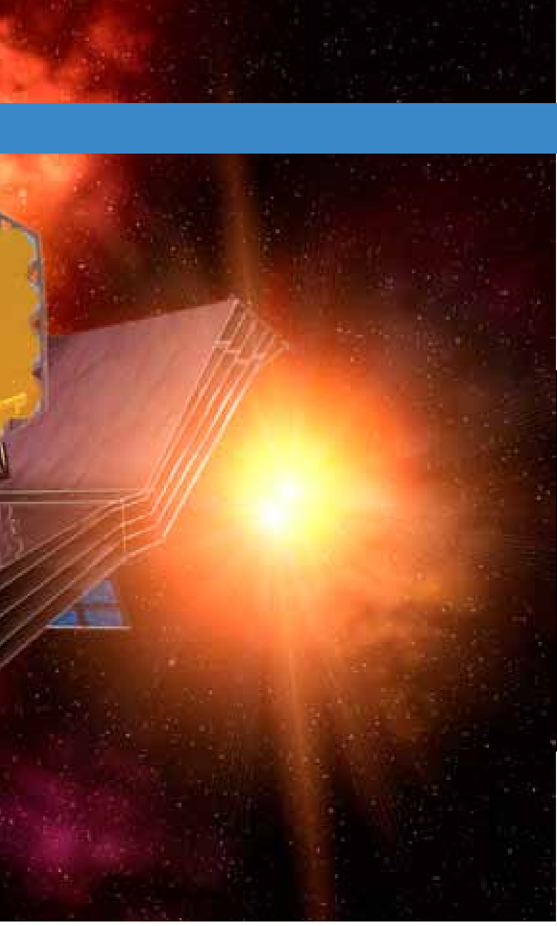


Image courtesy of ESA

An artist's impression of the James Webb Space Telescope, due to be launched in 2018

Mars

Image courtesy of Phil James (Univ. Toledo, USA), Todd Clancy (Space Science Inst., Boulder, CO, USA), Steve Lee (Univ. Colorado, USA), and NASA / ESA

ESA is a member of EIROforum[w11], the publisher of *Science in School*.

w9 – The Science and Technology Facilities Council carries out civil research in science and engineering, and funds UK research in areas including particle physics, nuclear physics, space science and astronomy. See: www.stfc.ac.uk

w10 – For a video of Maggie explaining to Newsnight's Jeremy Paxman why the Moon looks blood red during a lunar eclipse, see: www.bbc.co.uk/news/science-environment-13787011 or use the shorter link: http://tinyurl.com/7v6vxxy

w11 – EIROforum is a collaboration between eight of Europe's largest inter-governmental scientific research organisations, which combine their resources, facilities and expertise to support European science in reaching its full potential. As part of its education and outreach activities, EIROforum publishes *Science in School*. To learn more, see: www.eiroforum.org

Resources

The Celestia Motherlode website offers 12 detailed educational space tours to more than 400 destinations, with student worksheets to complete. See: www.celestiamotherlode.net/catalog/educational.php

The European Southern Observatory (ESO) is the foremost inter-governmental astronomy organisation in Europe and the world's most productive astronomical observatory. Its website offers a wealth of news, images, videos and other material about astronomy, space and the Universe, aimed at schools and the public. See: www.eso.org

ESO is a member of EIROforum[w11], the publisher of *Science in School*.

If you enjoyed this article, why not browse the other feature articles in *Science in School*. See: www.scienceinschool.org/features

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Dr Eleanor Hayes is the editor-in-chief of *Science in School*. She studied zoology at the University of Oxford, UK, and completed a PhD in insect ecology. She then spent some time working in university administration before moving to Germany and into science publishing in 2001. In 2005, she moved to the European Molecular Biology Laboratory to launch *Science in School*.

To learn how to use this code, see page 57.

Image courtesy of janeff / iStockphoto

Hydrogen: the green energy carrier of the future?

Hydrogen may be the fuel of the future, but how can we produce it sustainably? **Karin Willquist** explains.

Hydrogen has been called 'the energy carrier of the future' – because it can be oxidised in a fuel cell to generate electricity, for example to power cars, without releasing carbon dioxide (CO_2), and it can be produced in remote places without an electricity infrastructure. In contrast to available resources such as natural gas and gasoline, hydrogen has to be produced, making it an *energy carrier* and not a fuel.

An energy system in which hydrogen is used to deliver energy – a *hydrogen economy* – was proposed by John Bockris in 1970; in 1977, an international hydrogen implementing agreement was established to work towards it[w1].

Hydrogen is mainly used now as a chemical reagent rather than an energy carrier, but there is no doubt that it has the potential to transform our transport and energy systems. However, realising its potential is not easy. Most fuels currently in use are liquids, solids or gases with high energy per volume (energy density). Hydrogen, in contrast, has a low energy density: at a given pressure, burning one litre of hydrogen produces one third of the energy that burning a litre of methane does. This poses problems of storage, distribution and use that are being addressed by scientists (Schlapbach & Züttel, 2001)[w2]. A more fundamental challenge, however, is that of producing hydrogen in a sustainable manner. This is what I shall focus on here.

Ways to produce hydrogen

Hydrogen is an abundant element on Earth's surface, normally linked to carbon in carbohydrates (in plants) or to oxygen in water (H_2O). Hydrogen gas (H_2), in contrast, exists only in small quantities on Earth. One of the challenges for sustainable hydrogen production is releasing H_2 from its bonds with carbon and oxygen.

Currently, H_2 is produced mainly from fossil fuels (e.g. natural gas) by steam reforming: heating the fuels to high temperatures with water[w2]:

- Biochemistry
- Environmental science
- Biology
- Organic chemistry
- Hydrogen economy
- Energy
- Ages 14-19

REVIEW

Following the publication of Jeremy Rifkin's book on the hydrogen economy (2002), this topic is frequently addressed in media as a real possibility for the near future. Another common issue surrounding hydrogen is its supposed role as a clean energy source. In this article, Karen Willquist offers a thorough overview of the issues involved in hydrogen production and of the ongoing research – including her own work – into sustainable ways to achieve this goal.

Given the author's clear approach, the article is particularly suitable for science teachers and upper-secondary-school students (ages 14-19) wishing to deepen their knowledge of this complex topic. Furthermore, both teachers and students will benefit from the many resources listed.

The article would be relevant for lessons on biochemistry (respiration, fermentation and photosynthesis), physics (fuel cells, thermodynamics: energy and efficiency), environmental science (energy resources, fossil fuels and renewable resources), biology (algae, bacteria, cyanobacteria and Archaea) and organic chemistry (hydrocarbons and steam reforming). It could also provide valuable background reading before a visit to a power plant or research laboratory working on fuel cells or hydrogen production, use or storage.

The article could be used to initiate a discussion on the difference between energy resources and energy carriers; the problems of hydrogen use and storage; and possible scenarios for the transition from our hydrocarbon economy to a hydrogen economy.

Suitable comprehension questions include:

1. Which of the following apply to respiration, to dark fermentation, or to both?
   a) The presence of glucose
   b) The presence of oxygen
   c) The absence of oxygen
2. Which of the following *is not* a process involved in converting acetate into hydrogen?
   a) Dark fermentation
   b) The use of electricity in a microbial fuel cell
   c) The hythane process

Giulia Realdon, Italy

$$CH_4 + H_2O \rightarrow CO + 3H_2 \quad (1)$$
$$CO + H_2O \rightarrow CO_2 + H_2 \quad (2)$$

However, this method relies on fossil fuels and releases CO_2, causing the same emission problems as burning fossil fuels. Steam reforming is only sustainable if renewable hydrocarbons such as biogas are used, because the CO_2 released has previously been absorbed in the production of the hydrocarbons.

H_2 can also be produced by electrolysis[w2], whereby electricity is used to split H_2O into H_2 and oxygen:

$$2H_2O \rightarrow 2H_2 + O_2 \quad (3)$$

This method can be sustainable if the electricity is from renewable resources such as wind, wave or solar power. H_2 can thus be used to store energy on windy days when the windmills produce more electricity than can be consumed.

Interestingly, H_2O splitting occurs naturally in the oceans, because microscopic algae and cyanobacteria use solar energy to split water in a process called biophotolysis (Equation 3). However, the rate of H_2 production is extremely slow.

Efforts have been made to increase the production rate under controlled conditions using modified micro-organisms, but the processes are still too slow and expensive to be a realistic source of H_2 any time soon (Hallenbeck & Ghosh, 2009).

Finally, *biohydrogen* can be produced from crops and from industrial,

Figure 1: *C. saccharolyticus* bacteria under the electron microscope

forestry and agricultural waste, using bacteria. Like us, these bacteria oxidise plant material as a source of energy, but unlike us, they live in anaerobic environments (lacking oxygen). In aerobic respiration, we use O_2 to oxidise sugars, e.g.

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6\,H_2O \quad (4)$$

In contrast, to oxidise the substrate as far as possible and thus optimise their energy gain, these anaerobic bacteria reduce protons, released during substrate oxidation, to H_2 (Equation 6, below).

Hot bugs

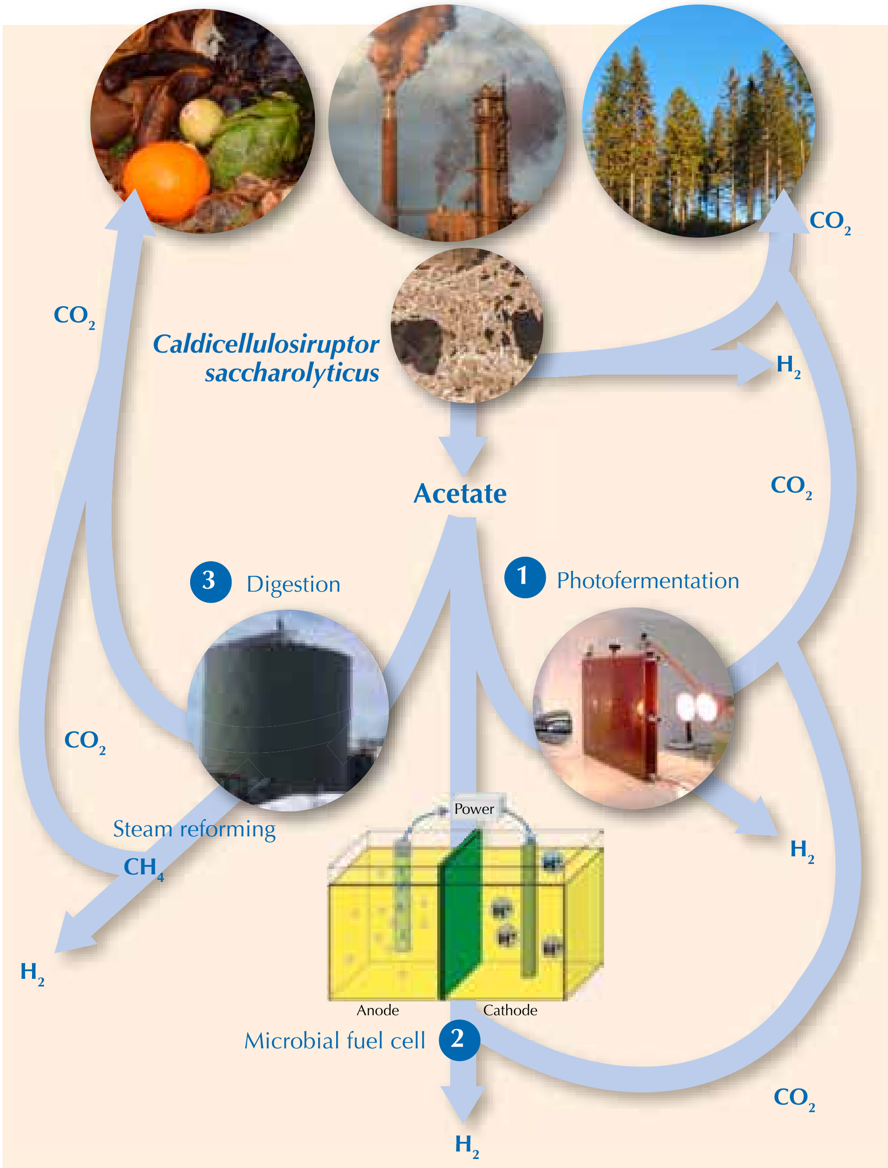
During my PhD, I investigated the hydrogen-producing abilities of one of these bacteria, *Caldicellulosiruptor saccharolyticus* (Figure 1, page 13), which lives in hot springs: anaerobic environments at 70 °C, with low levels of available carbohydrates. This bacterium is of particular interest because it is twice as efficient as most bacteria used for H_2 production.

Unlike humans, *C. saccharolyticus* gains energy from a wide spectrum of plant building blocks: not only glucose, but also, for example, xylose (Willquist et al., 2010). This allows the bacteria to produce H_2 from waste such as that produced during potato, sugar and carrot processing, as well as from industrial waste from pulp and paper production, or agricultural waste such as straw.

This is a promising start, but even *C. saccharolyticus* releases only 33% of the potential H_2 that could be released from the substrate. Equation 5 shows the potential complete oxidation of glucose, releasing $12H_2$ per molecule of glucose. Equation 6 shows the dark fermentation performed by *C. saccharolyticus*, which releases only $4H_2$ (33%) per molecule of glucose. The rest of the energy is released as acetate (CH_3COOH).

Total conversion of glucose to H_2:

$$C_6H_{12}O_6 + 6H_2O \rightarrow 12H_2 + 6CO_2 \quad (5)$$



Images courtesy of Holger / pixelio.de (waste), Michael Cavén (paper factory), Keith Bryant (trees), Marcel Verhaart (C. saccharolyticus), Jakub Cebicki (photobioreactor), Gokce Avcioglu, METU Biohydrogen Research Lab, Turkey (anaerobic digestion reactor) and Karin Willquist (microbial fuel cell)

Figure 2: Biohydrogen production from waste. Waste is degraded and oxidised to H_2 and acetate by *C. saccharolyticus*. Acetate is converted to methane (CH_4) by anaerobic digestion (3), or to H_2 either by a microbial fuel cell (2) or by photofermentation (1). The CO_2 produced is taken up by the substrate, which results in a CO_2-neutral process

Dark fermentation:

$$C_6H_{12}O_6 + 2H_2O \rightarrow 4H_2 + 2CO_2 + 2CH_3COOH \quad (6)$$

To release the rest of the H_2 from the acetate requires external energy. Alternatively, methane (CH_4) – which can be steam reformed to release H_2 (Equations 1 and 2) – can be generated from acetate. Luckily, there are three promising ways of doing this (Figure 2).

1. Using sunlight to convert acetate to H_2 with photofermentative bacteria (Equation 7)[w3]. However, like algal H_2 production, this process is currently too slow and expensive to be commercially viable in the near future (Hallenbeck & Ghosh, 2009).

$$2CH_3COOH + 4H_2O \rightarrow 8H_2 + 4CO_2 \quad (7)$$

2. Using electricity to push the reaction of acetate to H_2 in a microbial fuel cell with a mixture of bacterial species (Equation 7)[w4]. This is an elegant concept, but its application is currently limited by low production rates (Hallenbeck & Gush,

2009). (To learn how to build your own microbial fuel cell, see Madden, 2010.)

3. Using methane producers (Archaea) to digest the acetate, generating methane (Equation 8). The combination of dark fermentation (Equation 6) and methane production is known as the hythane process (*hy*drogen me*thane*), and can convert approximately 90% of the original substrate to H_2 and methane.

$$CH_3COOH \rightarrow CH_4 + CO_2 \qquad (8)$$

The methane can then be steam reformed, releasing H_2.

To put the hythane process into perspective: if four people in a house eat 10 kg potato products each in one month, their waste could fuel 0.5% of their monthly domestic energy requirement (3500 kWh), provided that the H_2 produced is used directly (to avoid energy losses) and that the house is equipped with a heat and power fuel cell[w5]. More hydrogen could of course be generated from other waste – 0.5% is just from potatoes.

This is a rough estimate of the *potential* of the hythane process, based on a) 30% energy loss in the production of H_2 and CH_4 (hythane) and b) 30% in then steam reforming CH_4 to H_2. The steam-reforming step (b) is used in the production of hydrogen from natural gas, and is a well developed commercial technique. The production of hythane (a), however, is not yet that efficient, although research is ongoing to improve the efficiency to reach 70% (as in the example) and thus make the production of biohydrogen competitive with the steam reforming of fossil fuels for producing hydrogen.

Although there has been some recent progress[w6] (see box, right), it is too early to give a reliable time estimate for when sustainable H_2 production could play a significant part in supplying us with energy. However, as poet Mark Strand once said, "The future is always beginning now."

Image courtesy of Felix O; image source: *Flickr*

One of London's buses powered by hydrogen fuel cells

Image courtesy of Bull-Doser; image source: *Wikimedia Commons*

The Hyundai ix35 FCEV, powered by a hydrogen fuel cell

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Research into hydrogen storage and production

NEUTRONS FOR SCIENCE

ESRF

Storing hydrogen safely and efficiently is one of the main technological challenges to adopting hydrogen as an energy carrier. The Institut Laue-Langevin (ILL)[w7] has firmly established itself in frontier research into the hydrogen economy, using neutron diffraction to monitor hydrogenation and dehydrogenation reactions in potential hydrogen storage materials. To find out more, visit the ILL website[w7].

The powerful X-ray beams of the European Synchrotron Radiation Facility (ESRF)[w8] have recently probed the complex mechanisms by which hydrogen is produced by enzymes called hydrogenases. Most of these enzymes work under anaerobic conditions and are, in fact, inhibited by the presence of oxygen. Hydrogenases that remain active under aerobic conditions, therefore, are of great interest for technologies such as enzymatic fuel cells and the light-driven production of hydrogen. A German team of scientists has recently solved the crystalline structure of one of these enzymes (Fritsch et al., 2011) – perhaps a step towards a hydrogen economy?

Both ILL and ESRF are members of EIROforum[w9], the publisher of *Science in School*.

Image courtesy of David Berkowitz; image source: Flickr

Portable Fuels mobile phone charger from Powertrekk. Just add some water, and after a few minutes you have a battery for your mobile phone

References

Fritsch J et al. (2011) The crystal structure of an oxygen-tolerant hydrogenase uncovers a novel iron-sulphur centre. *Nature* **479**: 249–252. doi: 10.1038/nature10505

Download the article free of charge from the *Science in School* website (www.scienceinschool.org/2012/issue22/hydrogen#resources), or subscribe to *Nature* today: www.nature.com/subscribe

Hallenbeck P, Ghosh D (2009) Advances in fermentative biohydrogen production: the way forward? *Trends in Biotechnology* **27**: 287–297. doi: 10.1016/j.tibtech.2009.02.004

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Willquist K, Zeidan A, van Niel E (2010) Physiological characteristics of the extreme thermophile *Caldicellulosiruptor saccharolyticus*: an efficient hydrogen cell factory *Microbial Cell Factories* **9**: 89. doi: 10.1186/1475-2859-9-89

Microbial Cell Factories is an open-access journal, so the article is freely available.

Web references

w1 – To learn more about the hydrogen implementing agreement of the International Energy Agency, see: http://ieahia.org

w2 –To learn more about hydrogen prospects, see Joseph Romm's analysis on the Environmentalists for Nuclear Energy website (www.ecolo.org; under 'documents') or via the direct link: http://tinyurl.com/77dhx8x

See also Joan Ogden's peer-reviewed analysis *Hydrogen as an Energy Carrier: Outlook for 2010, 2030 and 2050* on the website of the University of California: http://escholarship.org/uc/item/9563t9tc

w3 – For a video about how hydrogen is released from potato biomass using sunlight, see: www.biohydrogen.nl/hyvolution

w4 – To learn more about microbial fuel cells, see: www.microbialfuelcell.org

w5 – To find out more about heat and power fuel cells, see: www.fchea.org/index.php?id=57

w6 – To read about recent progress on a biohydrogen fuel station in Taiwan, see the Focus Taiwan website (http://focustaiwan.tw) or use the direct link: http://tinyurl.com/7jao2tp

w7 – ILL is an international research centre at the leading edge of neutron science and technology, based in Grenoble, France. To learn more, see: www.ill.eu

For more information on ILL's research into the hydrogen economy, see the ILL website or use the direct URL: http://tinyurl.com/illhydrogen

w8 – Situated on the same campus as ILL, in Grenoble, France, ESRF operates the most powerful synchrotron radiation source in Europe. To learn more, see: www.esrf.eu

For more information on ESRF's research into hydrogen storage, see the ESRF website or use the direct URL: http://tinyurl.com/87bnj4c

w9 – To find out more about EIROforum, see: www.eiroforum.org

Resources

If you enjoyed this article, you may like to browse the other chemistry-related articles in *Science in School*. See: www.scienceinschool.org/chemistry

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Chemical engineer Karin Willquist obtained her PhD on biohydrogen production from Lund University, Sweden. Her research interests include microbial physiology, process optimisation and outreach activities. She works at Lund University, using computer simulations to improve the hythane process. She also organises courses on bioenergy for a multi-disciplinary bioenergy research platform (LUBiofuels) at Lund University. She is in the process of writing a book on bioenergy for high-school students.

To learn how to use this code, see page 57.

Revealing the secrets of permafrost

Studying permafrost enables us to look not only into the past, but also into the future. **Miguel Ángel de Pablo**, **Miguel Ramos**, **Gonçalo Vieira** and **Antonio Molina** explain.

