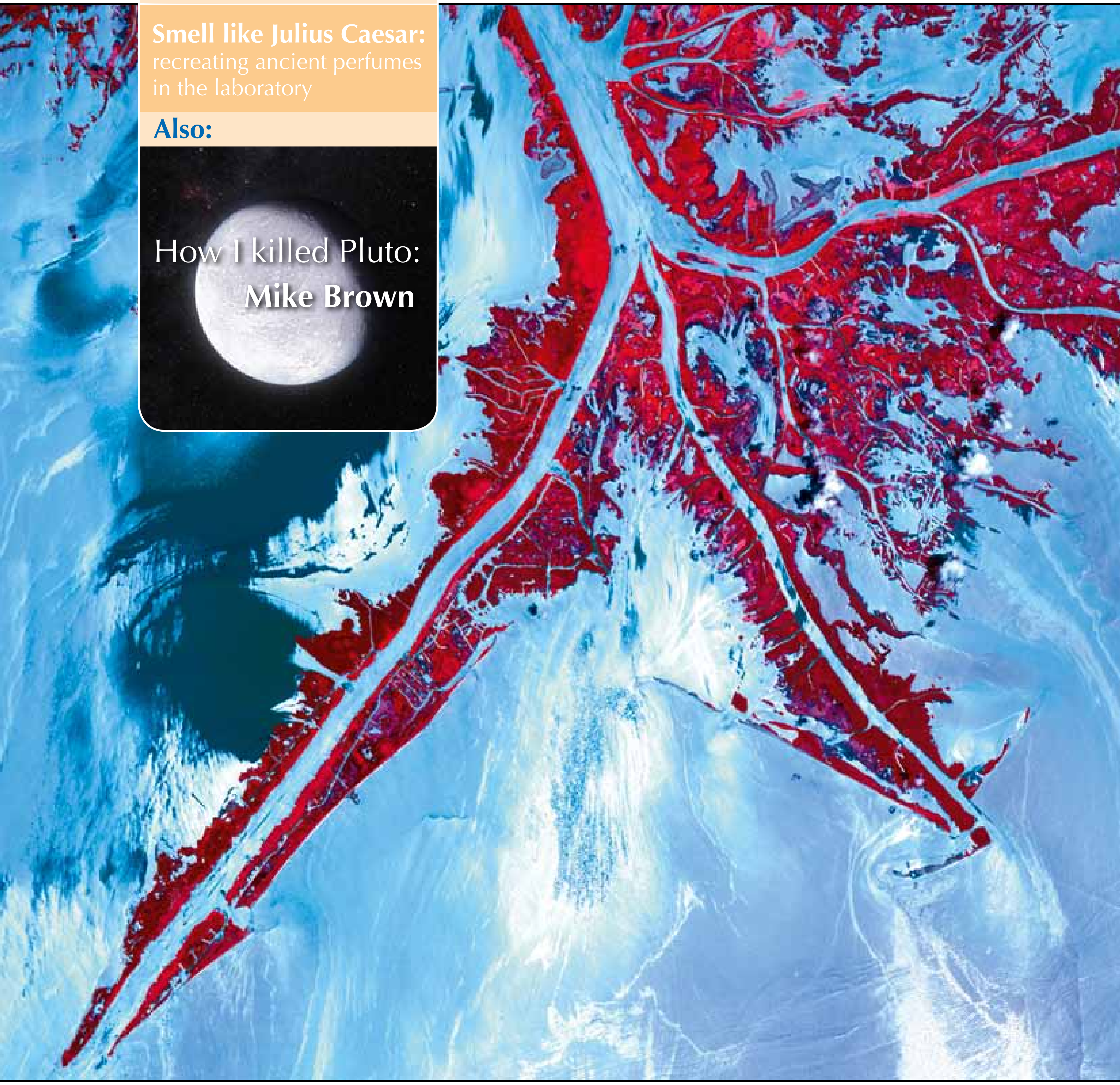
Winter 2011 Issue 21

SCIENCE in SCHOOL

The European journal for science teachers

In this issue:



Smell like Julius Caesar:
recreating ancient perfumes in the laboratory

Also:

How I killed Pluto:
Mike Brown

Published and funded by EIROforum

Editorial

Thanks to everyone who donated to *Science in School* via our website; we were overwhelmed by the positive response. With your help and the support of our advertisers, we have been able to print and distribute Issue 21, as those of you who are reading this in print will realise. The battle is not yet won, however: we need support from all of you to help us to continue printing your favourite science-teaching journal – and to provide it to you free of charge.