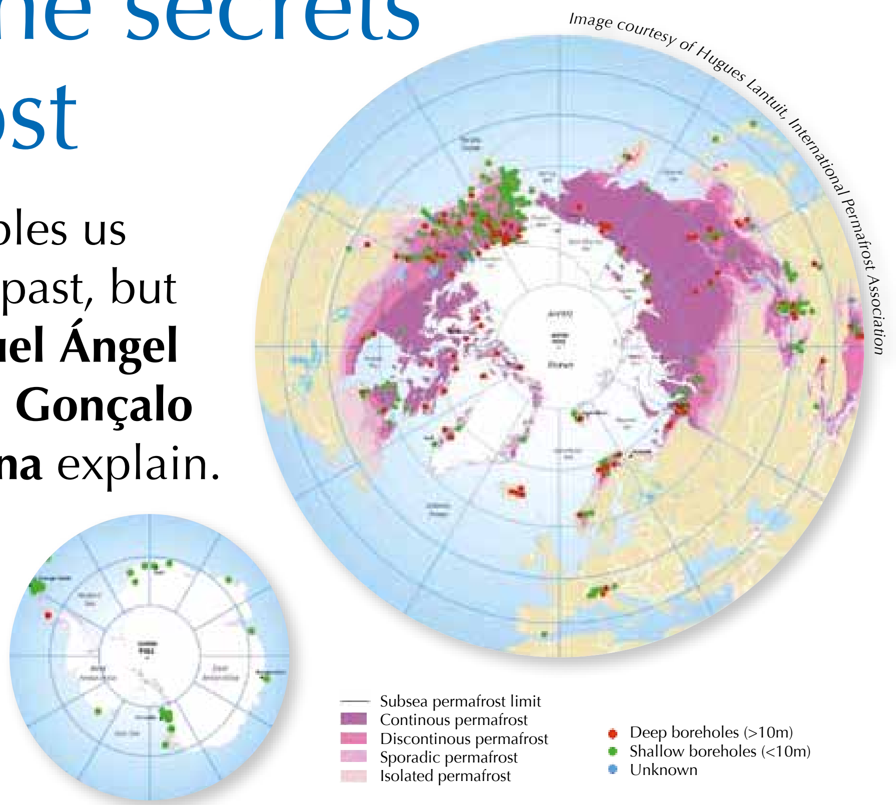


Figure 1: Permafrost distribution in the northern hemisphere and in Antarctica, showing boreholes used for permafrost monitoring

Bracing themselves against the icy Antarctic wind, four bulky figures struggle uphill. Could they be penguins? Seals? No. They are permafrost scientists – well wrapped up against the cold, and laden with high-tech equipment.

This is how we spend about two months of each year before returning to our warm European laboratories to analyse our data. What are we doing and why do we do it?

What is permafrost?

When winter arrives and the temperatures drop, ice forms on puddles or ponds. When the temperature stays below 0 °C for long enough, even the ground freezes. In some cases, the ground can remain continuously frozen for more than two years; we call this *permafrost*. Clearly, this only happens in extreme environments: permafrost is found mostly around the poles and in high mountains (Figure 1). Nonetheless, in the northern hemisphere, where it has been most studied, permafrost covers 20% of the continental area.

Figure 2: Cross-section showing different types of permafrost

REVIEW

- Biology
- Chemistry
- Environmental science
- Geology
- Meteorology
- Physics
- Ages 13-19

Many people know what permafrost is: frozen ground. But if researchers spend decades studying permafrost, there must be a lot more to know than just this simple information.

This article describes what permafrost is, how it can be researched, what can be learned from this research, and why the information revealed is valuable. Additionally, it contains information that could be used in the secondary-school science classroom for teaching many subjects and topics, including biology (e.g. ecology), environmental science (e.g. climate change), physics and chemistry (e.g. water and material properties), geology (e.g. rock properties) and meteorology (e.g. wind and temperature).

For lower-secondary-school students (ages 13-15), the article would be a good source of information about what permafrost is, how it is studied and what kind of important information it reveals. For upper-secondary-school students (ages 16-19), the article would also be helpful in understanding how everything that happens on the planet has direct or indirect implications that go far beyond what anyone can first imagine. For example, students will realise that global warming can negatively affect human land use and development.

Suitable comprehension and discussion questions include:

1. What are the major differences between permafrost, talik and the active layer, with regard to properties and location?
2. Which criteria are commonly used by researchers to locate permafrost sites?
3. Explain how changes in the active layer can contribute to global warming.
4. Why is it important to measure the temperature at different depths inside permafrost?
5. A construction company plans to build houses in an area where permafrost exists. Would you support these plans? Explain your reasoning.

The article would be most appropriate for study in the countries of northern Europe as well as countries with very high mountains, as these countries are the ones that have permafrost. Nevertheless, because climate change, which affects and is affected by permafrost, is a global problem, this article can provide valuable information in any classroom, anywhere in the world.

Michalis Hadjimarcou, Cyprus

Mixed up with the permafrost may be patches of ground that remains unfrozen all year round (*talik*), the result of local pressure, high salinity or groundwater flow. This means that the permafrost may be spatially continuous, covering large regions, but can also be discontinuous (Figure 1, page 17). The depth of the permafrost varies widely, depending on the environment: it can extend hundreds of metres into the ground, whereas on Deception Island in Antarctica, which is an active volcano, it is only 3 metres deep.

Detecting permafrost

In theory, detecting permafrost is relatively easy: simply insert a thermometer into the ground and take regular measurements over two years. However, obtaining accurate and representative data is more complicated. This is because the ground's most superficial layer is directly affected by solar radiation and weather conditions, so unlike the permafrost below, it thaws in the warm season. The surface layer above the permafrost is known as the *active layer*, and the repeating freeze-thaw cycles can cause it to form peculiar small-scale landforms such as polygonal terrains, stone circles and patterned ground.

Image courtesy of Miguel Ángel de Pablo

Figure 3: Stone circles formed by active layer dynamics due to seasonal freeze-thaw cycles

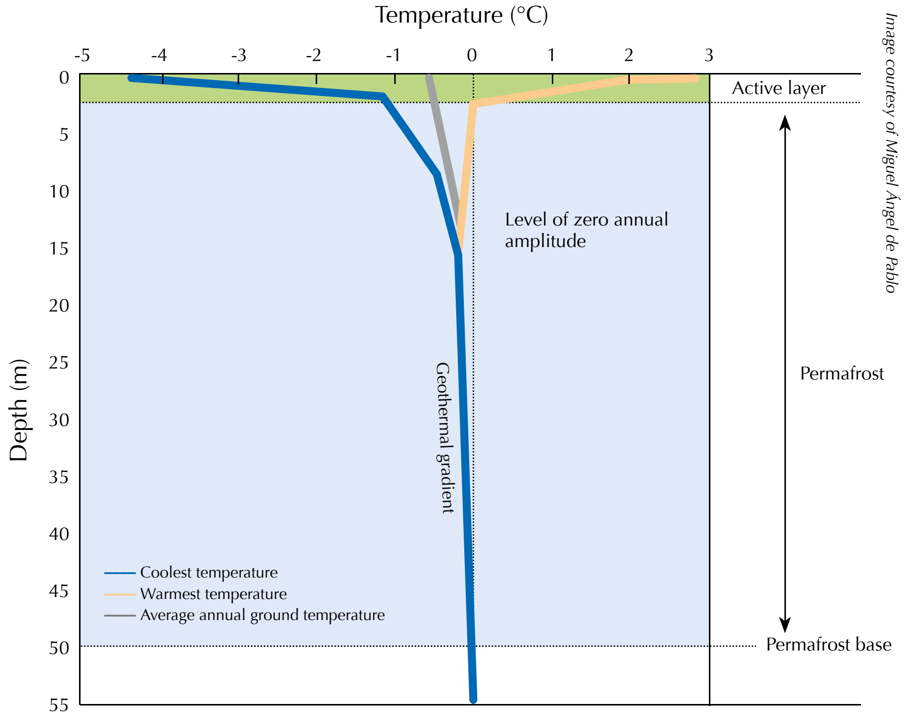


Image courtesy of Miguel Ángel de Pablo

Figure 4: A thermal profile taken from borehole data in Antarctica. At its warmest, only the active layer rises above 0 °C; below the level of zero annual amplitude, there are no seasonal temperature changes; below the permafrost base, the ground temperature is above 0 °C

These landforms, therefore, may indicate the presence of permafrost below. To check, we and other permafrost scientists drill boreholes and introduce temperature sensors at depths of as little as 50 centimetres or as much as 50 metres. After several years of data logging, we can determine whether permafrost exists and what its thermal evolution was: how the ground temperature changed over the monitored period at different depths.

What can we learn from permafrost?

Why do we and other scientists want to know if the ground is frozen below the surface? Permafrost can be important in daily life, as well as telling us about the past and future climate on Earth; it can even teach us about other planets.

By measuring the temperature near the surface, we can see if the active layer is becoming thicker – as the permafrost below thaws – or thinner. This tells us how the climate is changing, as the thickness depends not only on air temperature, but also on factors such as snow cover. By monitoring the thickness of the active layer at different sites on Earth, we can investigate the influence of global warming on ground temperatures.

Permafrost not only tells us about our current climate, but can also reveal our past climate. If a piece of rock warms up during the day, it will start to cool down the following night. However, it will remain warm for some time – especially deep in the rock, far from the surface where heat is being lost. Measuring temperatures at different depths inside the piece of rock can tell us about the rock's previous thermal conditions. We can do the same in permafrost – the deeper we dig, the further we are travelling into the past.

Soils and rocks, however, transfer heat at different speeds depending on their composition and structure; we call this *thermal conductivity*. If we know the thermal conductivity of the soil and rocks in the permafrost, we can convert depth into time, reconstructing climate evolution over the past decades or centuries. For example, finding colder rocks below the surface indicates that the climate at that depth (time) was colder than today. In theory, these calculations would also work in unfrozen ground but there, the geothermal gradient

Image courtesy of Vladimir Romanovsky, UAF

Figure 5: Infrastructure collapse due to thawing ice-rich permafrost terrain, Alaska, USA

(the heat from the centre of Earth) also influences the temperature. In permafrost, the surface temperature plays a much more significant role.

Recently, scientists have discovered that changes in the active layer not only indicate climate change but can actually contribute to it. In the northern hemisphere, permafrost soils contain huge amounts of frozen organic matter. As global warming causes the active layer to thicken, this organic matter is exposed to decomposition by micro-organisms, releasing carbon dioxide and methane – important greenhouse gases – into the atmosphere, increasing the rate of global warming.

Permafrost can also have a direct impact on humans, in areas where houses, roads and railways have been built on permafrost. When the permafrost thaws, the ground resistance drops and constructions can collapse[w1] (Figure 5, page 19). Increasing global temperatures will cause this to happen more frequently. By detecting permafrost below the surface, we can enable engineers to take precautionary measures to strengthen the constructions or not build them above permafrost in the first place.

Finally, permafrost can help us to understand the dynamics of other planets, such as Mars. Mars has large amounts of frozen water forming permafrost (Figure 6), so studying the evolution of permafrost on Earth may help us to understand the past and present climate of Mars. Future permanent bases there may even use Martian permafrost as a source of water.

Figure 6: Water ice under the surface of Mars discovered and analysed by the Phoenix mission

Image courtesy of Phoenix / ASU / JPL / NASA

Studying permafrost in Antarctica

For over two decades, our team has been conducting long-term permafrost research on different sites on Livingston and Deception Islands in the Antarctic Peninsula region (Figure 7). We measure the ground temperature both near the surface and inside boreholes as deep as 25 metres. We monitor the temperature in the ground, compare it with air and surface temperatures, and study the factors that affect ground temperature: from wind speed to rock properties such as thermal conductivity, porosity and humidity. We also measure the thickness of the active layer every year in the thaw season. Some of the boreholes have been monitored continuously for up to 25 years; others were drilled in the past six years.

We selected the Antarctic Peninsula region because:

1. Most permafrost research is in the northern hemisphere, so we wanted to extend the monitored areas. Like our colleagues working in the north, we use international protocols for monitoring the active layer and measuring temperature inside the boreholes, as defined by the International Permafrost Association (IPA)[w2].
2. The peninsula is one of the few ice-free areas of the Antarctic – important because permafrost is stable if there is ice above it, and we wanted to investigate the active layer.

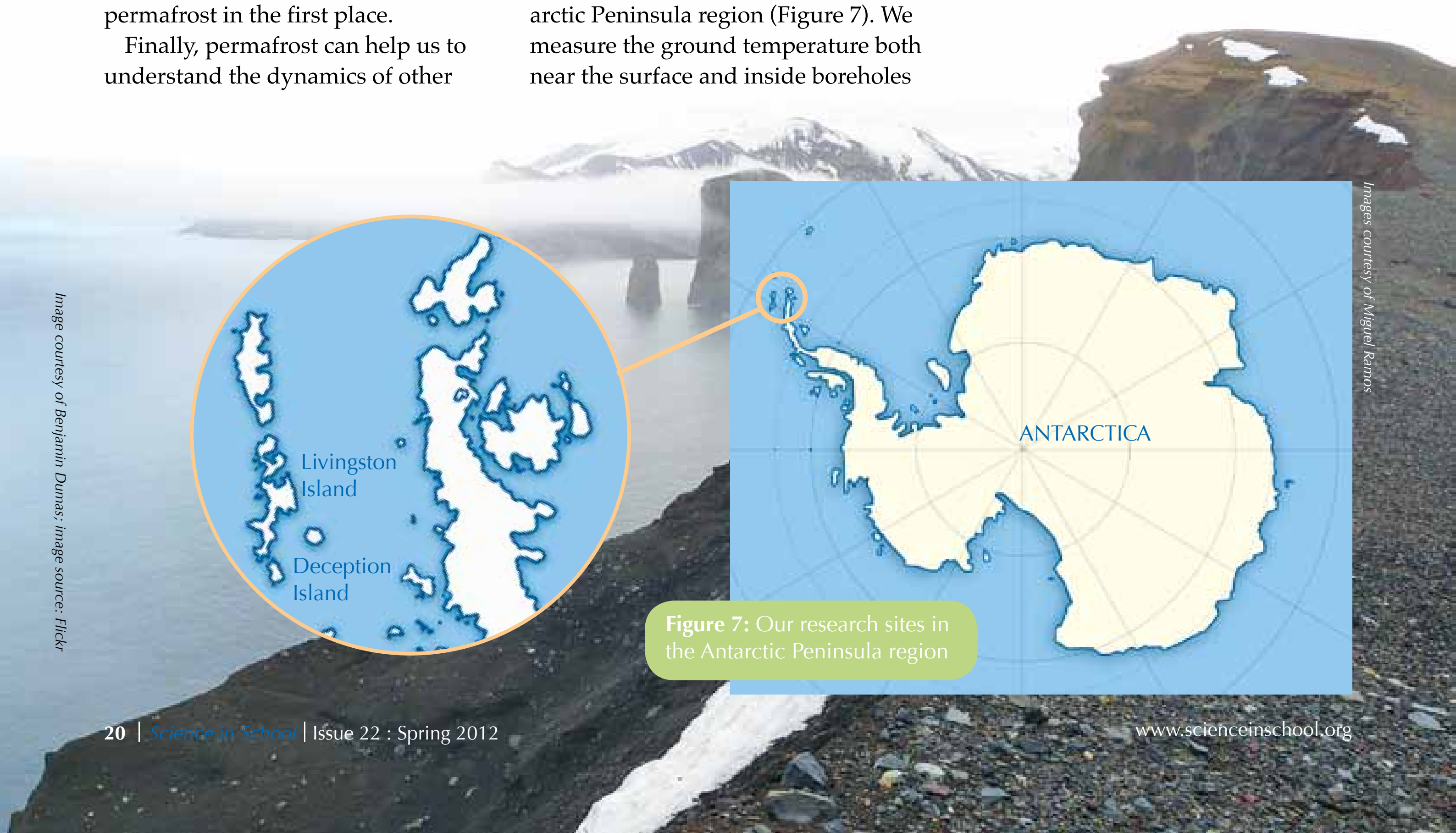
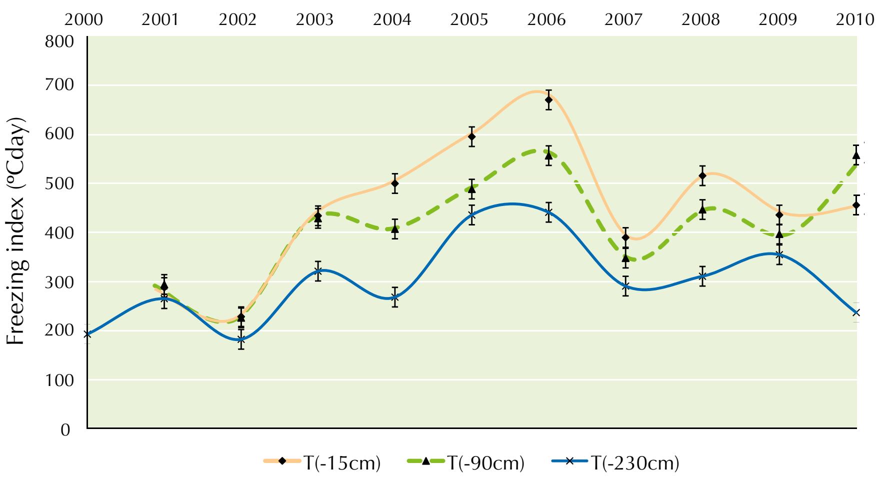


Figure 7: Our research sites in the Antarctic Peninsula region

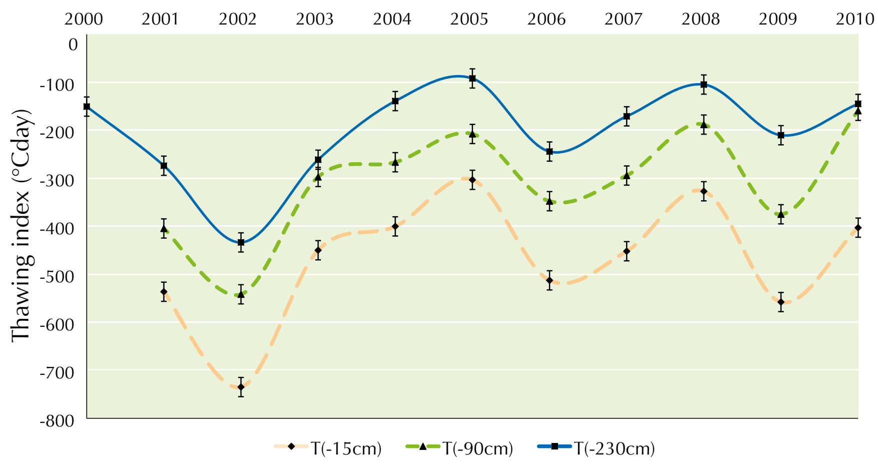
Images courtesy of Miguel Ramos

Image courtesy of Benjamin Dunas; image source: Flickr

Figure 8: Patterns in freezing and thawing at three different depths in the Incinerador borehole (230 cm deep) on Livingston Island, between 2000 and 2010. Currently, we do not have enough spatial and temporal information to conclude that the permafrost in the Antarctic Peninsula is affected by global warming. In the Incinerador borehole, there is a slight positive trend in the thawing index, but the freezing index shows no change – overall, the permafrost is still stable.



a) The thawing index for each year is defined as the cumulative positive daily temperatures (in °C) during the thaw period.



b) The freezing index for each year is defined as the cumulative negative daily temperatures (in °C) during the freezing period

Images courtesy of Miguel Ramos

Image courtesy of the Image Science & Analysis Laboratory, NASA Johnson Space Center

Permafrost temperature monitoring borehole in the South Shetland Islands, Antarctica

Image courtesy of Miguel Ángel de Pablo

3. It is close to the northern boundary of Antarctic permafrost, where ground temperatures are close to 0 °C and the permafrost is therefore more sensitive to climate change.

What do our data reveal? The main result is that although some areas that were previously permafrost are now unfrozen all year round, most of the ground on Livingston and Deception Islands is approximately as frozen as it was 10 years ago, despite global warming (Figure 8). These local differences are determined by the properties of the soil and rocks: material with higher thermal conductivity, for example, thaws more quickly. Over the next few decades, therefore, we expect permafrost with lower thermal conductivity to succumb to global warming, too. We hope to wrap up warm and return to Antarctica regularly to find out.

Web references

w1 – The US Public Broadcasting Service has developed an activity to make your own permafrost in class, build a house on it and observe the consequences of thawing. See: www.pbs.org/edens/denali/permawht.htm w2 – The International Permafrost Association co-ordinates international co-operation among scientists and engineers working on permafrost. See: www.ipa-permafrost.org

Resources

The US National Snow and Ice Data Center runs an educational website on frozen ground, including many activities and resources on permafrost. See: http://nsidc.org/frozenground

The Scientific Committee on Antarctic Research offers a wealth of teaching resources on the Antarctic for students of all ages, in different languages, including dressing an Antarctic scientist in appropriate clothing. See: www.scar.org/about/capacitybuilding/antarcticeducation

The United States Antarctic Museum has made lists of educational opportunities for teachers to experience the Antarctic and of resources for their students. See: www.usap.gov/usapgov/educationalResources.cfm?m=5

To find some wonderful pictures of Antarctica to use in your lessons, visit: www.coolantarctica.com

To learn about one school teacher's trip to the Antarctic, see:

Hayes (2007) Teaching on ice: an educational expedition to Antarctica. *Science in School* **6**: 78-81. www.scienceinschool.org/2007/issue6/antarctica

It is more than 25 years since a hole in the ozone layer was discovered over Antarctica. To find out what caused it and what the current situation is, see:

Harrison T, Shallcross D (2010) A hole in the sky. *Science in School* **17**: 46-53. www.scienceinschool.org/2010/issue17/ozone

If you found this article useful, why not browse the full series of climate-change-related articles in *Science in School*? See: www.scienceinschool.org/climatechange

Image courtesy of Paul Ward, CoolAntarctica.com

Studying permafrost in Antarctica

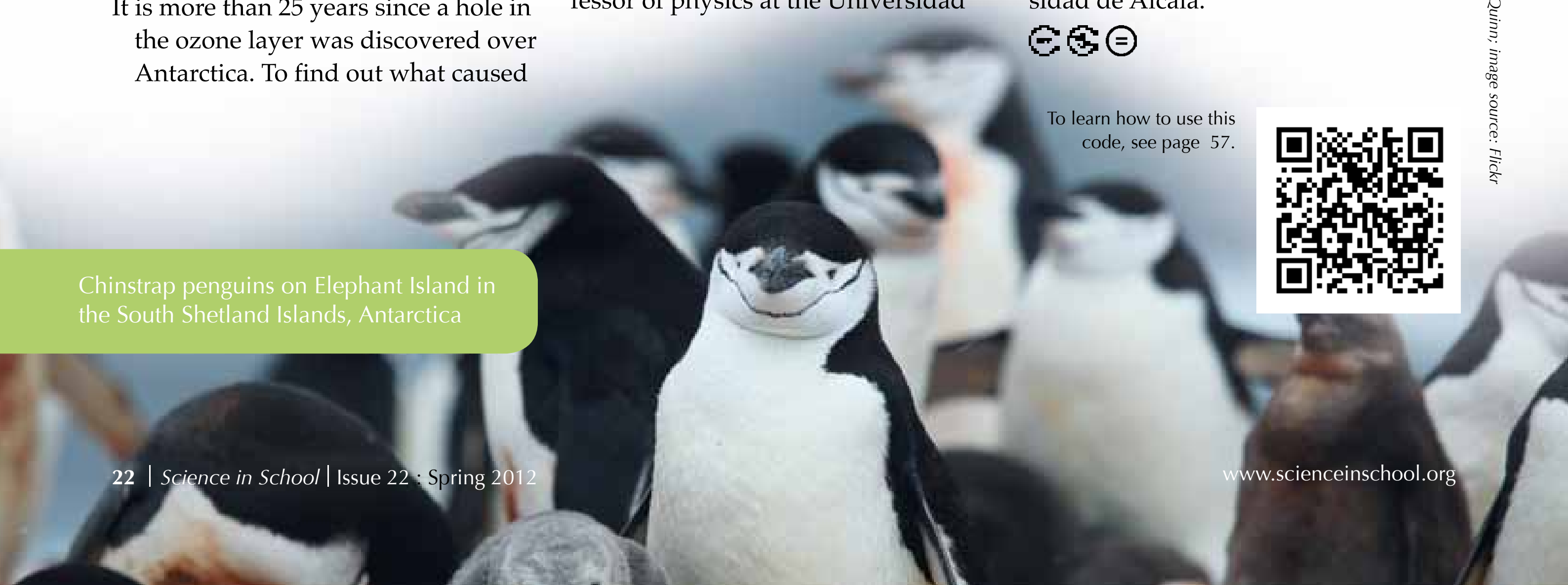
Miguel Ángel de Pablo is an assistant professor of geology at the Universidad de Alcalá in Madrid, Spain. He is a geologist and has a great deal of experience working on the geology of Mars, where the surface remains frozen. He joined the Antarctic research team in 2007 to study terrestrial permafrost in an effort to understand the Martian geological processes related to frozen terrains.