Speaking about charging – have you ever seen a lion charging an ostrich? That is an extremely fast race. Discover the secret of the fastest flightless bird (page 12). In Europe, we rarely have to run for our lives as ostriches do, but when we need to get anywhere in a hurry, we often seem to get stuck in a crowd. How can physics help us to understand and control crowd behaviour, and how can we investigate it in the classroom (page 23)?

Crowds are prone to form when we try to squeeze through small gaps such as exits. On a smaller scale, molecules also move through small gaps as they pass through membranes – a phenomenon that is essential to kidney dialysis and can be investigated simply at school (page 28).

Dialysis is a well-understood procedure, but medical treatments are not always easy to explain. If you take a tablet and get better, was it really the drug or could it have been the colour of the tablet – just a placebo effect? This effect is no mumbojumbo, but a real physiological phenomenon (page 52).

Staying with the topic of medicine, Massimiliano Mazza tells us about a new idea of how tumours could be formed that may lead to new treatment strategies: cancer stem cells (page 18). The first reports of tumours date back to ancient Egypt. Following in the steps of ancient scientists, chemistry teacher Gianluca Farusi shows us how to prepare Julius Caesar's favourite perfume (page 40).

To create perfume, you can extract aromatic chemicals from plants – but extraction can also work in the other direction: some plants can remove poisonous chemicals from polluted soil or water, such as the aquatic fern *Azolla*. Vered Yephlach-Wiskerman uses it in a classroom project on bioremediation (page 36).

Air pollution can also be a problem, caused not only by obvious sources such as cars or industry, but even by something as beautiful as fireworks. Using freely available databases, this and other aspects of air pollution can be investigated in the classroom (page 47).

While we're looking at the sky, do you remember when the Solar System used to have nine planets? Astronomer Mike Brown played an important role in the reclassification of Pluto as a dwarf planet (page 6). He based his observations on the visible part of the electromagnetic (EM) spectrum, but other astronomers analyse X-rays and gamma-rays from space (page 57). Finally, right at the other end of the EM spectrum are radio waves. If you tune into them at just the right frequency, you may catch Swiss chemistry teacher Marco Martucci on air with his science show. Read the interview with him online, where you will also find our book reviews and further materials (www.scienceinschool.org).

Marlene Rau
Editor of *Science in School*
editor@scienceinschool.org
www.scienceinschool.org

To learn how to use this code, see page 65.

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.

Inspiring science teachers worldwide

The *Science in School* website offers articles in 28 languages and is read worldwide. The free quarterly journal is printed in English and distributed across Europe.

Advertising: tailored to your needs

Choose between advertising in our print journal, website or e-newsletter. For maximum impact, reach our entire readership with an advertorial (online and in print). Online and in print, we have a total of 100 000 readers per quarter.

- The majority of our readers are secondary-school science teachers.
- Our readership also includes many primary-school teachers, teacher trainers, head teachers and others involved in science education.
- The journal reaches significant numbers of key decision-makers: at the European Commission, the European Parliament and in European national ministries.

For more information, see www.scienceinschool.org/advertising or contact advertising@scienceinschool.org

Subscribing

Register free online to:

- Subscribe to the e-newsletter
- Request a free print subscription (limited availability)
- Post your comments.

How can I get involved?

Science in School relies on the involvement of teachers, scientists and other experts in science education.

- Submit articles or reviews
- Join the referee panel
- Translate articles for publication online
- Tell your colleagues about *Science in School*
- Make a donation to support the journal.

See www.scienceinschool.org or contact us.

Contact us

Dr Eleanor Hayes / Dr Marlene Rau
Science in School
European Molecular Biology Laboratory
Meyerhofstrasse 1
69117 Heidelberg
Germany.

Contents

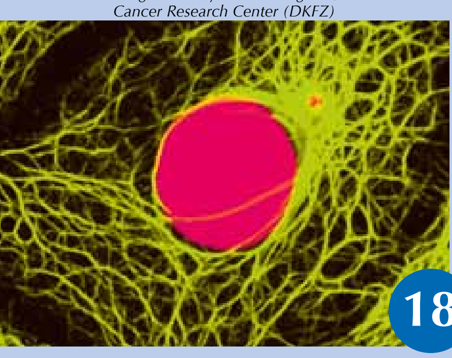
Image courtesy of ESO / L Calçada

6

Image courtesy of John Carnemolla / iStockphoto

12

Image courtesy of Lutz Langbein, German Cancer Research Center (DKFZ)



18

Image courtesy of 澎湖小雲雀; image source: Flickr

36

Image courtesy of angelhell / iStockphoto

52

Additional online material

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

To read the whole issue, see: **www.scienceinschool.org/2011/issue21**

To learn how to use this code, see page 65.

Trapped by scientists: antimatter, cholesterol and red blood cells

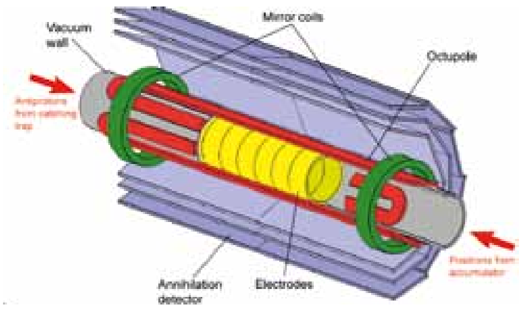


Image courtesy of CERN

Schematic drawing of the ALPHA experiment: antiprotons are captured and held in ultrahigh vacuum using electric and magnetic fields. Mixing them with positrons, the antihydrogen atoms are formed and confined using an octupole magnetic trap and mirror coils

CERN:
Antimatter in the trap

Precision studies of antimatter – the elusive counterpart of matter – should help scientists to find out why all antimatter produced in the Big Bang has disappeared. The most promising new 'anti-object' is antihydrogen, the simplest element in a hypothetical anti-world.

The first nine antimatter atoms ever were produced at CERN in 1995, but they moved almost with the speed of light – too fast for precision studies. The next breakthrough came in 2002, when the ATHENA experiment showed how to make millions of slow-moving antihydrogen atoms. But it has taken another nine years for the next step – trapping a few of them. Now researchers from the ALPHA experiment at CERN have succeeded in trapping 38 anti-atoms for 172 milliseconds. In July 2011, they announced that they had managed to keep a few hundred of them for as long as 15 minutes. This paves the way for a precision comparison of the energy levels between hydrogen and antihydrogen, using ultra-precise laser systems.

To learn more, see the research publication:

The ALPHA Collaboration (2011) Confinement of antihydrogen for 1000 seconds. *Nature Physics* 7: 558-564. doi: 10.1038/nphys2025

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:
JET fired up again

After the installation of 4500 new tiles on its inside walls and 22 months since its last run, the EFDA-JET fusion device re-started experiments at the end of August 2011.

A crowded JET control room with an expectant air of excitement witnessed a spectacular, 1 mega-ampere plasma as it developed and lasted for 15 seconds. This was a remarkable achievement as typically, the first plasma after an engineering shutdown appears only as a brief flash of light lasting less than a second.

Imminent experiments will further the understanding of how the next international fusion device, ITER, will behave, as the new JET wall tiles are identical to those proposed for ITER. Such an impressive start at JET will only heighten the optimism around the project – as it continues to blaze a trail towards commercial fusion power.

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.jet.efda.org.

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

The JET control room as the first new plasma developed

Image courtesy of EFDA-JET

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).

A theoretical scenario of star formation

Image courtesy of ESA-AOES Medialab

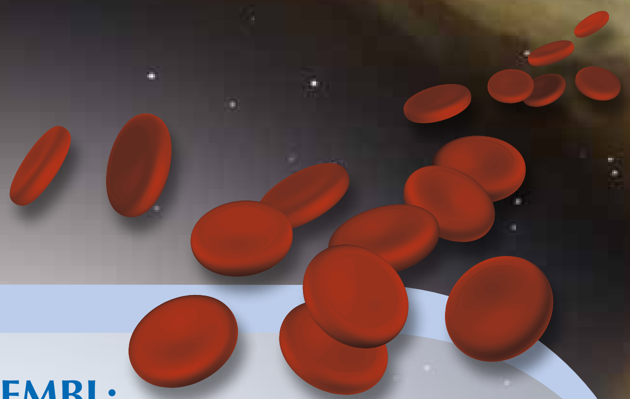


Image courtesy of André-Pierre Olivier

EMBL: Making red blood cells green

Scientists at the European Molecular Biology Laboratory (EMBL) in Monterotondo, Italy, have devised a new labelling technique which enables researchers to pinpoint for the first time those stem cells in the bone marrow that give rise to red blood cells.