Miguel Ramos is an associate professor of physics at the Universidad de Alcalá, and leads the university research into Antarctic permafrost. He has spent 25 years working on Antarctica, studying the effect of climate on the thermal evolution of the South Shetland Islands.

Gonçalo Vieira is an assistant professor of geographical studies at the Universidad de Lisboa in Lisbon, Portugal. He is a geographer and the head of a Portuguese team working on permafrost and other periglacial processes, mainly in Antarctica. He has collaborated with Miguel Ramos since 2002.

Antonio Molina is a PhD student in the department of planetology and habitability at the Centro de Astrobiología CSIC / INTA in Madrid, Spain. He is a young researcher who has been studying Martian processes and the terrestrial analogues, especially those related to frozen soils, since 2009. He has participated in one Antarctic campaign as a member of the Antarctic research team of the Universidad de Alcalá.

To learn how to use this code, see page 57.



Chinstrap penguins on Elephant Island in the South Shetland Islands, Antarctica

Image courtesy of Lian Quinn; image source: Flickr

Bad science: learning from science in the media

When you read the newspaper, how do you know what to believe? **Ed Walsh** guides you and your students through the minefield of science in the media.

Science is all around us – but so is pseudoscience. Few of us read the original research papers behind every 'science' story, so how do we know what to believe? And why aren't all media stories about science reliable? This classroom activity aims to teach students:

- The difference between observational and intervention studies
- Why we need to carefully scrutinise media reports about the health outcomes associated with different aspects of diet
- That the decision to change lifestyle is often dependent upon a range of factors.

REVIEW

- **Biology**
- **Digestion**
- **General science**
- **Ages 11-16**

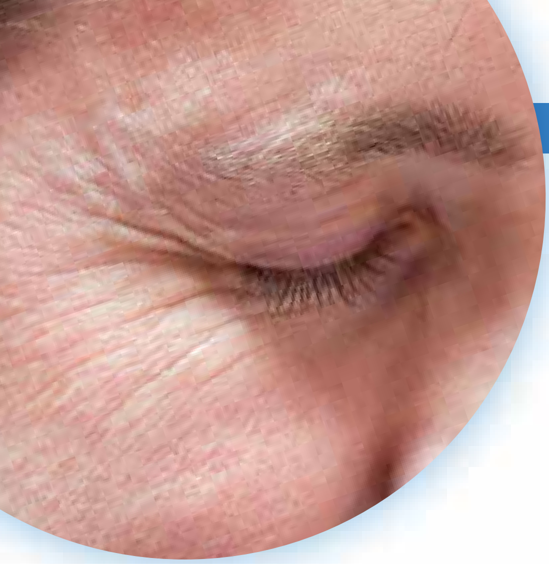
This article enables students to learn to think scientifically about what they read or hear in the media. Beginning with a role-play, the activity triggers their thinking and group discussion. The activity relates to digestion and health, and would therefore be suitable for biology lessons, but the structure of the activity could be used in any science lesson to encourage critical thinking.

For students aged 14-16, the activity could be used as described. For younger students (aged 11-13), this article could encourage the teacher to use the media cautiously to raise awareness of science topics or as the basis of class discussions on topics related to the curriculum.

At the end of the activity, a class discussion could move beyond the science curriculum, examining the implications of dieting, sun exposure and cosmetic surgery.

Stephanie Maggi-Pulis, Malta

Image courtesy of Selitbul / iStockphoto



Can consuming more olive oil stop you getting wrinkles?

Introduction

1. Ask students to imagine that they have decided to emigrate. They are going to live and work in one of the following regions: Sweden / rural Greece / Melbourne, Australia. Show students images of these regions[w1].
2. In small groups, they should discuss all the things that might be different about living in these situations, such as pollution, diet, healthcare, pace of life, prosperity, types of employment, and climate.
3. Explain that after a number of years, the wrinkling of their skin will be measured, quite scientifically. Which of the factors they have identified might make a difference to the amount of wrinkling? Establish that there could be a number of causes.

It is often hard to find out which of many possible causes has produced a particular outcome, such as skin wrinkling, especially if some of the possible causes are interlinked. In a scientific study we try to change only one thing at a time. This may sometimes be difficult, and we need to think of a way to account for that shortcoming, or consider conducting a different kind of study.

Main activity

1. Ask the students to imagine that they are working as scientists and have been asked to conduct research into the use of olive oil in people's diets as a way of reducing skin wrinkling. The hypothesis is that 'more olive oil consumed leads to fewer wrinkles'.
2. Ask students to decide how they could set up such an investigation. Get them to think about such factors as:
   - The size of the groups
   - How to make it a fair test
   - How to control the variables.
3. What problems are there with conducting such research?

Explain that there are two main types of study that scientists could use to answer this question, an *observational study* and an *intervention study*. Observational studies are when scientists find people who have already brought the change they are studying into their lives (e.g. who has been using olive oil in their diet and who hasn't?).

4. Ask the students to consider the advantages and disadvantages of this kind of study.
   Draw out that observational studies use existing behaviours, so are cheap and easy to do, but may struggle to isolate single variables. People in the study group may well use different amounts of olive oil in their diets, but there are almost certainly going to be lots of other differences as well. As a result, it may be extremely difficult to clearly identify the extent to which the presence of olive oil is the significant factor in preventing the wrinkling of skin.

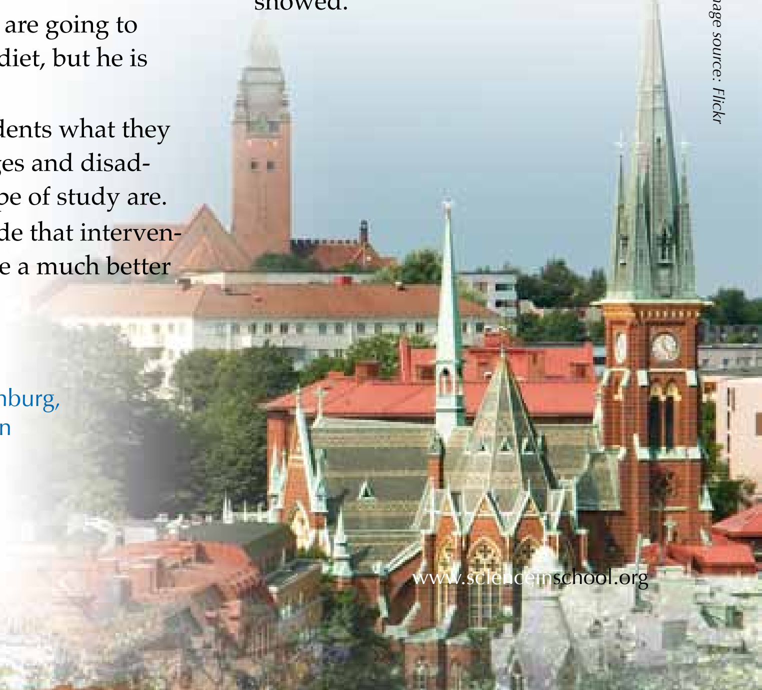
Explain that intervention studies ('trials') are when the scientists control the variables (e.g. you are going to have olive oil in your diet, but he is not).

5. Again, ask the students what they think the advantages and disadvantages of this type of study are. Ideas should include that intervention studies involve a much better control of variables and the groups can be balanced to eliminate other variables. However, they are more expensive to run and may be unethical: imagine researching smoking in this way. They may also take longer: if you want to examine the effect of a lifetime of eating olive oil on life expectancy, you would have to start your experiment with children, but wait perhaps up to 70 years until you had your answer.
6. Return to the investigations proposed by the students, and ask them to determine which type of study they used.

Explain that in 2001 a detailed scientific study was conducted into the wrinkling of skin on people who lived in Sweden, Greece and Australia, and that you are going to share the findings. Depending on the age and ability of the students, you could do this in one (or more) of three ways:

- Explain verbally, making key points on the board
- Give students copies of the edited findings (student worksheet 1, page 26, which can also be downloaded from the *Science in School* website[w2])
- Give students copies of the original research paper (br Purba et. al., 2001).

7. Ask the students to work in groups and explore what the research showed.



Gothenburg, Sweden

Image courtesy of jaime.silva; image source: Flickr

Image courtesy of venetia koussia; image source: Flickr

Image courtesy of Helene Souza; image source: pixelio.de

BACKGROUND

Bad Science is good for school science

Bad Science is a book (Goldacre, 2008), a newspaper column in *The Guardian* and a website[w3] by Ben Goldacre, an award-winning writer and broadcaster who specialises in unpicking questionable scientific claims made by scaremongering journalists, dodgy government reports, evil pharmaceutical corporations, public relations companies and quacks. It promotes a healthy scepticism as a way of detecting powerful and effective uses of science and its misuses and abuses.

Ed Walsh, science advisor for Cornwall Learning, has taken eight of the case studies from the book and turned them into lessons to excite students (aged 14-16) and to encourage them to think for themselves and to use the *Bad Science* approach. To download the rest of the teaching materials, visit the Bad Science for Schools website[w4]

Rural Greece

- Was this an observational or an intervention study?
- The study found an association between features of people's diets and the amount of wrinkling they had. That might be because different diets cause wrinkles to different extents. But what alternative explanations are there? Are there factors which might be independently associated with both diet and wrinkles, such as social class, working outdoors, sunlight exposure, smoking, and so on? (In this situation, scientists would call these alternative explanations 'confounding variables'.)
- Did this study prove that changing your diet will help you get fewer wrinkles?

8. Ask the students to work in small groups. Each group has to write a short piece of text (no more than 50 words) for a local newspaper using this report as the basis.
   The editor has made it clear that they want something engaging about how readers can enjoy the summer sun without being affected by it. Keeping the editor happy might be difficult because the research has shortcomings and does not give a clear answer. The pieces should be written in large writing on sugar paper and displayed around the room.
9. Ask students to assess each other's work and give each piece two marks (out of five): one mark for 'how engaging it is' and the other for 'how accurate it is'.
10. Show the students the extract from the *Daily Mirror* ('Sun protection on a plate', student worksheet 2, page 27, which can also be downloaded from the *Science in School* website[w2]), part of a longer article with a series of tips about improving diet. Ask the students to discuss the extent to which the article's conclusion is reasonable. Emphasise that we are not saying that olive oil is not good for you, but asking whether this conclusion is entirely justified.

Some students may think that the news stories make the good advice in a rather dry research paper accessible to a wide range of people. Others may feel that it is not quite as simple as that, and that if you want smoother skin in old age you might have to do a bit more than consume more olive oil. Some may feel that simplifying the story to make it accessible, and leaving out the caveats, has also made it misleading.

11. Draw attention to the abstract from the research paper, which said that "This study illustrates that skin wrinkling in a sun-exposed site in older people of various ethnic backgrounds may be influenced by the types of foods consumed." Remind students of the confounding variables they identified earlier in the lesson and ask them the extent to which either their report or the one from the *Daily Mirror* recognised these.
12. Ask students to work in pairs to list the pros and cons of observational and intervention studies.

Take a show of hands – if students saw the newspaper headline tomorrow, 'Scientific study shows butter causes s kin cancer', would they stop eating butter immediately?

Melbourne, Australia

Image courtesy of Oliver Brunner; image source: pixelio.de

Student worksheet 1: Summary of conclusions from the research paper

This study (br Purba et al., 2001) was set up to see if there was a correlation between the intake of various foods and nutrients and the wrinkling of skin in places with significant amounts of sunlight.

The study included four groups:

Group 1: 177 people born in Greece but now living in Melbourne, Australia

Group 2: 69 people born in Greece and living in rural Greece

Group 3: 48 Anglo-Celtic Australians living in Melbourne

Group 4: 159 people born in and still living in Sweden.

They were participating in the International Union of Nutritional Sciences 'Food habits in later life' study and had their dietary intakes measured and their skin assessed.

The results showed that Group 4 had the least skin wrinkling in a sun-exposed site, followed by groups 1, 2 and 3. Analysis of the data and identifying correlation with food groups suggested that there may be less skin damage amongst people with a higher intake of vegetables, olive oil, fish and legumes, and lower intakes of butter and margarine, milk products and sugar products.

High intakes of vegetables, legumes and olive oil seemed to offer protection against wrinkling whereas a high intake of meat, dairy and butter appeared to have the opposite effect.

This study illustrates that skin wrinkling in a sun-exposed site in older people of various ethnic backgrounds may be influenced by the types of foods consumed.

Gothenburg, Sweden

Image courtesy of Alex Garcia; image source: Flickr

Image courtesy of James Peacock; image source: Flickr

Student worksheet 2: *Daily Mirror* article

Sun protection on a plate!

By Angela Dowden 13/06/2006

With temperatures soaring to record levels, it's vital to protect yourself from the Sun's rays. Here are the foods that can help...

By making a few simple changes to your diet, you can help protect your skin from sunburn, ageing and even cancer. Of course, you also need to keep wearing your sun lotion and a hat and stay in shade during the heat of the day, but here's how to get some of your SPFs [sun-protection factors] on a plate...

Olive oil

An Australian study in 2001 found that olive oil (in combination with fruit, vegetables and pulses [legumes]) offered measurable protection against skin wrinkling. Eat more olive oil by using it in salad dressings or dip bread in it rather than using butter.

Image courtesy of wrw; image source: pixelio.de

Image courtesy of andrea.pacelli; image source: Flickr

References

br Purba, M et al. (2001) Skin wrinkling: can food make a difference? *Journal of the American College of Nutrition* **20(1)**: 71–80

The article is freely available here: www.jacn.org/cgi/reprint/20/1/71.pdf

Goldacre B (2008) *Bad Science*. London, UK: Harper Collins. ISBN: 9780007240197

Web reference

w1 – A worksheet with the images of rural Greece, Melbourne and Sweden used in this article can be downloaded from the *Science in School* website: www.scienceinschool.org/2012/issue22/badscience#resources

To find more freely available photographs to use, try Flickr (www.flickr.com) and the German website Pixelio (www.pixelio.de).

For a more extensive review of free image databases for science lessons, see:

Science in School (2006) Free image databases. *Science in School* **1**: 87. www.scienceinschool.org/2006/issue1/web

w2 – To download student worksheets 2 and 3, visit the *Science in School* website: www.scienceinschool.org/2012/issue22/badscience#resources

w3 – To read Ben Goldacre's newspaper column, visit the Bad Science website: www.badscience.net

w4 – To download the eight 'Bad science for schools' lesson plans, visit: www.collinsnewgcsescience.co.uk/badscience

Resources

For a review of Ben Goldacre's book *Bad Science*, see:

Hayes E (2011) Review of *Bad Science*. *Science in School* **18**. www.scienceinschool.org/2011/issue18/badscience

If you enjoyed this article, you might find the other teaching activities in *Science in School* useful. See www.scienceinschool.org/teaching

You might also like to browse the medicine-related articles in *Science in School*. See: www.scienceinschool.org/medicine

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Ed Walsh is a curriculum developer with experience of working with teachers, schools, local authorities and national agencies. As Science Advisor for Cornwall Learning he provides support and guidance to schools in Cornwall, UK, about curriculum development in general and science in particular, including writing and editing material for classroom use and teacher support.

To learn how to use this code, see page 57.

Build your own microscope: following in Robert Hooke's footsteps

Nektarios Tsagliotis explains how to build an effective microscope using simple materials – enabling your students to discover a hidden world, just as Robert Hooke did in 1665.

- Biology
- Physics
- Microscopy
- Lenses and optics
- Ages 15-18*

REVIEW

I would never have thought it was so easy and cheap to construct a light microscope. The activities in this article will surely help students to understand how a microscope works and appreciate their work once they get to use the microscope and see with their own eyes what set Robert Hooke on his fascinating journey. This is a very interesting project that could even be carried out as part of a school science exhibition – with a prize for the best, coolest microscope!

Although the author carried out the project with 10- to 14-year-old students, I would use it for older students (15-18), as in my experience younger students tend to lack the necessary dexterity and patience. For older students, the activity could be extended to investigate what happens if you use lenses of different sizes.

Andrew Galea, Giovanni Curmi Higher Secondary School Naxxar, Malta

*Note that the author performed the project with students aged 10-14

Rita Greer's portrait of Robert Hooke (2009), painted for The Open University, UK. Among the items in front of him are his book, *Micrographia*, and a microscope

Image courtesy of Rita Greer; image source: Wikimedia Commons

Like the telescope, the microscope was made famous by the achievements of one of its earliest users. When we consider the telescope in history, we think of Galileo Galilei (1564–1642) and his pioneering observations of the Moon and planets. Similarly, the English scientist Robert Hooke (1635–1703) was one of the first to realise the potential of the microscope. In his book *Micrographia*, published in 1665, Hooke astonished the public with a fantastical world, where everyday objects such as needles and hairs, ants and spiders, were transformed by magnification.

From a very early age, Robert Hooke's curious mind drew him into many scientific fields (for this reason he has been called the 'Leonardo of England'). In 1662, he was hired by England's recently founded academy of science, The Royal Society, to carry out studies with the microscope. Three years later, he published these and many of his other studies in *Micrographia*.

This huge book is filled with descriptions of what Hooke saw under the microscope. He claimed that his goal was to use 'a sincere hand, and a faithful eye, to examine, and record the things themselves as they appear'. Along with descriptions, Hooke included stunningly detailed drawings of the objects he viewed. His lively drawings of insects made them seem, as he remarked, 'as if they were lions or elephants seen with the naked eye'. The book was a great success and is still considered a masterpiece of scientific literature.

Micrographia was the inspiration for my classroom project, which had two aims. First, to build a working microscope inspired by early models from inexpensive, easily obtainable modern materials that students could use in class; and second, for the students to investigate the microscopic world for themselves, taking Robert Hooke's studies as a starting point and producing their own observations in the form of sketches and descriptions.

The microscope I built with my students is a modified version of one described by researchers at the Museo Galileo in Florence, Italy[w1]. It is similar in construction to those used by Hooke and other scientists during the late 16th and early 17th centuries and has the same essential elements: two lenses (objective and eyepiece), a microscope tube, and a diaphragm to reduce optical distortion. The modern materials we used include plastic lenses, each of which was extracted from a single-use disposable camera. Once built, the microscope has a magnification of approximately 20 times – quite sufficient to reveal the wonders of the microscopic world as Hooke saw them.

This microscope is durable and portable, and can be assembled quickly once the materials have been collected, cut and glued appropriately (see online video[w2]). It can be used repeatedly for microscope studies and / or observations, requiring minimal maintenance, such as lens cleaning and battery supply for the spotlight. Moreover, it can be stored easily in the classroom and laboratory, as it occupies a small space.

Materials

- 2 lenses with a focal length of 35 mm, each salvaged from a single-use disposable camera.
  Make sure the flash has been discharged and remove the battery before you open the camera. Use insulated tools (like screwdriver and pliers). The students might need help extracting the lenses from of the cameras.
- 2 metal washers with an external diameter of 2 cm and an inner hole of approximately 1 cm diameter
- 1 black cardboard or rubber disc with an external diameter slightly smaller than the washers (approxi-

Image courtesy of Nektarios Tsagliotis

Images courtesy of Nektarios Tsagliotis

mately 1.2 to 1.5 cm) and a small hole of approximately 2-3 mm diameter.

This is the diaphragm: it ensures that the centre of the lens is used rather than its edges, as these can distort the image.

- 4 plastic tubes, to form the microscope body and support, with the following dimensions:
  - Microscope body tube: 16.5 cm length of Ø18 (1.8 cm external diameter, internal diameter 1.6 cm)
  - Main support tube: approximately 17 cm length of Ø23 (2.3 cm external diameter, internal diameter 2 cm)
  - Two smaller support tubes: each an approximately 10 cm length of Ø16 (1.6 cm external diameter)s

  These are plastic tubes used for electrical home installation, obtainable from hardware stores and / or electrical supplies shops.
- 1 rigid base made from thick cardboard, wood or similar, approximately 10 x 10 cm
- 2 strong rubber bands (for a more stable construction, use 1 strong rubber band and 1 plastic cable tie)
- 1 piece of opaque black paper, approximately 15 x 5 cm
- 1 black plastic 35 mm film container or similar. Alternatively, a plastic connector for the Ø18 tube
- A reading spotlight, preferably with a clip for attaching it to the microscope base
- Blutack® (malleable stickyish plastic used for temporary fixing)
- Glue gun with hot silicone and instant glue
- Scissors
- Paper cutter
- Hacksaw
- Ruler
- Pen or pencil

Procedure

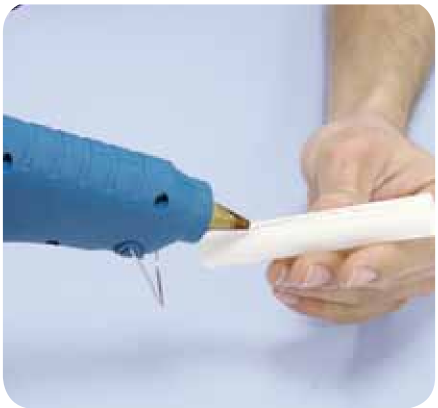
1. Take the tube that will form the microscope body (Ø18). Roll the opaque black paper lengthways and insert it into the tube so that it forms a lining for the tube.
2. Attach each lens to a washer using Blutack or glue them carefully with instant glue. Then add a ring of Blutack around the edge of the lens and washer.
3. Place one lens-and-washer unit at one end of the tube, with the washer on the outside, using the Blutack ring to hold it firmly in position. Then fix the other lens-and-washer unit at the other end in the same way.
4. Place the black cardboard or rubber disc on top of one of the washers at the end of the tube and secure it with Blutack. The disc forms the microscope's objective.
5. Make the microscope eyepiece: in the bottom of the film container, cut a hole just large enough to fit the microscope body tube into (if you use a tube connector, see list of materials, you do not need to

Image courtesy of Nektarios Tsagliotis

An ant, as illustrated in Hooke's *Micrographia*

Image courtesy of the Project Gutenberg

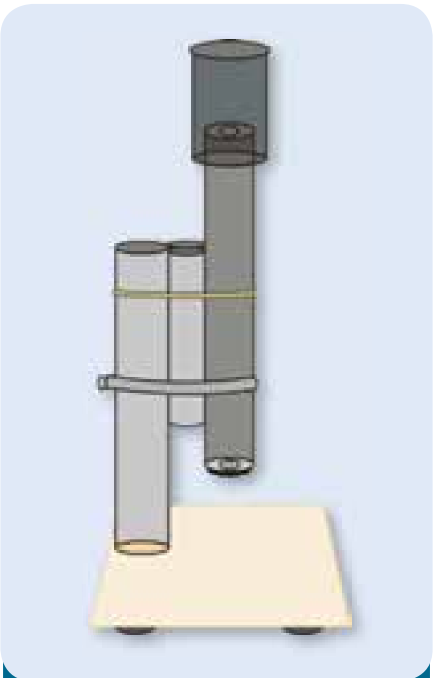
Images courtesy of Nektarios Tsagliotis



cut a hole). Push the tube (the end without the black disc) a short way inside the film container and secure it with glue if necessary.

6. Now construct the support for the microscope body. Using the glue gun and hot silicone, fasten the two smaller tubes to the main support tube (the longest remaining tube) so that they lie alongside each other, touching, with all three tubes aligned at one end and the longest tube extending beyond the others at the other end.

Image courtesy of Nektarios Tsagliotis



The finished microscope with a cable tie and a rubber band

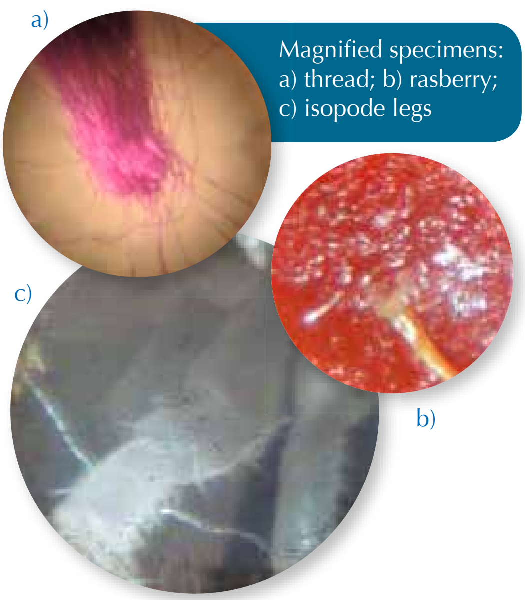
7. Then use the glue gun to attach the free end of the longest tube to the base, positioning it towards one end of the base. Hold the tube steady in a vertical position until the hot glue has cooled.
8. Complete the microscope by joining the microscope body to the support. Place the two rubber bands around the three support tubes, one near the top and one near the bottom. (Or use a plastic cable tie instead of the lower of the two rubber bands.) Then slide the microscope body under the bands, with the eyepiece at the top. Make sure the bands are tight enough to hold the body tube in position, but that it can still move up and down.
9. Adjust the position so that the objective end is a few centimetres above the base. Your microscope is now ready!
10. To view an object under the microscope, place it on the base, under the objective. Bring it into focus by sliding the body tube up and down until you find the right position. (If you are using the cable-tie version, focus by turning the microscope tube gently and simultaneously moving it up and down[w3].)

Image courtesy of Nektarios Tsagliotis

Shining a bright light, such as a desk lamp or a small torch or spotlight on the object will give you even better images.

If you have a compact digital camera, you can even take photos of your magnified specimens. Hold the camera against the eyepiece lens, keep it steady and you will be surprised at the clarity of the images you produce.

Images courtesy of Nektarios Tsagliotis



Magnified specimens: a) thread; b) rasberry; c) isopode legs

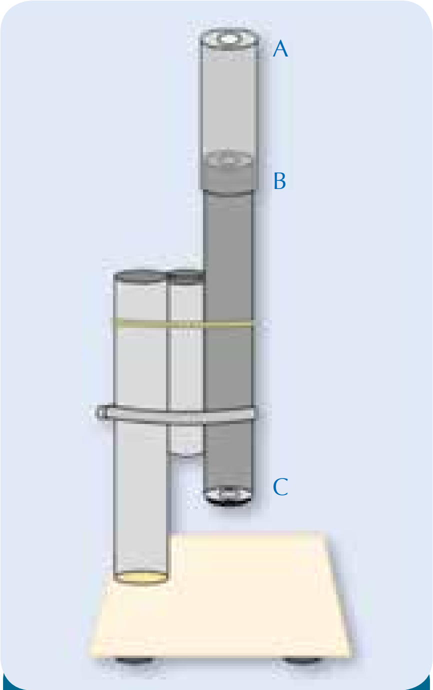
Image courtesy of Nektarios Tsagliotis

Improving the images

To achieve even sharper images, with less distortion, you can build a version with an additional lens (a field lens) between the eyepiece and the objective. For this you need to have used a tube connector rather than a film container for the eyepiece, since the film container's diameter is too wide to hold the lens. Then all you have to do is add another lens-and-washer unit at the top of the connector: this is the new eyepiece. The eyepiece of the original model (described above) becomes the field lens of the three-lens model.

Image courtesy of Nektarios Tsagliotis

Image courtesy of Nektarios Tsagliotis



The three-lens microscope
A: The new eyepiece;
B: the field lens, which was the eye piece of the original microscope;
C: the objective lens

Image courtesy of Nektarios Tsagliotis

Materials for the improved microscope with three lenses

Classroom activity

The idea is for 10- to 14-year-old students to use the microscope in a similar way to Robert Hooke, recreating an authentic scientific method of discovery. The students view an object using the microscope and then produce a detailed sketch and a description. Afterwards, the class discusses their results.

1. Prepare some printouts of pages from *Micrographia*, including Hooke's sketches of items similar to those the students will study with the microscope (see list below), paired with a simplified version of the text description in each case[w4].
2. Collect a selection of suitable objects for looking at under the microscope. You could try:
   - A printed and a hand-written full stop (dot)
   - The point of a needle
   - Pieces of fabric
   - Grains of sand, sugar and salt
   - Plant seeds and other parts of plants
   - Small insects (e.g. ants) or other arthropods (e.g. isopods – woodlice) anaesthetised by placing in alcohol solution (20-30%, e.g. an antiseptic solution) for around 15 min
3. Then set up the microscopes (we made one per pair of students), ensuring that there is sufficient light for viewing (e.g. with a reading spotlight or a strong torch).
4. Start the lesson with a brief account of who Robert Hooke was and his life story (I found this effective in engaging the students' curiosity about his work). A series of paintings by historical artist Rita Greer, depicting Robert Hooke's life from boyhood onwards, are a useful resource[w5].
5. Divide the students into pairs, with pencils and paper for sketching and writing notes, plus a drawing and description from *Micrographia* as an example to follow. Each student in a pair should

take a turn with the microscope, viewing and sketching the object, then writing a description.

As part of our project, I developed a set of seven worksheets for each type of specimen observed. These can be downloaded free of charge in English or Greek[w6].

6. The students should discuss their observations, writings and drawings in pairs and / or in groups of four, before reporting to the whole class.

My students were enthusiastic about the activity, making a big effort to work in a 'scientific' way, like Hooke. Even those who complained that they could not draw tried hard[w7] and attempted to describe the object verbally. The whole project encouraged my students to 'do science' themselves, demystifying it in the process: they were using an instrument that they had built themselves using simple materials.

Acknowledgments

This project is part of the research work undertaken by the Greek group for the 'History and Philosophy of Science in Science Teaching' (HIPST) project[w8], funded under the 7th Framework Program, Science in Society-2007-2.2.1.2 – teaching methods.

The author would like to thank the coordinator of the Greek research group of the HIPST project, Fanny Seroglou (associate professor at the Aristotle University of Thessaloniki) for her support on the project.

Web references

w1 – To learn how to build the Museo Galileo version, see: http://brunelleschi.imss.fi.it/esplora/microscopio/dswmedia/risorse/erisorse.html

This website also offers a collection of historical texts about 17th century microscopy.

Image courtesy of Rita Greer; image source: Wikimedia Commons

The Scientists, by Rita Greer (2007). After Robert Hooke finished his education and secured his doctorate at Christ Church, Oxford, UK, he assisted Robert Boyle. Hooke is shown in Dr Cross's apothecary's shop in Oxford, setting up an experiment using the air pump that he designed and made. Hooke is attaching the glass globe while Boyle supervises. The artist used Hooke's own working drawing of the air pump for accuracy w2 – For a video of my students building the microscope, see: http://hipstwiki.wetpaint.com/page/Videos

w3 – To see some alternative suggestions for improving the stability of the microscope, see: http://hipstwiki.wetpaint.com/page/constructing+the+microscope

For a photographic account of how to construct our microscope, as well as a more advanced one with three lenses (objective, field lens and eyepiece), click on 'constructing the microscope'

w4 – The original text and images of *Micrographia* can be downloaded from the Project Gutenberg website: www.gutenberg.org/ebooks/15491

w5 – Rita Greer's paintings of Robert Hooke's life are freely available via Wikimedia Commons: http://commons.wikimedia.org/wiki/Category:Paintings_by_Rita_Greer

w6 – To download the microscopy worksheets, visit http://hipstwiki.wetpaint.com/page/study+worksheets_gr (Greek) or http://hipstwiki.wetpaint.com/page/study+worksheets_en (English)

w7 – For examples of my students' work, see: http://hipstwiki.wetpaint.com/page/children%27s+texts+%26+drawings

w8 – To learn more about the HIPST project, see: http://hipstwiki.eled.auth.gr

Resources

For a more detailed article about this project, see:

Tsagliotis N (2010) Microscope studies in primary science: following the footsteps of R Hooke in *Micrographia*. In Kalogiannakis, M Stavrou D, Michaelidis P (eds) *Proceedings of the 7th International Conference on Hands-on Science*. 25-31 July 2010, Rethymno-Crete, pp. 212–221. www.clab.edc.uoc.gr/HSci2010

For a description of a similar simply constructed microscope, see:

Vannoni M, Buah-Bassuah PK, Molesini G (2007) Making a microscope with readily available materials. *Physics Education* **42(4)**: 385-390. doi: 10.1088/0031-9120/42/4/008

For a detailed account of how to construct a somewhat more complex but more stable microscope, see: www.funsci.com/fun3_en/ucomp1/ucomp1.htm

If you enjoyed this article, you might like to browse the other project articles in *Science in School*. See: www.scienceinschool.org/projects

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Nektarios Tsagliotis is a teacher-researcher in the field of science education. He has taught primary science for the past 15 years and also works as a researcher at the University of Crete, in the department of primary education. In this role, he is in charge of the Primary Science Laboratory at the 9th Primary School of Rethymno, Crete, providing support and in-service training for the teachers of the region. He is interested in inquiry-based teaching and learning in science, in authentic investigative environments.

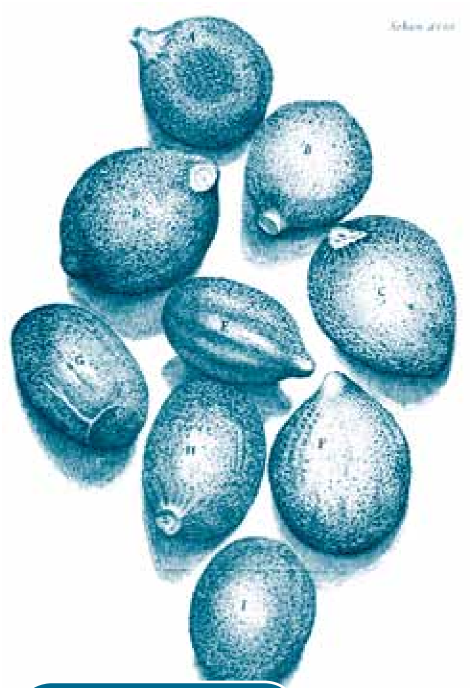


Image courtesy of the Project Gutenberg

Thyme seeds, as illustrated in Hooke's *Micrographia*

To learn how to use this code, see page 57.

Launch of Renu sounding rocket

Image courtesy of Arve Jørgen Tokheim

Sky-high science: building rockets at school

Ever wanted to launch a rocket? **Jan-Erik Rønningen**, **Frida Vestnes**, **Rohan Sheth** and **Maria Råken** from the European Space Camp explain how.

Space science is a fascinating field of study, whether at school or, in our case, at the one-week European Space Camp in Norway (see box on page 39). One hands-on aspect that can be easily introduced in the classroom is rocketry.

Paper rockets are small and relatively simple to construct, and can achieve flight distances of 50 metres or more, enabling students to compete in terms of either height or distance, depending on the space available. Students can also be creative, designing visually appealing rockets or using different types of material. Making a paper rocket is the perfect way to have fun and learn plenty of physics at the same time. Here, we describe a simple rocket that we built and launched during the 2011 European Space Camp.

Building paper rockets enables students to tie together many different concepts in physics – in particular, the equations of motion linking velocity, acceleration, distance and time, as well as the principles of aerodynamics. It also provides an exciting introduction to what it is like to be a scientist: designing a rocket from theoretical principles, carrying out an experiment by launching rockets, and finally analysing the results, drawing conclusions and identifying points for improvement for the future.

Building your rocket

Materials

- Two pieces of A4 paper
- Scissors
- Sticky tape
- Putty or Plasticine®

REVIEW

- Physics
- Space Science
- Maths
- Ages 13-19

Building and launching rockets is definitely a unique experience that students can enjoy with their peers. It is one way of merging old and contemporary science, as it applies standard equations and theories to advanced techniques used for space exploration.

The activity described in the article would definitely create excitement among school students, most of whom would try their best to build the best possible rocket. Before attempting to build their rocket, they should explore and discuss how the shape, dimensions and materials used will affect the range, apogee and time of travel of the rocket. After the activity, a new dimension of discussion, re-modelling and evaluation can be explored, with students discussing their individual results with the whole class and seeing which methods and models worked better and why. Furthermore, they can try to improve their model and re-test their hypotheses.

Some topics, not all of them scientific, can be discussed with the class, before or after the activity, including:

- Human curiosity about our Universe
- Space missions that were successful
- Missions that were less successful
- Justifying the budget involved in some of these missions in view of current economic problems
- Academic, physical and psychological training required by astronauts.

This activity involves a wide range of physics topics ideal for ages 13-16, and also involves physics concepts, equations and mathematics suitable for students aged 16+. The teachers can adapt the calculations involved according to the level of their class. The topics involved are gravitation and escape velocity; stability and centre of gravity; projectile motion; air resistance in relation to mass and shape of rocket; conservation of momentum and energy during launching; and material properties.

Catherine Cutajar, Malta

Procedure

The aim when building the rocket is to minimise drag (air resistance). Drag is mostly dependent on the velocity, but also on the frontal surface area of the rocket and its overall shape – important considerations when designing a rocket.

Rocket body:

1. Roll one piece of paper into a cylinder to form the body of the rocket.
2. Seal one of the open ends of the cylinder with tape, making the front of the rocket. Check that the seal is airtight by blowing into it.

Nosecone:

1. From the other piece of paper, cut out a circle (diameter 7.5 cm), then cut a sector of approximately 90 degrees from the circle.
2. Twist the remaining piece into a cone and place a small ball of putty inside the tip of the cone before fastening the cone to the sealed end of the rocket body with tape.

Fins:

1. Cut four paper triangles of exactly the same size and fold one of the sides of each triangle to form a flap, which will be attached to the rocket.

Students should think about the optimal shape of the fin – some fin profiles will cause the rocket to spin more, others less. Is spin desirable in a rocket?

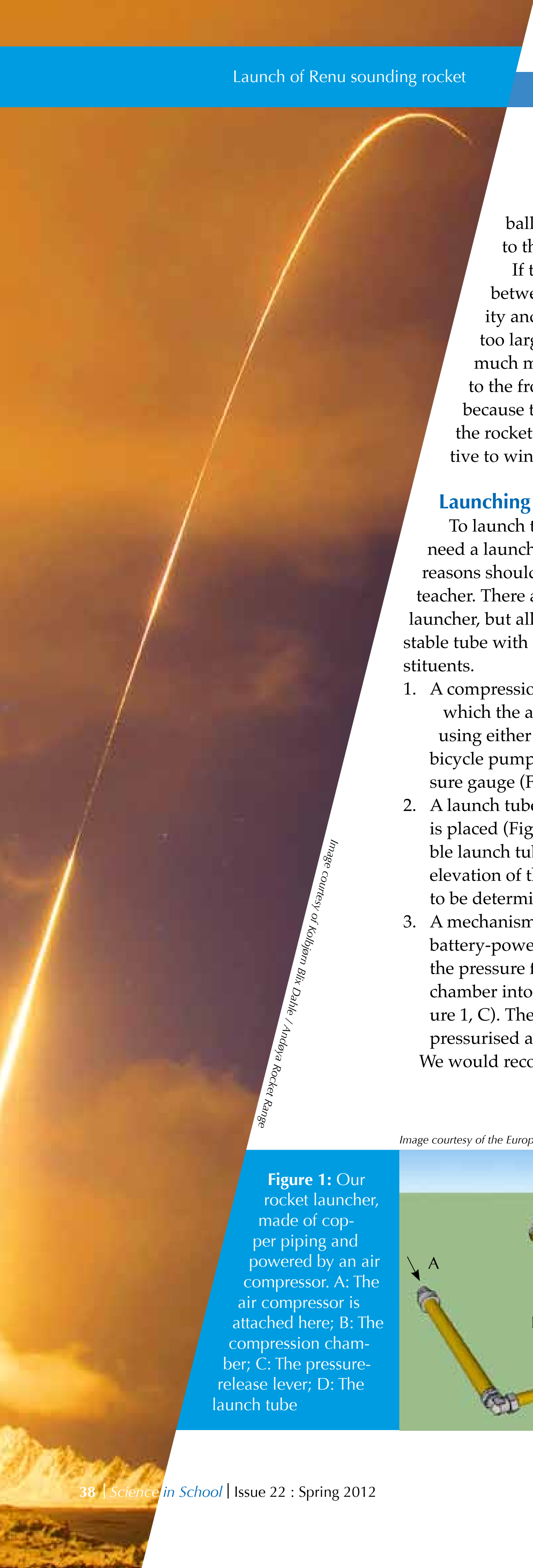
Stability

The stability of a rocket depends on where the centre of gravity and the centre of pressure are in relation to each other. For a stable rocket, the centre of gravity should be in front of the centre of pressure at all times. Simply put, the centre of pressure is where the sum of all drag forces acts.

If the centre of pressure is in front of the centre of gravity, a turning moment will occur, causing the rocket to flip over in mid-flight. This is why

Forming the nosecone

Image courtesy of the European Space Camp



Launch of Renu sounding rocket

Image courtesy of Kolbjørn Blix Dahle / Andøya Rocket Range

ballast is usually applied to the nosecone.

If the relative distance between the centre of gravity and centre of pressure is too large, either because too much mass has been applied to the front of the rocket or because the fins are oversized, the rocket will be more sensitive to wind.

Launching the rocket

To launch the rocket, you will need a launcher, which for safety reasons should be built by the teacher. There are many types of launcher, but all are essentially a stable tube with the same three constituents.

1. A compression chamber in which the air is pressurised, using either a compressor or a bicycle pump with a built-in pressure gauge (Figure 1, A+B).
2. A launch tube on which the rocket is placed (Figure 1, D). An adjustable launch tube allows the angle of elevation of the rocket at take-off to be determined.
3. A mechanism (e.g. a lever or a battery-powered valve) to release the pressure from the compression chamber into the launch tube (Figure 1, C). The sudden release of pressurised air launches the rocket.

We would recommend building a robust launcher out of metal piping, with an adjustable launch tube. This allows reproducible launches, with different angles of elevation. At the European Space Camp, we used a launching system in which air was pumped into a copper pipe system using a low-cost air compressor, a robust and stable system that can be used over and over again. For downloadable instructions, see the *Science in School* website[w1]. A robust launcher can also be built out of PVC, using materials readily available from hardware shops, as described on the NASA website[w2].

When launching your rocket, note that higher air pressure does not necessary lead to better flight performances. This is because aerodynamic drag on the rocket increases with velocity: the rocket's fins may be distorted, increasing drag and reducing performance.