The bone marrow of mammals such as humans or mice contains several different groups of stem cells, which differentiate into the different types of blood cell. With the new technique, cells in a mouse's bone marrow turn fluorescent green only when they commit to becoming red blood cells. This is possible thanks to a fluorescent tag that attaches itself to the RNA product of a gene that only this lineage of blood cells expresses. The new technique, which other labs have already started to use, will help scientists to understand which groups of stem cells give rise to red blood cells, and to probe the molecular mechanisms involved.

To learn more, see the research publication:

Rasmussen KD, O'Carroll D (2011) The miR-144/451eGFP allele, a novel tool for resolving the erythroid potential of hematopoietic precursors. *Blood* **118(11)**: 2988-2992. doi: 10.1182/blood-2011-04-350728

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: Herschel paints new story of galaxy evolution

The rate of star formation peaked in the early Universe, about 10 billion years ago. Back then, some galaxies were forming stars ten or even a hundred times more frequently than our galaxy does today. Such high birth rates are very rare in the nearby, present-day Universe, and always seem to be triggered by galaxies colliding with each other. So astronomers assumed that this had been true throughout history.

Using the European Space Agency (ESA)'s Herschel infrared space observatory, however, astronomers have recently looked at galaxies that are very far away, and have thus seen them as they were billions of years ago. This peek into the past revealed that galaxies do not need to collide with each other to drive vigorous star birth. The finding overturns this long-held assumption and paints a clearer picture of how stars form – and galaxies evolve.

For more information, see the research publication:

Elbaz D et al. (2011) GOODS–*Herschel*: an infrared main sequence for star-forming galaxies. *Astronomy & Astrophysics* **533**: A119. doi: 10.1051/0004-6361/201117239

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

Image courtesy of ALMA (ESO / NAOJ / NRAO); visible light image: the NASA / ESA Hubble Space Telescope

The Antennae Galaxies (also known as NGC 4038 and 4039) are a pair of distorted colliding spiral galaxies about 70 million light-years away, in the constellation of Corvus (The Crow). This view combines ALMA observations, made in two different wavelength ranges during the observatory's early testing phase, with visible-light observations from the NASA / ESA Hubble Space Telescope

ESO:
ALMA opens its eyes

The world's most complex ground-based astronomy observatory, the Atacama Large Millimeter / submillimeter Array (ALMA), has officially opened for astronomers. ALMA is a partnership of Europe, North America and East Asia in co-operation with the Republic of Chile. The European Southern Observatory (ESO) is the European partner in the project. The first released image, from a telescope still under construction, reveals a view of the Universe that cannot be seen at all by visible-light and infrared telescopes. Thousands of scientists from around the world have competed to be among the first few researchers to explore some of the darkest, coldest, furthest and most hidden secrets of the cosmos with this new astronomical tool.

For more information, see the press release: www.eso.org/public/news/eso1137

To learn more about ALMA, see:

Mignone C, Pierce-Price, D (2010) The ALMA Observatory: the sky is only one step away. *Science in School* **15**: 44-49. www.scienceinschool.org/2010/issue15/alma

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:
X-rays rock!

Scientists at ESRF have developed a technique that may revolutionise chemical analysis of rare materials such as meteoric rock samples and fossils. Normally, X-rays are sensitive to the shape and texture inside a given sample but cannot reveal chemical states. The new technique produces X-ray images of the chemical bond distribution for key elements embedded deep in opaque materials, which was thought to be impossible without destroying the sample. "I would love to try this on Martian or Moon rocks. We can see not only which elements are present in any inclusion but also if there is oxygen, whether it belongs to a water molecule or not," says Simo Huotari, from Helsinki, Finland, who developed the technique.

To learn more, see the news item ('New synchrotron technique could see hidden building blocks of life') on the ESRF website (www.esrf.eu) or via the direct link: http://tinyurl.com/69o9g7g

See also the research paper:

Huotari S et al. (2011) Direct tomography with chemical-bond contrast. *Nature Materials* **10**: 489–493. doi: 10.1038/nmat3031

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

Carbon and oxygen are difficult to analyse if they are embedded inside other materials. A new synchrotron X-ray technique can not only detect them, but even distinguish their chemical bonds.