Before deciding on the angle at which to launch their rocket, the students should think about how the angle of elevation affects the total distance travelled and the rocket's apogee (its highest point above the ground).

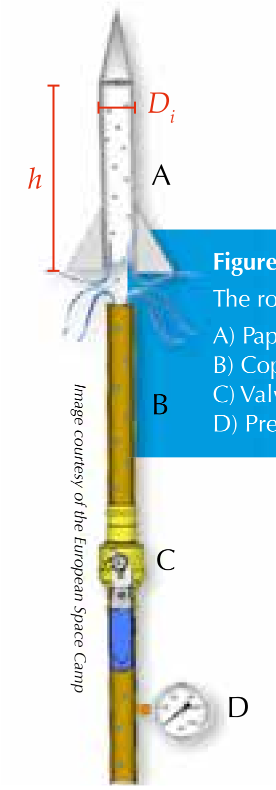


Image courtesy of the European Space Camp

Figure 2: The rocket launcher
A) Paper rocket
B) Copper tube
C) Valve
D) Pressure gauge

Image courtesy of the European Space Camp

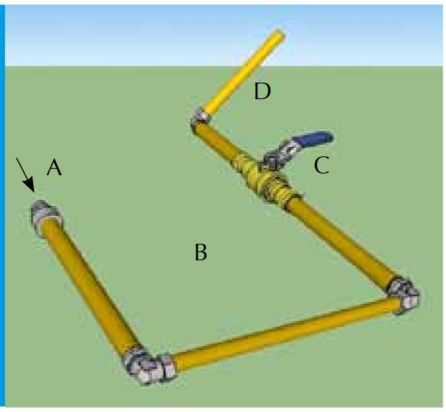


Figure 1: Our rocket launcher, made of copper piping and powered by an air compressor. A: The air compressor is attached here; B: The compression chamber; C: The pressure-release lever; D: The launch tube

Our rocket launcher, made of copper piping and powered by a bicycle pump. A: The compression chamber; B: The pressure-release lever

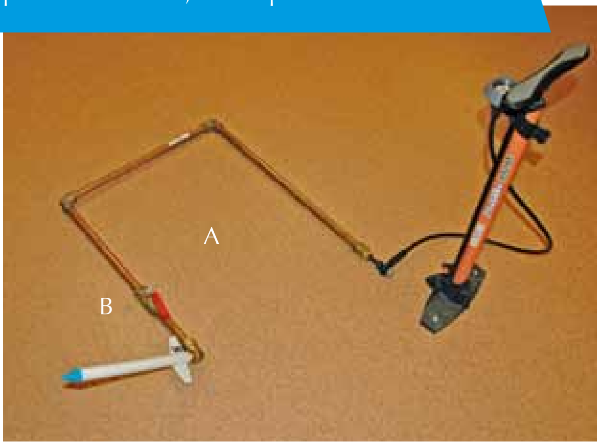


Image courtesy of the European Space Camp

Images courtesy of the European Space Camp

Launching the rocket

Image courtesy of Kolbjørn Blix Dahle / Andøya Rocket Range

Safety

Safety is important when launching rockets. Students should wear safety glasses and stand behind the launcher at all times to avoid being hit by the paper rockets. When using a compressor for the launcher, be sure not to exceed the pressure limit, which could cause parts of the launcher to fall apart or even rupture. The exact limit will depend on the materials you use: the copper launcher we built at the European Space Camp[w1] could withstand more than 8.3 bar (120 psi) of pressure; the NASA PVC launcher[w2] is limited to 2.0 bar (30 psi).

Follow-up

After the launch, the students can analyse the rocket's trajectory to calculate the maximum height (apogee) attained by the rocket and also its initial velocity. To perform the trajectory analysis, some measurements need to be taken before the launch (see Figure 2):

- Length of the rocket body (h, in m)
- Inner diameter of the launch tube (D_i, in m)
- Pressure within the launcher (P, in Pascal) before launch while the valve is closed; this can be read off the foot pump or the compressor, and converted from psi or bar into Pascal. (The pressure is assumed to be constant across the length of the tube.)
- Mass of the rocket (m_r, in kg)
- Angle of elevation (θ, in degrees; Figure 3, page 40).

BACKGROUND

The European Space Camp

The European Space Camp focuses on topics important in the space industry, motivating and inspiring young students by showing them how theoretical ideas can be put into practice.

During the one-week camp at the Andøya Rocket Range in Norway, the northernmost permanent launch facility in the world, 24 students aged 17-20 are treated as real rocket scientists, using professional equipment and solving advanced problems in international teams.

Each team addresses a different aspect of rocketry such as system design, experimental instrumentation, payload assembly or telemetry, all working towards the launch of a 'sounding rocket' to carry instruments. Participants also receive lectures from some of Europe's best scientists, on topics ranging from rocket physics to the Northern Lights. Some of the lectures are supplemented by fascinating hands-on activities, such as building the paper rocket described in this article.

Students interested in applying to participate in the 2012 camp (24 June – 2 July 2012) should visit the website[w3] or email contact@spacecamp.no.

A successful flight

1. The first step is to calculate the initial velocity (v_0) of the rocket. This is equal to the acceleration (a) of the rocket multiplied by the time (t_0) for which the force was acting on it:

$$v_0 = a \cdot t_0 \qquad (1)$$

2. The force acting on the rocket can be calculated using two equations. A_i is the cross-sectional area of the rocket body.

$$F = P \cdot A_i = P \cdot \frac{\pi \cdot D_i^2}{4} \qquad (2)$$

$$F = m_r \cdot a \qquad (3)$$

3. The acceleration of the rocket can be expressed by combining these two equations:

$$a = \frac{P \cdot \frac{\pi \cdot D_i^2}{4}}{m_r} \qquad (4)$$

4. By time t_0, the rocket has travelled a distance equal to the length of the rocket body (h), and this length can be expressed by:

$$h = \tfrac{1}{2} a \cdot t_0^2 \qquad (5)$$

5. To find an expression for t_0, Equation 5 can be rearranged:

$$t_0^2 = \frac{2h}{a} \quad \text{<->} \quad t_0 = \sqrt{\frac{2h}{a}} \qquad (6)$$

The rocket's initial velocity (v_0) can now be expressed in terms of known variables, by inserting the expressions for the time t_0 (Equation 6) and acceleration a (Equation 4) into the equation for initial velocity (Equation 1):

$$v_0 = \frac{P \cdot \frac{\pi \cdot D_i^2}{4}}{m_r} \cdot \sqrt{\frac{2h}{\frac{P \cdot \frac{\pi \cdot D_i^2}{4}}{m_r}}} \quad \text{<->} \quad v_0 = \sqrt{\frac{2h \cdot P \cdot \frac{\pi \cdot D_i^2}{4}}{m_r^4}} \qquad (7)$$

We assume that the rocket has a parabolic flight path, and this allows us to calculate the equation for the trajectory of the rocket.

1. By decomposing the initial velocity vector v_0 into the x and y directions, the distance travelled by the rocket in these directions will then be:

$$x = v_0 \cos(\theta) \cdot t \qquad (8)$$

$$y = v_0 \sin(\theta) \cdot t - \tfrac{1}{2} g t^2 \qquad (9)$$

where g is the gravitational constant.

2. From the equation for the distance travelled in the x direction (Equation 8), an expression of the time t can be inserted into the equation for the distance travelled in the y direction (Equation 9), and this gives us the equation for the trajectory of the rocket:

$$t = \frac{x}{v_0 \cos(\theta)}$$

$$y(x) = v_0 \sin(\theta) \frac{x}{v_0 \cos(\theta)} - \frac{1}{2} g \left[\frac{x}{v_0 \cos(\theta)}\right]^2$$

$$\rightarrow y(x) = v_0 \tan(\theta) - \frac{1}{2} g \left[\frac{x}{v_0 \cos(\theta)}\right]^2$$

3. The apogee of the rocket (H) can then be calculated by:

$$H = \frac{v_0^2}{2 \cdot g} \cdot \sin^2(\theta)$$

Each rocket will probably be able to be launched only once, as the nosecones are usually damaged on landing. However, if the rockets are still intact, the students can carry out repeat experiments and perhaps vary the launch angle.

On the basis of their results, the students could discuss the following questions:

1. How does the weight of the rocket affect the height and distance it travels?
2. Why does wind affect the performance of the paper rocket?
3. What would happen if you placed the fins near the nosecone?
4. Where should the launcher be pointed in relation to the wind direction?

Image courtesy of the European Space Camp

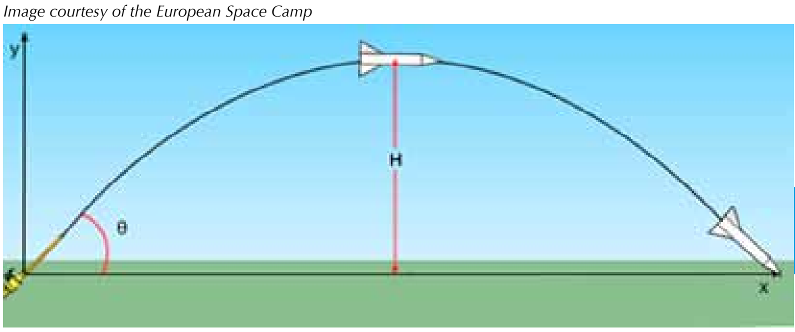


Figure 3: The flight path of the rocket

Web references

w1 – For instructions for building our rocket launcher, see the *Science in School* website: www.scienceinschool.org/2012/issue22/rockets#resources

w2 – Instructions for building a rocket launcher from PVC piping can be downloaded from the NASA website (www.nasa.gov – search for 'High-Power Paper Rocket Launcher Directions') or via the direct link: http://tinyurl.com/7lydxuc

The instructions are part of the NASA rockets educator guide, which offers many more activities for the classroom. See www.nasa.gov or use the direct link: http://tinyurl.com/yx2et6

w3 – To find out more about the European Space Camp and how to apply, see http://www.spacecamp.no

Resources

The US magazine *Make* offers downloadable instructions for building a PVC rocket launcher and paper rocket (http://blog.makezine.com; 'weekend project: compressed air rocket') or use the direct link: http://tinyurl.com/7twlba6

There's also a video showing how to build the launcher on YouTube: www.youtube.com/watch?v=eNFfK5uo6D0

You can even buy a kit with all the pieces you need (though note that the materials are all US standard, so may not be compatible with European parts). See: www.makershed.com or use the direct link: http://tinyurl.com/75vdss4

For instructions in English and Norwegian for building a water rocket, see the website of Sarepta, Using Space in Education (www.sarepta.org), or use the direct link: http://tinyurl.com/7kl7q5q

If you are interested in lessons to take you even further into space, find out how to build a space habitat in the classroom. See:

Tranfield E (2011) Building a space habitat in the classroom. *Science in School* **19**: 43-49. www.scienceinschool.org/2011/issue19/habitat

To find out how to build a CO_2-powered rocket, see:

Rau M (2011) Fizzy fun: CO_2 in primary chool science. *Science in School* **20**: 24-29. www.scienceinschool.org/2011/issue20/co2

For further space-related inspiration, why not browse the other space science articles in *Science in School*? See: www.scienceinschool.org/space

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Jan-Erik Rønningen is a propulsion engineer at Nammo Raufoss and is the leader of the rocket system design group at the European Space Camp. He has worked in the missile products division of Nammo Raufoss since 1997, developing new rocket technology and improving existing hybrid rocket technology. At the European Space Camp, he is the foremost expert on rockets and how they function.

Rohan Sheth is a third-year student at Imperial College London, UK, studying towards a master's degree in mathematics, and is currently spending a year as an Erasmus exchange student at the Humboldt University in Berlin, Germany. He is the British representative at Team Space Camp, which organises the European Space Camp together with the Norwegian Centre for Space Related Education (NAROM).

Frida Vestnes is a first-year student at the Norwegian University of Science and Technology, studying for a master's degree in mechanical engineering. She is the head of Team Space Camp.

Maria Råken is a first-year student at the University of Oslo, Norway, taking a one-year programme in science before starting a master's degree in chemistry at the Norwegian University of Science and Technology. She is a member of the Team Space Camp.

To learn how to use this code, see page 57.

Image courtesy of the European Space Camp

Harnessing the power of the Sun: fusion reactors

Renewable, clean, unlimited energy – how can it be achieved? **Christine Rüth** from EFDA introduces the tokamak, the most advanced fusion device.

Image courtesy of Rita Thielen / Pixelio

The Sun produces vast amounts of energy by fusing light atomic nuclei into heavier particles. If scientists could make this process work sustainably on Earth, we would have a nearly inexhaustible and climate-friendly energy source. A 1 gigawatt fusion power plant would consume only 250 kilograms of fuel per year and produce electricity without emitting carbon dioxide. A coal-powered plant with the same capacity burns 2.7 megatonnes of coal each year. And unlike fission, fusion is not a chain reaction, which makes it inherently and reassuringly safe: to halt the reaction, it is necessary only to stop the supply of fuel. Furthermore, although some components of a fusion reactor will become radioactive during operation, this radioactivity is short-lived: the materials can be safely disposed of after about 100 years, as opposed to the many thousands of years required for a fission reactor (for more details, see Warrick, 2006).

Image courtesy of EFDA-JET

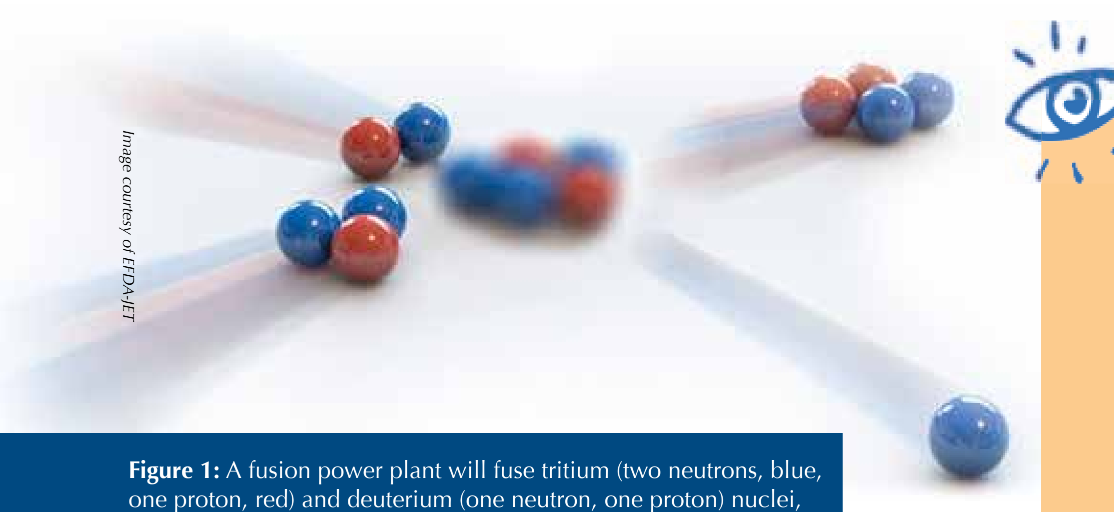


Figure 1: A fusion power plant will fuse tritium (two neutrons, blue, one proton, red) and deuterium (one neutron, one proton) nuclei, generating a helium-4 nucleus and a highly energetic neutron

Scientists at Europe's largest fusion experiment, the Joint European Torus (JET) in Culham, UK, have been making significant progress towards fusion energy for more than 30 years. Nonetheless, the JET experiment still requires more power than it generates – which is not good for a power plant. The next step will be the international experiment ITER, due to be switched on in 2019. ITER is expected to be the first to produce a net power surplus – 500 megawatts from a 50 megawatts input (see Warrick, 2006). This would prove that fusion power plants are viable.

So how does fusion work?

To achieve fusion on Earth, scientists picked the most efficient reaction that takes place in the Sun – the fusion of two isotopes of hydrogen: deuterium and tritium. This reaction yields a helium-4 nucleus and a neutron, which carries 80% of the fusion energy (Figure 1). These fast neutrons are captured in the steel wall of the fusion reactor, which transfers the heat to cooling fluids within the wall, which in turn drive a turbine to produce electricity.

The fusion device

Currently, the most advanced type of fusion device is the tokamak. At the heart of a tokamak is the reactor, a ring-shaped steel vessel with numerous openings for heating, measurement and other systems, and an inner wall lined with removable heat-resistant tiles (Figure 2). To start the fusion process, the vessel is subjected to high vacuum – at JET, this value is around 0.00000001 millibar – and a few grams of deuterium and tritium gas are injected. The gas is heated to above 10 000 °C, at which point the electrons

Image courtesy of EFDA

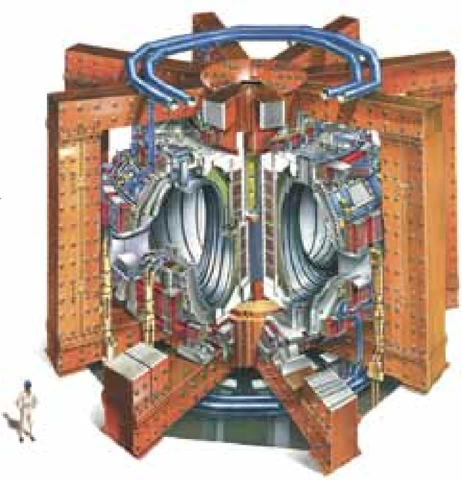


Figure 2: Cutaway diagram of the tokamak JET showing the steel vessel surrounded by eight large copper coils, which produce the magnetic fields. Note the person on the left to give an indication of size

REVIEW

- **Physics**
- **Interdisciplinary**
- **Environmental science**
- **Energy production**
- **Fusion**
- **Sustainability**
- **Ages 10-19**

This article describes the research into producing electrical energy by the fusion of light atomic nuclei – just as the Sun does. It offers physics or science teachers a detailed overview of how fusion works, and what the challenges are to producing energy in a fusion power plant.

The issues of climate change and the greenhouse effect mean that many countries have to solve the problem of how to produce renewable energy in a sustainable way. This article therefore could be useful not only for physics lessons, but also for biology, geography and language lessons.

The article would stimulate discussion around a broad range of questions, including:

- How does fusion work?
- Why, even after 30 years of research, are we not yet producing energy from fusion power plants? What are the challenges?
- What could be the advantages of using fusion reactors?
- Is the production of energy by fusion sustainable?

Gerd Vogt, Higher Secondary School for Environment and Economics, Yspertal, Austria

escape from their nuclei. This ionised gas is called plasma, or the fourth state of matter; it is the basis for producing fusion power.

Conditions for fusion

Getting nuclei to fuse is no easy feat: they are positively charged and repel each other, so they must collide at extremely high speeds to fuse[w1]. Because particle speed corresponds to temperature, the plasma has to be millions of degrees Celsius before the fusion process will start. Although the plasma loses heat at its edges, it can keep itself hot by absorbing energy carried by the helium nuclei produced in the reaction, and this self-sustained fusion process can continue as long as new fuel is injected. However, the challenge is to reach that state and ignite the plasma. To ignite, the plasma must be hot enough, dense enough (to ensure a sufficient fusion reaction rate) and keep its energy for long enough – this last condition is called the confinement time.

The product of the three parameters – temperature, density and confinement time – is the *triple product*, a central parameter in fusion science. Typically, for the fusion reaction to start, the plasma has to be 100-200 million °C, with a density of about 10^{20} particles per cubic metre, (approximately 1 mg/m^3, one millionth of the density of air) and this state must be confined for around 3-6 seconds[w2]. Such a high temperature sounds challenging, but heating is not the problem (see below). Instead, it is the confinement time that is hard to achieve – maintaining that temperature (and density) – because the plasma rapidly loses energy as well as particles (which also carry energy).

How does a tokamak work?

1) Keeping the plasma together: magnetic fields

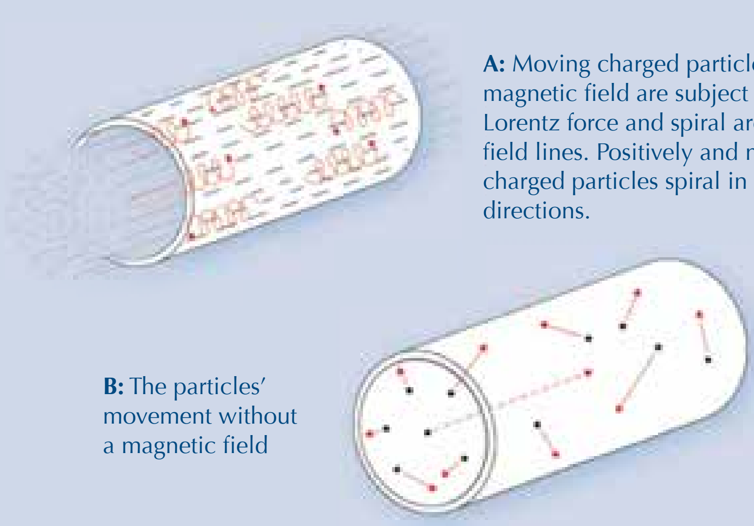
To maintain the high temperature and protect the reactor walls (which

Figure 3: A magnetic field B imparts a force on moving charged particles. The entire electromagnetic force on a charged particle with charge *q* and velocity *v* is called the Lorentz force and is given by

$$\mathbf{F} = q\mathbf{E} + q\mathbf{v} \times \mathbf{B}$$

The first term (*qE*) is contributed by the electric field. The second term *(qv x B)* is the magnetic force and has a direction perpendicular to both the velocity v and the magnetic field *B*. The magnetic force is proportional to *q* and to the magnitude of *v* × *B*. In terms of the angle φ between *v* and *B*, the magnitude of the force equals *qvB* sin φ.

(Source: Encyclopædia Britannica Online (magnetic force: moving charges). Accessed 23 January 2012. www.britannica.com/EBchecked/media/1319/Magnetic-force-on-moving-charges)



A: Moving charged particles in a magnetic field are subject to the Lorentz force and spiral around the field lines. Positively and negatively charged particles spiral in opposite directions.

B: The particles' movement without a magnetic field

Images courtesy of EFDA

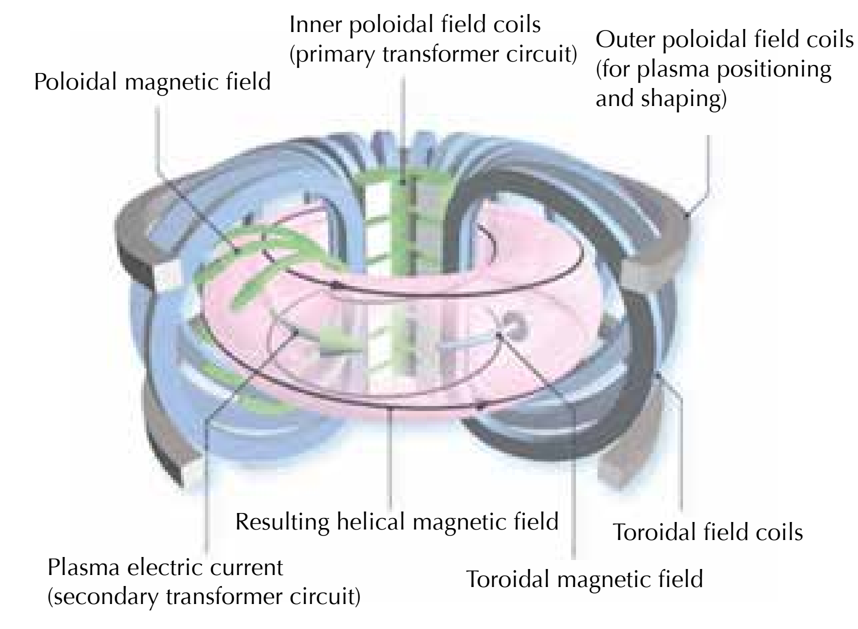


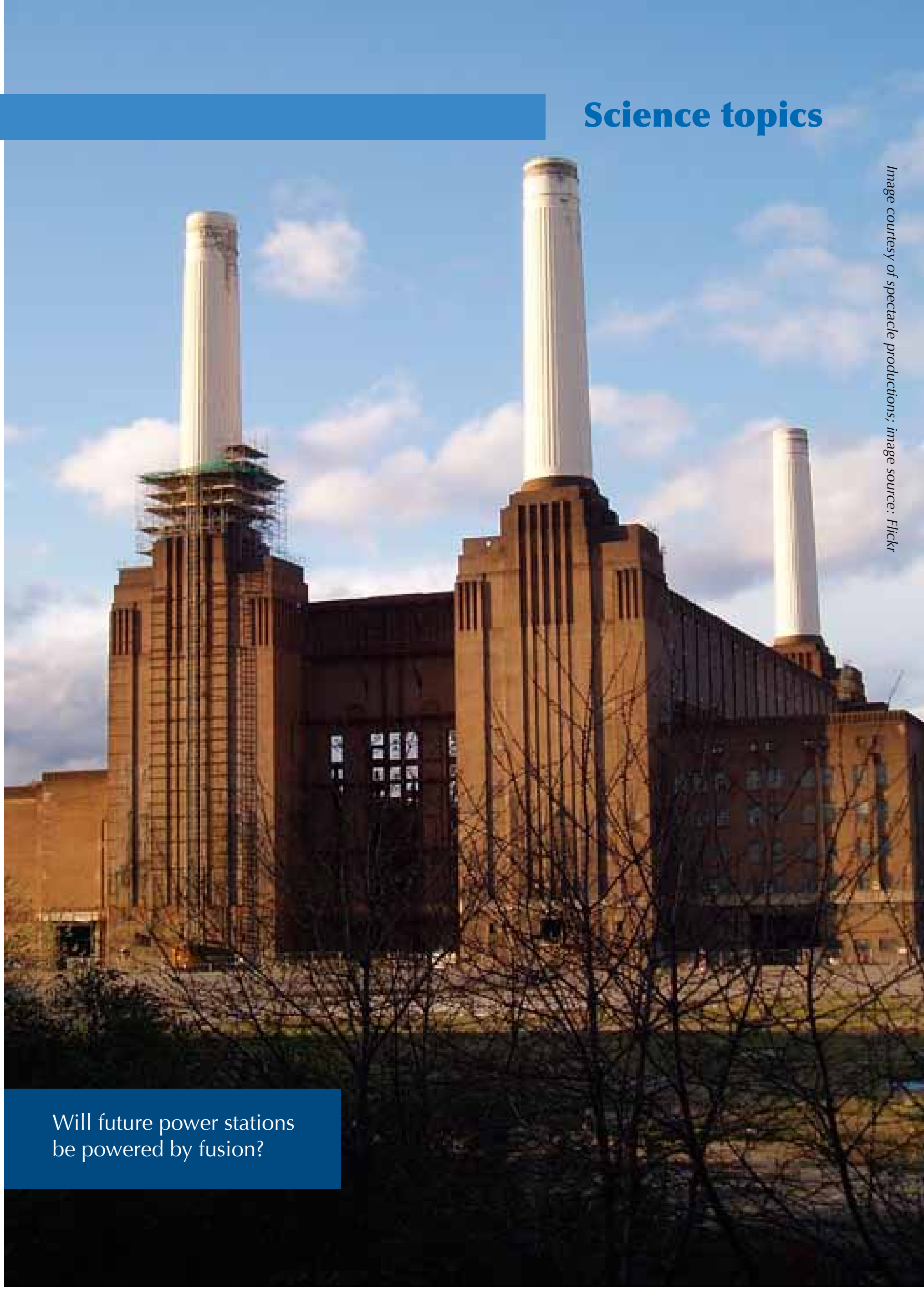
Image courtesy of EFDA

Figure 4: Several sets of coils, together with a plasma current, create the helical magnetic field that confines the plasma. The inner poloidal field coils in the central solenoid induce the plasma current

would otherwise erode quickly), the plasma needs to be kept away from the reactor walls. To do this, fusion scientists exploit the *Lorentz force* experienced by a moving charged particle when a magnetic field, is applied. This force is perpendicular to both the particle's direction of travel and the magnetic field, and therefore causes the particle to rotate around the magnetic field line. As a result, the particle spirals around the field line – with electrons and nuclei moving in opposite directions (Figure 3).

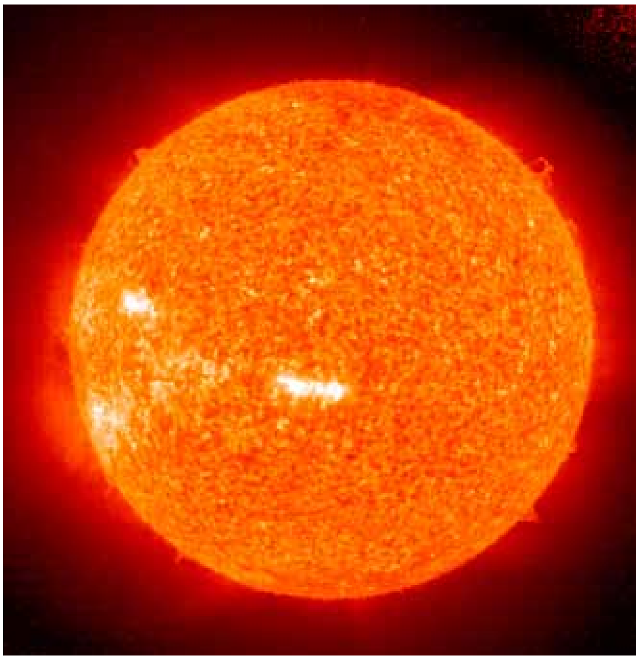
The most advanced magnetic confinement design is the tokamak, a ring-shaped vacuum chamber surrounded by coils. An electric current flowing through one set of coils (the toroidal field coils, Figure 4) generates a ring-shaped magnetic field. The strength of this toroidal (doughnut-shaped) field is not uniform across the ring, because the coils are closer together on the inside of the torus (doughnut). Therefore the particles experience a stronger Lorentz force on the inner side of the field line around which they are rotating. As a result, they gradually drift away from their field line towards the plasma edge.

To reduce this effect, a second magnetic field, the *poloidal field*, is generated. This helical field winds in spirals around the plasma and confines it very effectively. The easiest way to generate a poloidal field is with a plasma current. That in turn is generated when the plasma particles travel along the ring around the toroidal field lines – electrons and ions moving in opposite directions. Like a wire, this current creates a ring-shaped magnetic field around itself. It is induced by a transformer in which the plasma itself acts as a secondary coil around a large primary coil (the inner poloidal field coils). Because the plasma tends to drift vertically, an additional magnetic field created by the outer poloidal field coils is used to control its position and shape.



Will future power stations be powered by fusion?

Image courtesy of spectacle productions; image source: Flickr



The Sun, as imaged by the Extreme Ultraviolet Imaging Telescope aboard the Solar and Heliospheric Observatory (SOHO), stationed 1.5 million kilometres from Earth

Image courtesy of ESA, NASA, SOHO / EIT team

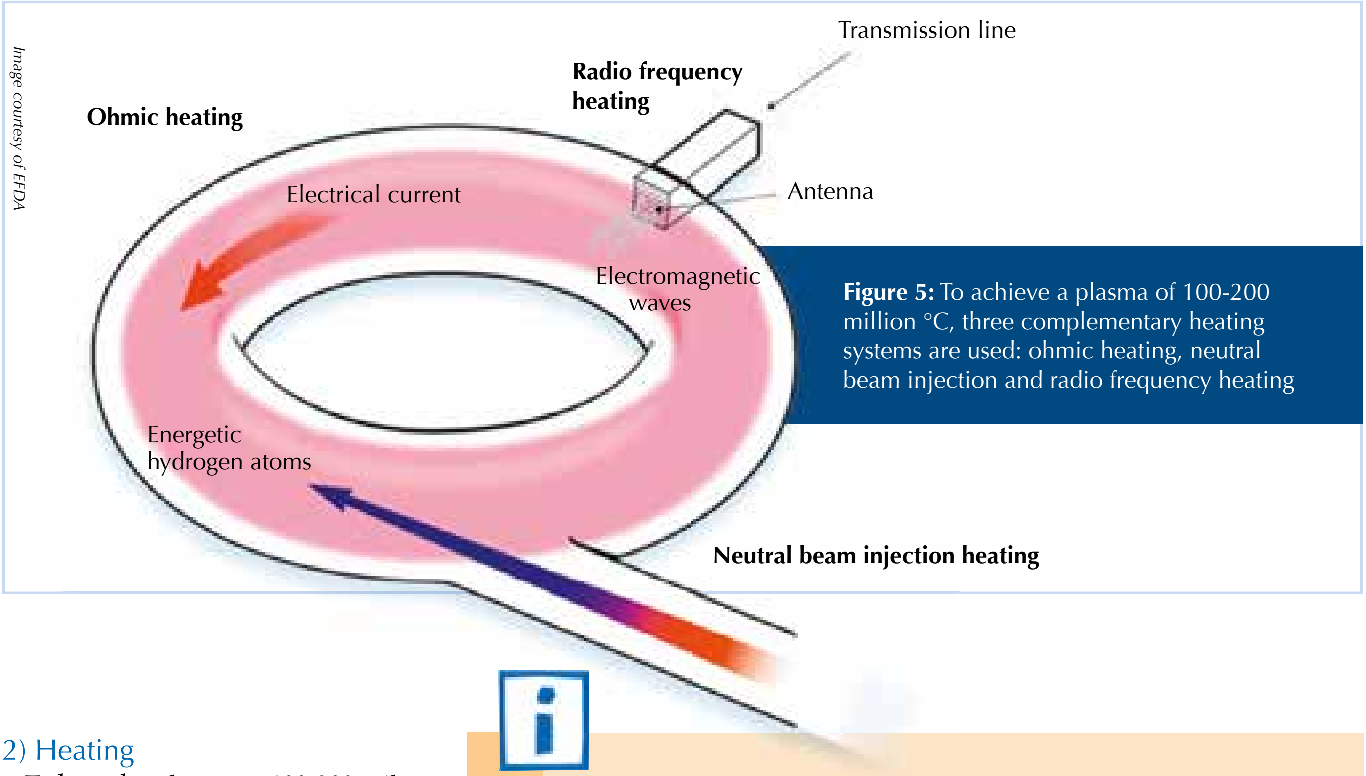


Image courtesy of EFDA

Figure 5: To achieve a plasma of 100-200 million °C, three complementary heating systems are used: ohmic heating, neutral beam injection and radio frequency heating

2) Heating

To heat the plasma to 100-200 million °C, fusion scientists use three complementary systems (Figure 5).

1. The plasma current produces heat (ohmic heating) itself – just as a wire warms up when an electric current flows through it.
2. Beams of high-energy particles, usually hydrogen atoms, are injected into the plasma, where they transfer their energy to the plasma particles via collisions (think of a fast billiard ball hitting a slower ball, which then speeds up). The particle beam is generated by accelerating ions with high voltage. Because charged particles cannot penetrate the magnetic field around the plasma, they are turned into neutral atoms before injection.
   In practice, this is no easy task. To give the particles the necessary velocity, a particle accelerator relies on the attractive force that a high voltage exerts on a charged particle (or ion). However, only uncharged (neutral) particles can penetrate the magnetic field

BACKGROUND

Fusion energy

The fusion of one tritium (T) and one deuterium (D) nucleus releases 17.6 MeV of energy, 80% of which – 14.1 MeV – is carried by the neutron and can be used to produce electricity. Fusing 1 kg D with 1.5 kg T (the mass of T is 1.5 times that of D) yields $14.1/(2*1.67262*10^{-27}) = 4.2*10^{27}$ MeV, taking into account that one D nucleus comprises two protons, each weighing $1.67262 \cdot 10^{-27}$ kg.

One kilogram of D contains $3 \cdot 10^{26}$ nuclei (one D nucleus comprises one neutron and one proton, each weighing $1.6 \cdot 10^{-27}$ kg). Fusing 1 kg of D (with 1.5 kg of T, as the mass of T is 1.5 times that of D) therefore results in $3 \cdot 10^{26}$ fusion reactions and yields $14.1 \times 3 \cdot 10^{26} = 4.2 \times 10^{27}$ MeV of energy.

A fusion power plant with an efficiency of 40% could generate 70 GWh of electricity (with 1 eV = $1.6*10^{-19}$ J or Ws) from 1 kg D, enough to supply 20 average households in an industrial country.

Deuterium can be extracted from seawater, which contains 35 grams per cubic metre. Tritium is not found in large quantities in nature but can be obtained from the light metal lithium, with the aid of some of the neutrons produced in the fusion reaction:

$^{6}Li + n \Rightarrow {}^{4}He + {}^{3}H$ + energy

or in a similar reaction with ^{7}Li. Most of Earth's minerals contain lithium, 2.3 kg of which yields 1 kg tritium. A fusion power plant producing 1 GW electricity (a capacity similar to those of nuclear fission plants) will use 150 kg T and 100 kg D per year.

around the plasma, so the (uncharged) hydrogen atoms must first be stripped of their electrons, accelerated and then neutralised again before injection[w3].

3. Antennae in the vessel wall are used to propagate electromagnetic waves of certain frequencies into the plasma. These cause the spiralling plasma particles to resonate and absorb the wave energy.

Why is fusion power taking so long?

In the 1970s, scientists believed that once they could heat the plasma sufficiently and create large enough magnetic fields, they would have reached the goal of fusion energy. But the plasma has turned out to be highly unstable and loses much more energy than they expected. Since then, scientists have been investigating the physics behind these phenomena and developing methods to control these instabilities. If, as expected, ITER finally generates a net surplus of fusion power, these issues can be considered to be solved and the first fusion power plant could be in operation by 2050.

More about EFDA-JET

As a joint venture, JET is collectively used by more than 40 European fusion laboratories. The European Fusion Development Agreement (EFDA) provides the platform to exploit JET with more than 350 scientists and engineers from all over Europe currently contributing to the JET programme.
EFDA-JET is a member of EIROforum[w4], the publisher of *Science in School*.

To see all EFDA-JET-related articles in *Science in School*, see: www.scienceinschool.org/efdajet

Acknowledgement

Thanks are due to Örs Benedekfi, former head of EFDA public information, for his contribution to this article.

Reference

Warrick C (2006) Fusion – ace in the energy pack? *Science in School* **1**: 52-55. www.scienceinschool.org/2006/issue1/fusion

Web references

w1 – At the 2007 Science on Stage international teaching festival, Zoltán Köllö won a prize for his simple demonstration of nuclear fusion and the Coulomb barrier using a couple of drops of water and the base of a drinks can. To learn how to do it,

Image courtesy of Khánh Hmoong; image source: Flickr see: www.esa.int/SPECIALS/Science_on_Stage/SEMRE58OY2F_0.html

To find out more about Science on Stage, the network of European science teachers, see: www.scienceonstage.eu

w2 – To learn more about fusion, fusion reactors and EFDA-JET, see: www.efda.org

In particular, for the full story of JET, its design and results, see: http://tinyurl.com/scienceofjet

To watch a video of a plasma pulse in JET, see the multimedia section of the EFDA website (www.efda.org/multimedia; 'Video Gallery' then 'JET Experiment') or use the direct link http://tinyurl.com/plasma-pulse

w3 – For more details of how the high-energy particle beams are produced, see the EFDA website (www.efda.org) or use the direct link: http://tinyurl.com/neutral-beam

w4 – To find out more about EIROforum, see: www.eiroforum.org

Resources

To learn more about fusion in the Sun, see:

Westra MT (2006) Fusion in the Universe: the power of the Sun. *Science in School* **3**: 60-62. www.scienceinschool.org/2006/issue3/fusion

For a comprehensive overview of fusion research in Europe, including background information on plasma physics and reactor types, as well as wonderful animations and videos, see: www.efda.org

To find out how scientists accidentally created plasma in their microwave, and how they used it for their research, see:

Stanley H (2009) Plasma balls: creating the 4th state of matter with microwaves. *Science in School* **12**: 24-29. www.scienceinschool.org/2009/issue12/fireballs

If you enjoyed reading this article, why not take a look at the full collection of articles on fusion published in *Science in School*? See: www.scienceinschool.org/fusion

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Dr Christine Rüth is the editor of the EFDA newsletter *Fusion in Europe*. She did her physics PhD in the field of climate research and finds it interesting to be involved now in climate-friendly energy solutions. After working as a physicist in industry, she gained a master's degree in science communication and has worked since then as a science and technology communicator.

To learn how to use this code, see page 57.

Image courtesy of Britta Tewes / Pixelio

Image courtesy of Khánh Hmoong; image source: Flickr

Genetic fingerprinting: a look inside

- Biology
- Genetics
- Forensic science
- Ages 14-19

The idea of using DNA to identify one individual in the world is mind-blowing. The genetic fingerprinting of an individual relies on the sequences are that not used in coding, but how are these fingerprints created? This article explains.

The ability to identify criminals from DNA databases raises important questions: is it ethical to hold human DNA in such databases or is it a breach of human rights? Should there be a DNA fingerprint for every person or just those who are arrested? How long should the DNA profile be kept?

Students may wish to discuss how genetic fingerprinting can help diagnose genetic diseases, as well as its application in the fight against poaching and species extinction. Ideally they should be able to try the technique for themselves, either as a real or a simulated experiment.

Shelley Goodman, UK

REVIEW

In popular TV detective series, genetic fingerprinting is commonly used to identify criminals. **Sara Müller** and **Heike Göllner-Heibült** take a look behind the scenes.

The idea of distinguishing people by their genetic characteristics is not new. Discovered in 1900 by Karl Landsteiner[w1], ABO blood typing was the first genetic marker to be used in forensics, later complemented by MN blood groups (1927) and the Rhesus factor (1937). Even when we analyse all three blood group systems simultaneously, however, about one in ten people give identical results; this is what makes blood transfusions possible. For forensic purposes, however, it is a disadvantage: the results may tell you that your blood sample *does not* come from Suspect X, but they cannot tell you with any acceptable level of certainty that it *does* come from Suspect Y.

Advances were made in the 1970s and 80s, with the analysis of different forms of enzymes (isoenzymes) in red blood cells and blood serum. The certainty that the sample really came from the suspect depended on

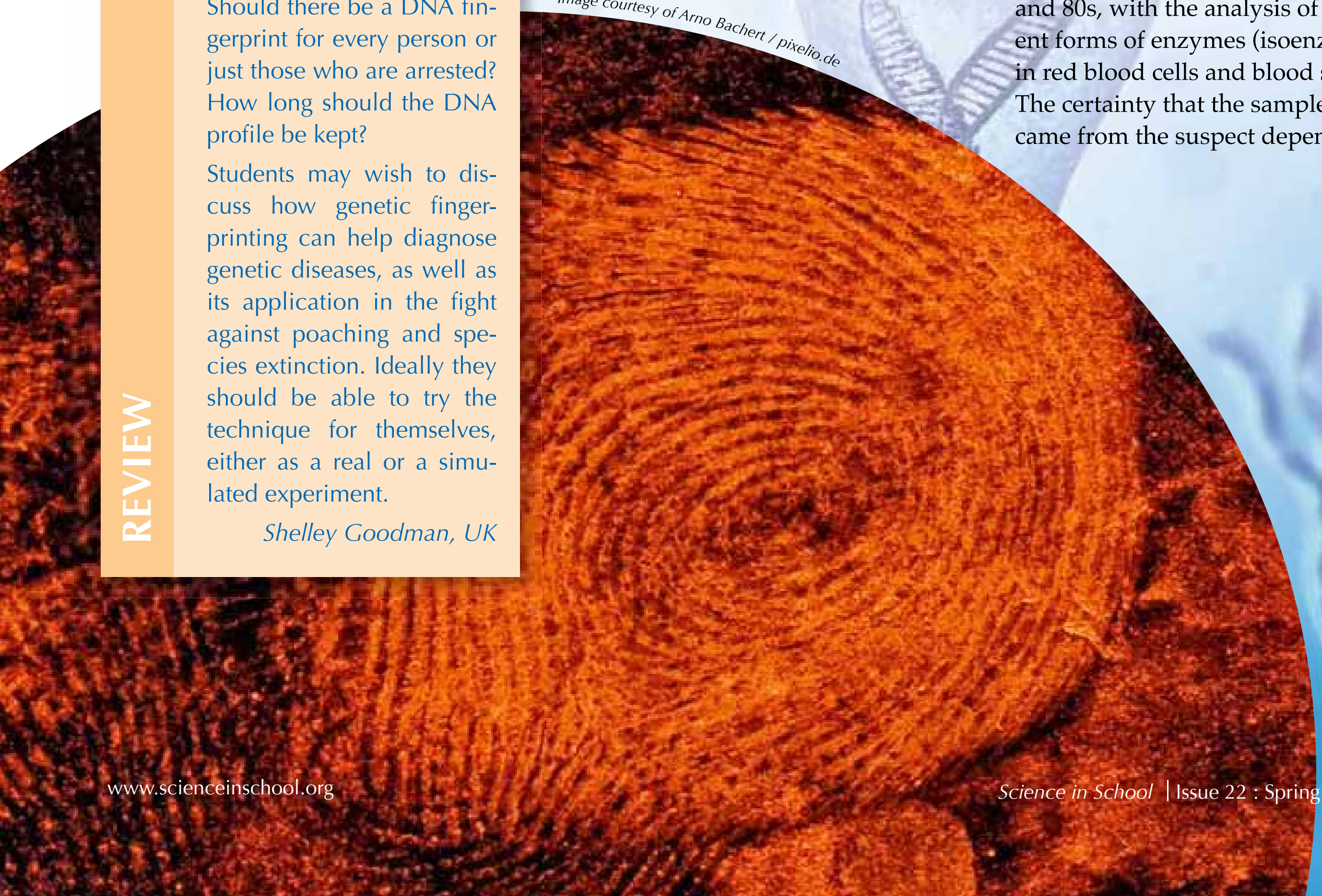

Image courtesy of Arno Bachert / pixelio.de

Image courtesy of Alex Mit / iStockphoto.com

Image courtesy of Darryl Leja, NHGRI / NIH

From base pairs to chromosomes (not to scale): how DNA is packaged

the number of proteins analysed (usually four); we call this certainty the *power of discrimination*. The power of discrimination that these combined techniques offered was still only 1:1000, better than the 1:10 power of blood group analysis but still not good enough. To get a better power, we needed to take a closer look at our genetic composition.

Our genetic composition – who we are

The human genome consists of 46 paired chromosomes: 23 from our mother, 23 from our father. We therefore have two of each chromosome (except – in the case of men – sex chromosomes) and thus two copies of each gene.

The main component of chromosomes is deoxyribonucleic acid (DNA), which contains information for building the proteins we need for life. However, of our 3 billion base pairs (bp), only about 4% actually code for proteins; the rest is often just 'filling' consisting of repetitive sequences organised in clusters. If you compare the DNA of two humans, most of it is identical, with the variability found largely in these repetitive sequences.

Different people can have different numbers of repetitions of these sequences: one person may have five repeats at a specific DNA *locus* (site); another person may have seven. Using samples, e.g. from blood or semen, we can analyse the repetitive sequences at several DNA loci; we call this analysis a *genetic fingerprint*. Like fingerprints, genetic fingerprints can be used to distinguish individuals.

Although the term 'genetic fingerprinting' (or *genetic profiling*) is commonly used, not everybody is aware that it actually encompasses two very different techniques, only one of which is commonly used in forensics today.

Early genetic fingerprinting: restriction fragment length polymorphism

The first method of genetic fingerprinting was invented in 1984 by Alec Jeffreys[w2], who used repeated DNA sequences known as variable number tandem repeats (VNTRs; e.g. sequence D1S80, $(AGGACCACCAGGAAGG)_n$). These sequences, 10-100 bp per repeat,

Image courtesy of Ulla Trampert / pixelio.de

Genetic fingerprinting can be used in conservation work, for example to analyse confiscated ivory can be investigated using restriction enzymes, which work like molecular scissors to cut the DNA at defined sequences (*recognition sequences*). In our entire genome, a 6 bp recognition sequence will occur around 730 000 times. This means that if you cut the genome with a particular restriction enzyme, you will get around 730 000 *restriction fragments* of varying lengths. And this is where the VNTRs become important: the number of repeats in a particular VNTR cluster may vary

Image courtesy of Sara Müller

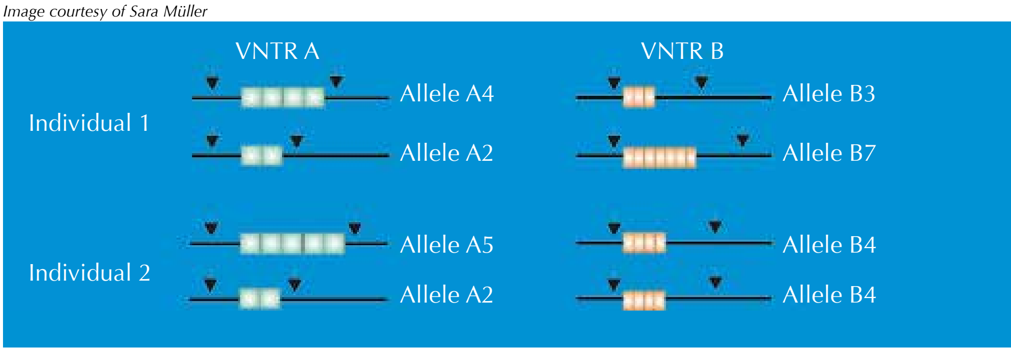

Figure 1: Overview about two VNTRs from two different individuals. Sites cut by restriction enzymes (molecular scissors) are indicated by an arrow. Depending on the number of VNTR repeats, DNA fragments of different sizes are generated (see also Figure 2, Step 4)

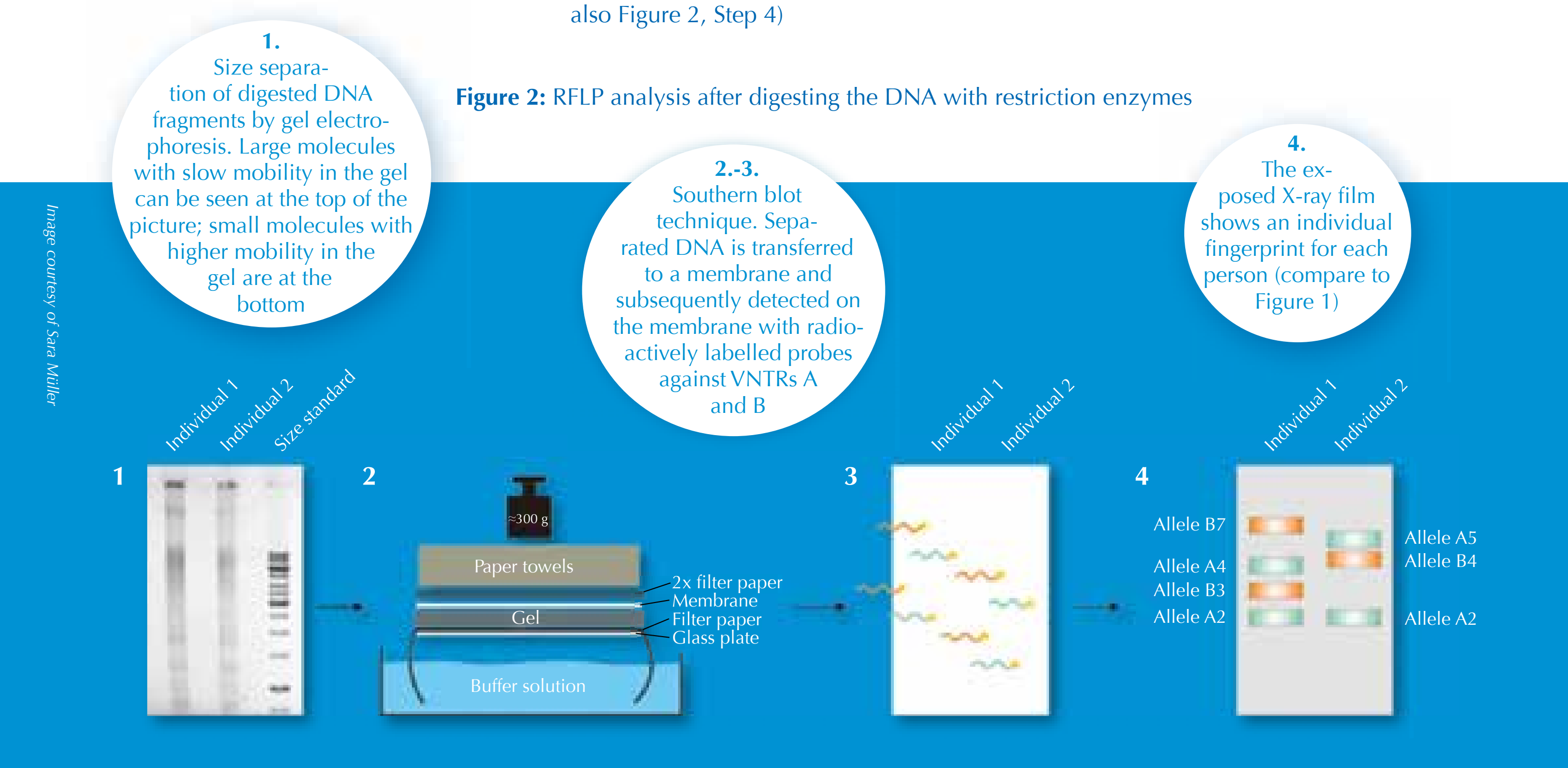

Figure 2: RFLP analysis after digesting the DNA with restriction enzymes

Image courtesy of Sara Müller

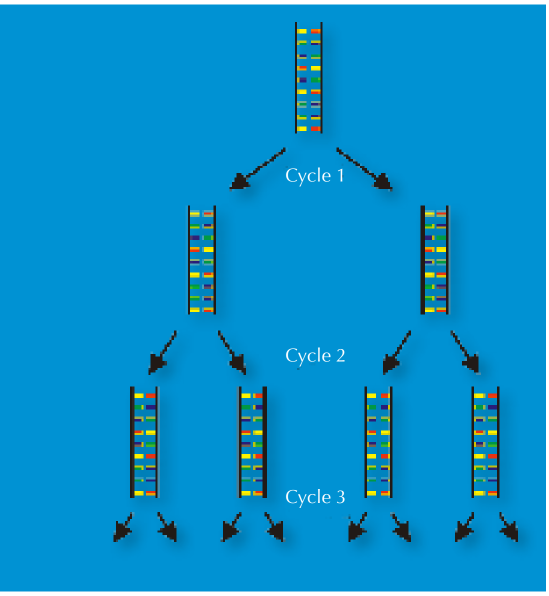

Figure 3: A simplified diagram showing how defined DNA fragments are amplified by PCR

between individuals, which means that the length of the corresponding restriction fragment will vary between individuals too (Figure 1). We call this phenomenon *restriction fragment length polymorphism* (RFLP).

Of the 730 000 restriction fragments, only some will differ between individuals – too few to be detected by eye. Instead, scientists used a technique called Southern blotting, which allowed only the sequences of interest to be visualised. To do this, they separated the restriction fragments according to size by gel electrophoresis, using an electric current to pull the charged molecules of DNA through a gel. The distance travelled was determined by the fragment size (Figure 2, Step 1, page 51). Next, they transferred the DNA to a membrane (Figure 2, Step 2) and applied a radioactively labelled probe that was complementary to the VNTR(s) of interest. The probe hybridised (stuck) to the matching sequences (Figure 2, Step 3) and by placing the membrane on an X-ray film, the scientists got a picture of the radioactively labelled bands, each of which represented a different length of fragment (Figure 2, Step 4). This picture was the genetic fingerprint.

So how many VNTRs needed to be compared to reliably distinguish between individuals? If the scientists chose VNTRs with enough variation (e.g. D1S80, which may be repeated anything from 15 to 41 times), they only needed to compare four different VNTRs to have a power of discrimination of 1:1 million – much better than the 1:10 offered by ABO blood typing.

The current technique: PCR-based genetic fingerprinting

Kary Mullis' invention, in 1983, of the polymerase chain reaction (PCR) won him the Nobel Prize in Chemistry[w3, w4]. This invention, together with the discovery in the late 1980s of short tandem repeats (STRs) – 2-9 bp repeated sequences, also called microsatellites – paved the way for the high-speed genetic fingerprinting technique that forensic scientists use today.

PCR enables a DNA locus of interest (e.g. the 4 bp STR known as D18S51, $(AGAA)_n$), to be amplified exponentially, generating a billion copies of a single DNA molecule in a few hours (Figure 3). For forensic scientists, this has the advantage of making the analysis of even very tiny samples possible – as few as 30 cells (see Table 1 on page 54 for a comparison with RFLP-based genetic fingerprinting).

For PCR analysis, we need STRs flanked by sequences that are identical in all human beings (we say these sequences are *conserved*). We then use *primers* – short molecules that are complementary to the conserved flanking sequences (genes 1134 and 1135 in Figure 4) – to initiate the PCR. Once the DNA has been amplified, we can separate it either by gel electrophoresis (Figure 5) or, in modern forensic science, by electrophoretic automated sequencing (Figure 6), and visualise it as a genetic fingerprint.

We have two copies of each chromosome, so we also have two copies of each STR. If, for each copy of the STR, someone has the same number of repetitions (i.e. the same allele), the PCR analysis reveals only one size of DNA fragment: the person is homozygous for that STR allele (green arrow in Figure 5, corresponding to individual 2 in Figure 4). If the two chromosomes carry non-identical alleles for that STR, we see two sizes of fragment and say that the person is heterozygous (red arrow in Figure 5, corresponding to individual 1 from Figure 4).

If we only analyse one STR, the chance of two unrelated people having the same PCR-based genetic fingerprint is high – between 1:2 and 1:100 (blue arrows in Figure 5). This is because STRs have fewer alleles and lower heterozygosity than the VNTRs used in RFLP-based genetic fingerprints. To overcome this disadvantage, we analyse multiple STRs simultaneously; with 16 STRs, as is common in forensic casework in Germany, we can achieve a power of discrimination of 1:10 billion (equivalent to one person in the world's population; Figure 6).

Image courtesy of Siegfried Fries / pixelio.de

Image courtesy of Sara Müller

Figure 4: Schematic view of the STR D1S80 (the nomenclature 'D1S80' tells us that the STR is on chromosome 1, in region 80) from two individuals. The black arrows represent the primers used to amplify that specific STR

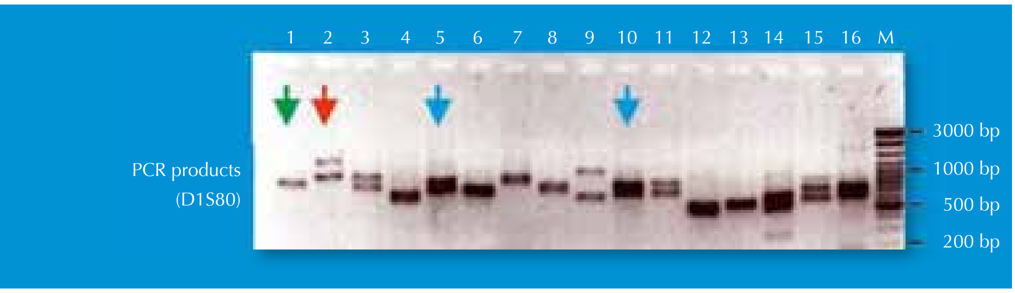

Image courtesy of Sara Müller

Figure 5: Genetic fingerprint of the D1S80 locus generated by school students (channels numbered 1–16) with their own DNA. The lane on the far right, labelled M, contains DNA fragments of known sizes, used as markers.

The individual indicated with the green arrow is homozygous for the D1S80 locus (only one band is visible). The individual marked by the red arrow is heterozygous (two bands). The blue arrows indicate two students who are heterozygous and have the same number of repeats for each allele at the D1S80 locus; this means that they cannot be distinguished by the fingerprint. They may be twins, but it is also likely that two unrelated persons will have the same number of repeats if only one STR is analysed

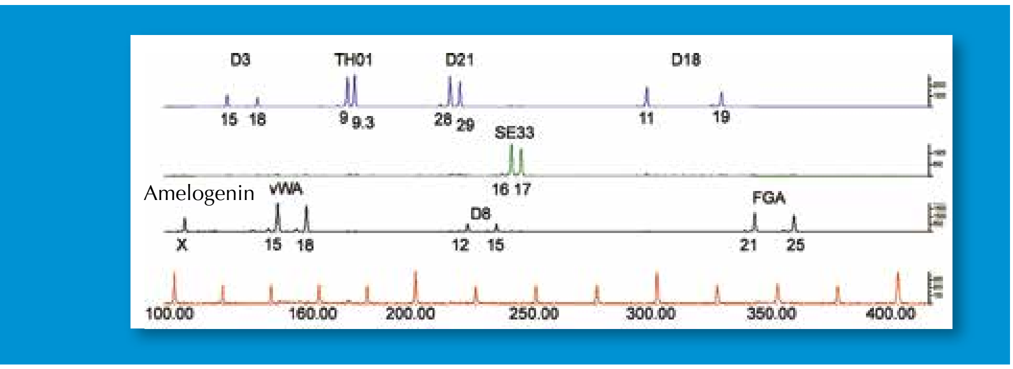

Image courtesy of Sara Müller

Figure 6: Electropherogram of a woman, generated by multiplex PCR and subsequent electrophoretic automated sequencing. Eight STRs (D3, TH01, D21, D18, SE33, vWA, D8 and FGA) and amelogenin (which indicates the sex) were analysed. The blue, green and black curves represent amplified STRs (with repeat numbers below the peaks). The red curve is the marker (DNA fragment size labelled in bp)

Applications of genetic fingerprinting

We now know what genetic fingerprinting is, but how is it used? PCR-based genetic fingerprinting is widely applicable in forensic investigations: it enables the police to exclude or identify suspects on the basis of genetic material such as hair follicles, skin, semen, saliva or blood (see the story that can be downloaded from the *Science in School* website[w5]). A genetic fingerprint alone, however, is not sufficient evidence for a conviction, as close relatives may have very similar fingerprints (and monozygotic twins will normally have identical ones). And to complicate international forensic investigations, although there is a European recommendation to analyse 16 STRs, each country can decide *which* STRs to analyse, which makes comparisons difficult.

The PCR-based method is also used in humans for paternity testing, diagnosing many genetic diseases (e.g. Huntingdon's disease), identifying disaster victims, tracing family trees, tracking down missing people and investigating historical figures (e.g. the last Tsar of Russia and his family). In other organisms, it can be used for conservation purposes (e.g. to analyse confiscated ivory), in drug investigations (e.g. by analysing seized cannabis plants), to control food or water quality (e.g. by identifying contaminating microbes), in medicine (e.g. to detect viral infections such as HIV, hepatitis or influenza) and in bioterrorism investigations (e.g. to identify microbial strains).

RFLP-based genetic fingerprinting, although largely obsolete due to the many advantages of the PCR method (Table 1), is still used for classifying plants and animals in basic research. It is particularly useful when there is insufficient information about the genome of the species – remember that for the PCR method, we need regions that vary widely between individuals

Table 1: Comparison of RFLP- and PCR-based DNA fingerprinting

	RFLP	PCR
Amount of starting DNA	30–50 µg	At least 200 pg (about 30 cells) for a complete STR pattern
Sensitivity	+	+++
DNA quality required for analysis	Complete genome	No complete genome necessary; degradation products also sufficient because of the short sequences involved (total sequence length of an STR, including multiple repeats and flanking sequences, approximately 50– 500 bp)
Time	Days to weeks	Hours
Discrimination power per locus	+++ (More alleles and more heterozygosity per locus)	+ (Fewer alleles and less heterozygosity per locus) *However, multiplex PCR amplification (PCR with more than one pair of primers) and multi-colour labelling allows more than 16 loci to be examined simultaneously, which provides an excellent power of discrimination*
Repeat unit	10 bp to 100 bp	2 bp to 9 bp (in forensic case work, mainly 4 bp)
Automated detection	Not possible	High-throughput sample processing possible
Number of validated loci (important if relatives are involved)	Limited number	Large number
Risk for contamination	+	+++
Additional safety measures required?	Yes (because of radioactive probing)	No (no radioactive probing)

After Butler 2010

Image courtesy of e3000; image source: Flickr

Identical twins would normally have identical genetic fingerprints

and are flanked by conserved regions of known sequence.

Genetic fingerprinting at school

The isolation of DNA at school gives the students a 'wow' moment when they realise that they are looking at the complete genetic information coding for an organism – a few cotton wool-like strands of DNA that were precipitated by alcohol. It is easy to perform at school using saliva[w6] (or epithelial cells from commercially available kits), peas (Madden, 2006), tomatoes, onions[w7] or calf thymus (although check local restrictions on using calf thymus at school)[w8].

Subsequent PCR of a specific STR in human DNA, for example D1S80 or TH01, can be performed at school[w6], using reasonably priced commercially available kits[w9] if necessary. If your

Image courtesy of the Romanov Collection, General Collection, Beinecke Rare Book and Manuscript Library, Yale University

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Nicholas II, the last Tsar of Russia (left and above), with Tsarina Alexandra and their four daughters (above). Following the Russian revolution, the entire family were murdered in July 1918. Their bodies, found in 1979 (the Tsar, Tsarina and three daughters) and 2007 (the Tsarevich and the remaining daughter, Maria) were identified by genetic fingerprinting

school has no access to a thermocycler, the thermocycling can be carried out in three water baths, although it is tedious and very hands-on.

If this equipment is not available, there are kits that both simulate and simplify the whole process of genetic fingerprinting[w10]. These kits contain fragments of DNA that simulate the amplification of different alleles of a single STR or VNTR. (In fact, they are restriction fragments of DNA from plasmid or lambda phage DNA.) The DNA requires electrophoresis and subsequent staining so that students are able to compare 'amplified' DNA sequences from a sample of evidence with those of several suspects. Of course, this is very different from detecting amplified STRs using electrophoretic automatic sequencing (and does not even accurately represent the visualisation of VNTRs using Southern blotting, as the DNA is stained directly on the gel), but it nonetheless demonstrates the principles of the analytical process. When using these simulation kits, the students should be made aware that the experiments give the impression that differences between individuals can be easily identified, which is not the case.

Acknowledgement

The authors would like to thank Wolfgang Nellen for his ideas about the article and for allowing the Science Bridge instructions to be made available free of charge.

They are also grateful to Shelley Goodman for her advice on using commercial kits at school.

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Web references

w1 – In 1930, Karl Landsteiner was awarded the Nobel Prize in Physiology or Medicine for his discovery of human blood groups. To learn more, see the Nobel Prize website (www.nobelprize.org) or use the direct link: http://tinyurl.com/7zjg2mw

w2 – To learn more about Alec Jeffreys' discovery, see: www2.le.ac.uk/departments/genetics/jeffreys

and http://genome.wellcome.ac.uk/doc_wtd020877.html

In an interview with *Science in School*, Alec Jeffreys discusses his discovery:
Hodge R, Wegener, A-L (2006) Alec Jeffreys interview: a pioneer on the frontier of human diversity. *Science in School* **3**: 16-19. www.scienceinschool.org/2006/issue3/jeffreys

w3 – The 1993 Nobel Prize in Chemistry was won by Kary B Mullis for his invention of the polymerase chain reaction (PCR). To learn more, see the Nobel Prize website (www.nobelprize.org) or use the direct link: http://tinyurl.com/7fkh7ku

w4 – To learn more about PCR, watch this video: www.youtube.com/watch?v=_YgXcJ4n-kQ

w5 – A story illustrating how genetic fingerprinting is used in forensic casework can be downloaded from the *Science in School* website: www.scienceinschool.org/2012/issue22/fingerprinting#resources

w6 – For instructions (in both English and German) for PCR-based genetic fingerprinting at school, see the Science Bridge website (www.sciencebridge.net) or use the direct link: http://tinyurl.com/89u7m53

Science Bridge membership is normally necessary to access these in-

structions, but readers of this article can request them free of charge from sara.mueller@sciencebridge.net

w7 – For instructions (in German) for isolating DNA from onions or tomatoes, see the Science Bridge website (www.sciencebridge.net) or use the direct link: http://tinyurl.com/7z56745

To find out how to isolate DNA from tomatoes (instructions in English), see: http://ucbiotech.org/edu/edu_aids/TomatoDNA.html

w8 – For instructions (in German) for isolating DNA from calf thymus, see the Science Bridge website (www.sciencebridge.net) or use the direct link http://tinyurl.com/6lwu83g

w9 – For examples of commercial kits that can be used for PCR analysis at school, see the 'crime scene investigator PCR basics kit' on the Biorad website (www.bio-rad.com) and the PCR advanced kits on the Edvotek website (www.edvotek.co.uk).

w10 – For examples of commercial school kits that simulate and simplify the process of genetic fingerprinting, see the 'forensic DNA fingerprinting kit' on the Biorad website (www.bio-rad.com) and the 'DNA fingerprinting by restriction fragmentation patterns kits' (under 'forensics' and 'DNA') on the Edvotek website (www.edvotek.co.uk).

Resources

To learn more about repetitive DNA and methods (RFLP and PCR), see:

Klug WS, et al. (2008) *Concepts of Genetics* 9th edition. San Francisco, CA, USA: Pearson. ISBN: 9780321524041

To find out more about PCR and STRs, as well as worldwide DNA databases and forensic case work, see:

Goodwin W, Linacre A, Hadi S (2010) *An Introduction to Forensic Genetics*. Chichester, UK: Wiley-Blackwell. ISBN: 978-0470710197

For a classroom game on DNA detection, see:

Wallace-Müller K (2011) The DNA detective game. *Science in School* **19**: 30-35. www.scienceinschool.org/2011/issue19/detective

The University of Arizona, USA, describes how to carry out a school activity on DNA profiling using STRs. See: www.biology.arizona.edu or use the direct link: http://tinyurl.com/7zteg9n

The website of the DNA Initiative: Advancing Criminal Justice Through DNA Technology offers a free online course in forensic DNA analysis. Aimed at lawyers, it and the accompanying case study provide an excellent introduction to the topic. See: www.dna.gov/training/otc

To investigate a real database of STRs, visit the website of the US National Institute of Standards and Technology: www.cstl.nist.gov/biotech/strbase

To learn more about how genetic diseases are diagnosed, see:

Patterson L (2009) Getting a grip on genetic diseases. *Science in School* **13**: 53-58. www.scienceinschool.org/2009/issue13/insight

If you enjoyed this article, you may like to browse the other biology-related articles in *Science in School*. See: www.scienceinschool.org/biology

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Sara Müller studied biology, chemistry and education at the University of Kassel, Germany, and received her teaching degree for secondary schools in 2008. In December 2011, she finished her PhD thesis in the field of epigenetics, also at the University of Kassel. Since February 2012, she has been doing her practical training as a teacher in Göttingen, Germany. She has been a member of the executive board of Science Bridge[w6] for the past seven years.

Heike Göllner-Heibült is a DNA forensic science expert with a background in molecular biology. She studied human biology at the Philipps University of Marburg, Germany, spending several months at the Erasmus University of Rotterdam, the Netherlands, and at the University of Cambridge, UK. In 2002, she finished her PhD in molecular biology at the Institute of Molecular Biology and Tumor Research in Marburg and started work in DNA forensics as a DNA expert and reporting officer. She currently works for the Forensic Science Institute of the office of criminal investigation in Berlin, Germany.

To learn how to use this code, see page 57.

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Therefore, before undertaking any activity, users should always carry out their own risk assessment. In particular, any local rules issued by employers or education authorities MUST be obeyed, whatever is suggested in the *Science in School* articles.

Unless the context dictates otherwise, it is assumed that:

- Practical work is carried out in a properly equipped and maintained science laboratory
- Any electrical equipment is properly maintained
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- Eye protection is worn whenever there is any recognised risk to the eyes
- Pupils and / or students are taught safe techniques for activities such as handling living organisms, hazardous materials and equipment.

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CERN

The European Organization for Nuclear Research (CERN) is one of the world's most prestigious research centres. Its main mission is fundamental physics – finding out what makes our Universe work, where it came from, and where it is going. See: www.cern.ch

EFDA-JET

The Joint European Torus (JET) investigates the potential of fusion as a safe, clean, and virtually limitless energy source for future generations. It can create the conditions (100-200 million °C) in the plasma sufficient for fusion of deuterium and tritium nuclei to occur – and it has observed fusion power to a maximum of 16 MW. As a joint venture, JET is collectively used by more than 40 European fusion laboratories. The European Fusion Development Agreement (EFDA) provides the platform to exploit JET, with more than 350 scientists and engineers from all over Europe currently contributing to the JET programme. See: www.jet.efda.org

EMBL

The European Molecular Biology Laboratory (EMBL) is one of the world's top research institutions, dedicated to basic research in the life sciences. EMBL is international, innovative and interdisciplinary. Its employees from 60 nations have backgrounds including biology, physics, chemistry and computer science, and collaborate on research that covers the full spectrum of molecular biology. See: www.embl.org

ESA

The European Space Agency (ESA) is Europe's gateway to space. Its mission is to shape the development of Europe's space capability and ensure that investment in space continues to deliver benefits to the citizens of Europe and the world. See: www.esa.int

ESO

The European Southern Observatory (ESO) is the foremost inter-governmental astronomy organisation in Europe and the world's most productive astronomical observatory. It operates telescopes at three sites in Chile – La Silla, Paranal and Chajnantor – on behalf of its 15 member states. At Paranal, ESO's Very Large Telescope is the world's most advanced visible-light astronomical observatory. ESO is the European partner of the revolutionary astronomical telescope ALMA, and is planning a 40-metre-class European Extremely Large optical / near-infrared Telescope, the E-ELT. See: www.eso.org

ESRF

The European Synchrotron Radiation Facility (ESRF) is one of the most intense sources of X-rays in the world. Thousands of scientists come every year to ESRF to carry out experiments in materials science, biology, medicine, physics, chemistry, environmental science, and even palaeontology and cultural heritage. See: www.esrf.eu

European XFEL

The European XFEL is a research facility currently under construction in the Hamburg area of Germany. It will generate extremely intense X-ray flashes to be used by researchers from all over the world. See: www.xfel.eu

ILL

The Institut Laue-Langevin (ILL) is an international research centre operating the most intense steady neutron source in the world. Every year, more than 800 experiments are performed by about 2000 scientists coming from all over the world. Research focuses on science in a variety of fields: condensed matter physics, chemistry, biology, nuclear physics and materials science. See: www.ill.eu

Diving into research at the EIROforum teacher school

Does school feel a long way from modern science? **Sonia Furtado Neves** explains how 30 teachers recently experienced the thrill of cutting-edge research.

Image courtesy of Artechnique

The Institut Laue-Langevin

"See, everybody's trying to discuss how to take this back and apply it at school," said Alan Glaze, pointing to an animated huddle at the next lab bench. Alan was one of 30 European science teachers attending the EIROforum teacher school in Grenoble, France, in October 2011. Selected from a pool of 200 candidates, these teachers spent four days exploring how electrons, neutrons and X-rays are providing exciting new insights into fields from palaeontology to magnetism.

Mathematics. Chemistry. Biology. Physics. In school, the sciences are often approached as discrete entities, but in practice these subjects overlap and intertwine. Under the title 'The physics and chemistry of life', a combination of lectures and practical tutorials enabled the teachers to experience that interdisciplinarity first-hand, imbibing the atmosphere of cutting-edge research and interacting with researchers.

In this school, the teachers did more than just visit the state-of-the-art facilities of three of the EIROforum[w1] members: the European Synchrotron Radiation Facility (ESRF)[w2], the European Molecular Biology Laboratory (EMBL)[w3] and the Institut Laue-Langevin (ILL)[w4]. At ESRF beamlines, they learned how to prepare protein crystals and explored the computational steps necessary to go from raw data to a three-dimensional model of protein structure, whereas at EMBL they observed a ribosome under a cryo-electron microscope. At ILL, they were able to see for themselves that neutrons sometimes behave like a wave (when they diffract) and sometimes like particles (when they hit a detector).

The lectures, which provided a context for the practical sessions as well as additional examples to share with their students, were also welcomed. "It was a fantastic way for me to get up-to-date scientific knowledge, too," says Lidia Minza, who teaches chemistry in Romania. Reawakening the teachers' excitement about the process of scientific research was a central aim of the course.

Image courtesy of P Ginter / ESRF

The building of the Partnership for Structural Biology, a joint activity of EMBL, ESRF and ILL

Lidia, Alan and the other 28 teachers were also enthusiastic at the prospect of swapping tips and experience with fellow practitioners, and discussing science education in their countries and in Europe in general – an exchange made possible thanks to the support from the course organiser, EIROforum, which covered participants' travel and accommodation costs.

And after the course? The aim is that the teachers will spread the insights gained in these four days not only to their current students but also to future classes and colleagues, and ultimately develop their own ways of applying this knowledge in the classroom. Alan intends to do just that: "I'll be going back to make class plans from some of this."

Image courtesy of Jan Pavelka

Web references

w1 – EIROforum is a collaboration between eight of Europe's largest inter-governmental scientific research organisations. It combines the resources, facilities and expertise of its member organisations to support European science in reaching its full potential. One of its activities is to publish *Science in School*. To learn more, see: www.eiroforum.org

w2 – ESRF, which shares a campus in Grenoble, France, with EMBL and ILL, operates the most powerful synchrotron radiation source in Europe. To learn more, see: www.esrf.eu

w3 – EMBL is Europe's leading laboratory for basic research in molecular biology, with its headquarters in Heidelberg, Germany, and an outstation in Grenoble, France. To learn more, see: www.embl.org

w4 – ILL is an international research centre at the leading edge of neutron science and technology, based in Grenoble, France. To learn more, see: www.ill.eu

Resources

Information on the tutorials and additional resources are available online at: http://tinyurl.com/eiroschool

A short video about the course is available on YouTube (www.youtube.com; search for 'Teachers school 2011, Grenoble') or via the direct link: http://tinyurl.com/89k5yds

Image courtesy of Jan Pavelka

Sonia Furtado Neves was born in London and moved to Portugal at the age of three. While studying for a degree in zoology at the University of Lisbon, she worked at Lisbon Zoo's education department; there, she discovered that what she really enjoys is telling people about science. She went on to do an MSc in Science Communication at Imperial College London, and is now the press officer at the European Molecular Biology Laboratory (EMBL) in Heidelberg, Germany.

To learn how to use this code, see www.scienceinschool.org/help#QR

The experimental hall and storage ring building of ESRF

Image courtesy of P Ginter / ESRF

Camp of brilliant brains

Petra Nieckchen from EFDA reports on the 23rd European Union Contest for Young Scientists (EUCYS) in Helsinki, Finland.

Sometimes even the richness of the English language is not enough. In their speeches describing participants at the European Union Contest for Young Scientists (EUCYS)[w1], representatives of renowned institutions used words such as "bright", "talented", and "enthusiastic" tirelessly. However, these are insufficient words to describe the young scientists who presented their work.

The perseverance and seriousness with which these 16- to 20-year-old students pursue their projects is astonishing. This generation of highly motivated young researchers has no shyness, and no hesitation in travelling 1500 km or more to present their project in a foreign language. Morten Lennholm, an engineer at JET[w2] – Europe's largest fusion device – attended EUCYS to deliver a talk about the science at JET. He had the chance to visit many stands and was extremely impressed with the young scientists: "Back when I was their age, I would not have had the initiative or the motivation to do the job they have done."

Azza Abdel Hamid Faiad, winner of the EFDA-JET prize

Image courtesy of EUCYS

EUCYS has a long history. Initiated in 1968, it was reborn in 1989 when the European Commission donated the first cash prizes. Over the years, more and more organisations have shown interest in encouraging the next generation of students and have donated prizes. Since 2000, the members of EIROforum[w3] (the EIROs) have each offered a visit to their organisation to a lucky prize winner. More recently, industry has been realising the great opportunity that this camp of brilliant brains presents for picking out potential employees.

The prizes awarded by the EIROs are an invaluable opportunity for promising students to meet 'real' scientists, to present their projects and, importantly, to start networking. EFDA-JET[w2] will be pleased to welcome the 2011 prize winner, Azza Abdel Hamid Faiad, from Egypt[w4]. The 16-year-old impressed the jury with her project, 'Production of hydrocarbon fuel by catalytic cracking of high density polyethylene wastes'. Azza investigated the potential use of waste plastics as a fuel source, testing a variety of catalytic converters.

The other EIROs were equally happy with their chosen young scientists. The prize from CERN, the world's largest particle physics laboratory, was awarded to Florentin Delaine (aged 18), Joseph Gennetay (18) and Jason Loyau (19) from France, for building a robot that can solve the famous Rubik's Cube without further help. The European Space Agency prize went to Andrea Emilio Amedeo Bracesco (19), Jacopo Prinetto (20) and Federica Villa (19) from Italy, who followed Kepler's path in estimating the mass of Jupiter by observing four of the planet's satellites. Erica Portony (18) from the USA can look forward to a visit to the European Molecular Biology Laboratory for developing a novel method of studying the region of a bacterial protein that is important for the bacterium to attach to kidney epithelial cells in its host.

Jane Cox (17), also from the USA, will travel to one of the European Southern Observatory's sites in the Chilean Andes after impressing the jury with her analysis of the amino acid composition of meteorites to distinguish terrestrial from extraterrestrial rocks. The prize from the Institut Laue-Langevin was awarded to Andris Alfrēds Avots (17) and Raivis Eglitis (18) from Latvia for developing a fire-resistant thermal insulation material. Finally, the winners of the European Synchrotron Radiation Facility prize are Michal Habera and Michal Fabian (both 18) from Slovakia for their project on the influence of magnetic fields on free-surface ferrofluid flow. The EIROs are looking forward to welcoming these budding scientists.

The ceremony at which these and many other prizes were awarded took place at Helsinki University main hall, a marvellous early 19th century building. As the prizes were handed out, the prize winners' delight was clearly visible, as was the disappointment of those who hadn't won.

It was a pleasure to exchange information with the next generation of researchers, and somehow comforting that after the award ceremony, these clever scientists turned back into young people – laughing and flirting, enjoying their scientific adventure, their lives, the opposite sex and the prospects of their promising future.

Image courtesy of EUCYS

The main hall of Helsinki University, where the EUCYS award ceremony was held

Image courtesy of Birgit Winter; image source: pixelio.de

Helsinki harbour, in the heart of the city

One of Helsinki's landmarks: the Protestant Cathedral

Image courtesy of Bildpixel; image source: pixelio.de

To learn how to use this code, see www.scienceinschool.org/help#QR

Web references

w1 – For more information about EUCYS 2011 in Helsinki, see: http://eucys2011.tek.fi

w2 – Situated in Culham, UK, JET is Europe's largest fusion device. Scientific exploitation of JET is undertaken through the European Fusion Development Agreement (EFDA). To learn more, see: www.efda.org

EFDA-JET is a member of EIROforum, the publisher of *Science in School*. To learn more, see: www.eiroforum.org

w3 – EIROforum is the publisher of *Science in School*. It combines the resources, facilities and expertise of its member organisations to support European science in reaching its full potential. To learn more, see: www.eiroforum.org

w4 – To listen to an interview with EFDA-JET prize winner Azza Abdel Hamid Faiad, visit the EFDA website (www.efda.org) or use the direct link: http://tinyurl.com/82zumt7

Resources

Rueth C (2012) Harnessing the power of the Sun: fusion reactors. *Science in School* **22**: 42-48. www.scienceinschool.org/2012/issue22/fusion

You may also enjoy the *Science in School* series of articles about fusion. See www.scienceinschool.org/fusion

Dr Petra Nieckchen is the head of EFDA's public information office. After her PhD in physical chemistry, she decided to follow her real passion and move into public information.

Designing a school: taking science out of the classroom

How can the architecture of a school influence its teaching? Allan Andersen, head teacher of Copenhagen's Ørestad Gymnasium, tells **Adam Gristwood** and **Eleanor Hayes**.

Take a walk around the breathtaking Ørestad Gymnasium[w1] (upper-secondary school) in Copenhagen, Denmark and the school might strike you as quite unusual. As you ascend the spiralling timber staircase connecting different parts of the school, you look over students lounging on orange beanbags discussing class work in specialised 'learning zones'. You could come across a student film crew working on their latest media project, or a science class dissecting frogs in an open workspace. There are few traditional classrooms and there is certainly no head teacher's office.

"The design of the building encourages teachers to organise lessons that involve the students more," explains Allan Anderson, head teacher of the school. "The idea is that teachers talk a lot less and, hopefully, students work a lot more, with more active work, more communication and more knowledge sharing."

In the four years since the completion of the building, the school (whose students are aged 16-19) has become the most popular in Denmark. Its concept embraces a theme that runs through every class, from media, communication and culture (the school's profile) to languages, mathematics and science – that the physical design of the building matters. And it is a formula that is working.

"Perhaps students do not learn more in terms of traditional content, but they do learn about co-operation, expressing themselves and working with technology," Allan says. "For example, because of our strength in media and communications, teachers try to teach science in a different way. They use a lot of videos and virtual laboratories. Instead of traditional experimental write-ups, students might create a podcast or develop an advertising campaign working together with local organisations or industry. Lots of students who have difficulties writing about science find it much easier to talk about it. The school has only been running for four years, so I can't yet prove it, but I do believe that our students leave with competencies that they don't gain in the same amount from other schools."

Teaching takes advantage of innovative workspaces that can be customised according to the needs of the lesson, which can have particular benefits in science classes. "By having a school that is built to enable students to work on their own, you can

Image courtesy of Peter Junker, Gesamtmetall

The Science on Stage international festival made good use of the open spaces at the Ørestad Gymnasium in 2011

The open spaces of the Ørestad Gymnasium gave plenty of opportunities for teachers to swap ideas at the Science on Stage international festival in 2011

Image courtesy of Peter Junker, Gesamtmetall

move away from science teaching that sees teachers demonstrating the same experiments they have used for 30 years, and instead make science more stimulating and hands-on," Allan says.

Equally important are interactions between teachers and students in large central spaces, rather than in cramped corridors, and through this emphasis on interdisciplinarity and personalisation, the school has been given a heart where social interactions have become a key part of education.

"The idea is that teachers and students should have interactions that move away from that of authority and towards that of colleagues," Allan explains. "When they know there are teachers around who can help them with their work, then students can develop a responsibility for their own learning."

There are plans to build in more private space for teachers to 'recharge', but the overall goal of a new vision of content, subject matter, organisation and learning remains unchanged. "The school has become somewhat of an icon," Allan explains. "On a school day, it is a really exciting experience just to walk around and see everything that is happening. In a normal school everything happens behind closed doors, but here you can see everything."

* * *

In April 2011, the Ørestad Gymnasium hosted the international teaching festival of Science on Stage, the network for European science teachers (Hayes, 2011). The spectacular architecture of the school provided a perfect backdrop for the eager exchange of ideas between 350 of Europe's best teachers.

In April 2013, the next Science on Stage international festival will take place in Słubice-Frankfurt (Oder) on the Polish-German border, with teachers from 27 countries sharing their most innovative teaching ideas in workshops, on-stage performances and the teaching fair. Each country will be represented by a delegation of teachers selected in a national event.

Participation is free for the delegates. To be considered for your national delegation, contact your national organisers now, as the selection events are already beginning in some countries. There will also be a limited number of places for non-delegates, who will be charged a registration fee. See the Science on Stage Europe website[w2] for details.

Reference

Hayes E (2011) Science teachers take to the stage. *Science in School* **19**: 6-9. www.scienceinschool.org/2011/issue19/sons

Web reference

w1 – To read more about Ørestad Gymnasium, see: www.oerestadgym.dk/welcome

w2 – To learn more about Science on Stage Europe, see: www.scienceonstage.eu

Resources

For a glimpse inside the Ørestad Gymnasium, see a 24-hour film of the school: www.youtube.com/watch?v=je2Fc4uS9bo

To read other *Science in School* articles about Science on Stage, see: www.scienceinschool.org/sons

If you enjoyed this article, you might like to browse the other teacher profiles in *Science in School*. See: www.scienceinschool.org/teachers

Adam Gristwood studied politics and philosophy at the University of York, UK, before working in events and publishing, focusing on education, local government, policing and science. Since 2009, he has been a communications officer at the European Molecular Biology Laboratory.

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