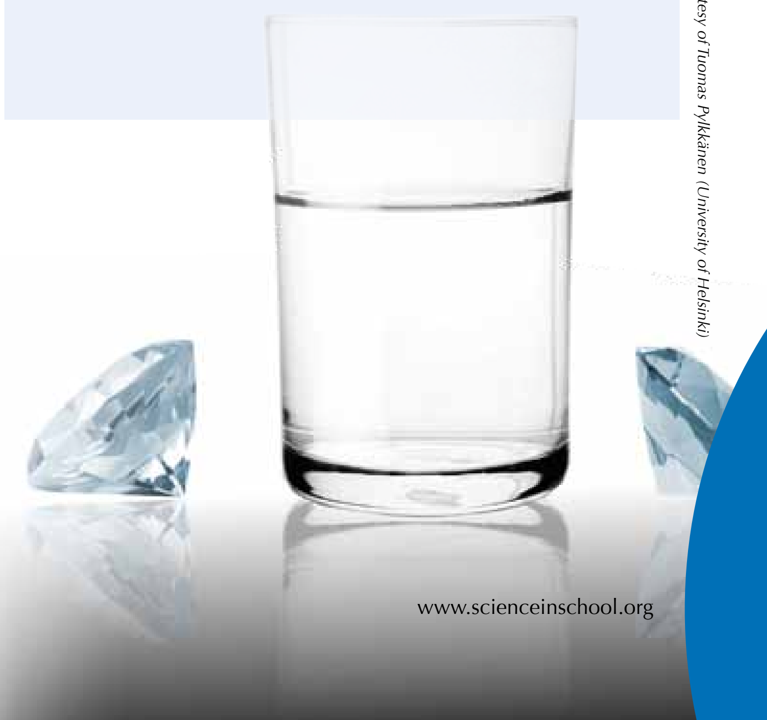


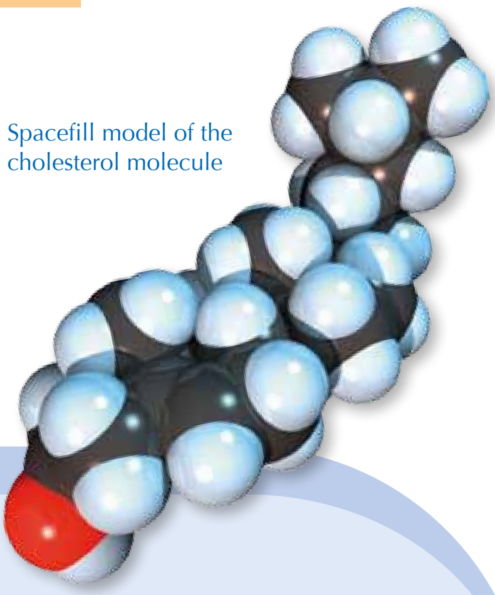
Image courtesy of Tuomas Pylkkänen (University of Helsinki)

European XFEL: The light at the end of the tunnel

European XFEL is a research facility currently under construction in the Hamburg area, 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

Image courtesy of European XFEL

Scientists examine one of the many tunnels that comprise the European XFEL facility. The photograph was taken shortly after the tunnel construction work was completed. At this very spot from 2014 on, electrons will be forced to produce extremely intense X-ray radiation by means of magnetic fields. Before that, they will have been accelerated to almost the speed of light in a tunnel more than 2 km long. Once the machine is fully operational, it would be very dangerous to stand where the three men are, so a sophisticated control system will prevent unauthorised visits to the tunnel, enabling the radiation to be safely used by researchers



Spacefill model of the cholesterol molecule

Image courtesy of RedAndr; image source: Wikimedia Commons

ILL: Slow cholesterol

Scientists using neutron scattering at the Institut Laue-Langevin (ILL) and at the NIST Center for Neutron Research in Gaithersburg, MS, USA, have found that the time cholesterol takes to move within and between cells is in the order of several hours, far slower than previously thought.

Cholesterol forms part of the outer membrane that surrounds every cell. It plays a vital role, enabling the transmission of chemical and nerve signals around the body: it is the basis of important hormones and provides insulation for nerve fibres. Maintaining the correct levels of cholesterol through redistribution between and within the cells is therefore very important. Abnormalities in cholesterol transport have been implicated in diseases such as Alzheimer's, atherosclerosis and various cardiovascular disorders. Investigating the precise rate of cholesterol transport could therefore help in developing new, improved treatments for these disorders.

For more information, see the research paper:

Garg A et al. (2011) Noninvasive neutron scattering measurements reveal slower cholesterol transport in model lipid membranes. *Biophysical Journal* **101(2)**: 370-377. doi: 10.1016/j.bpj.2011.06.014

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

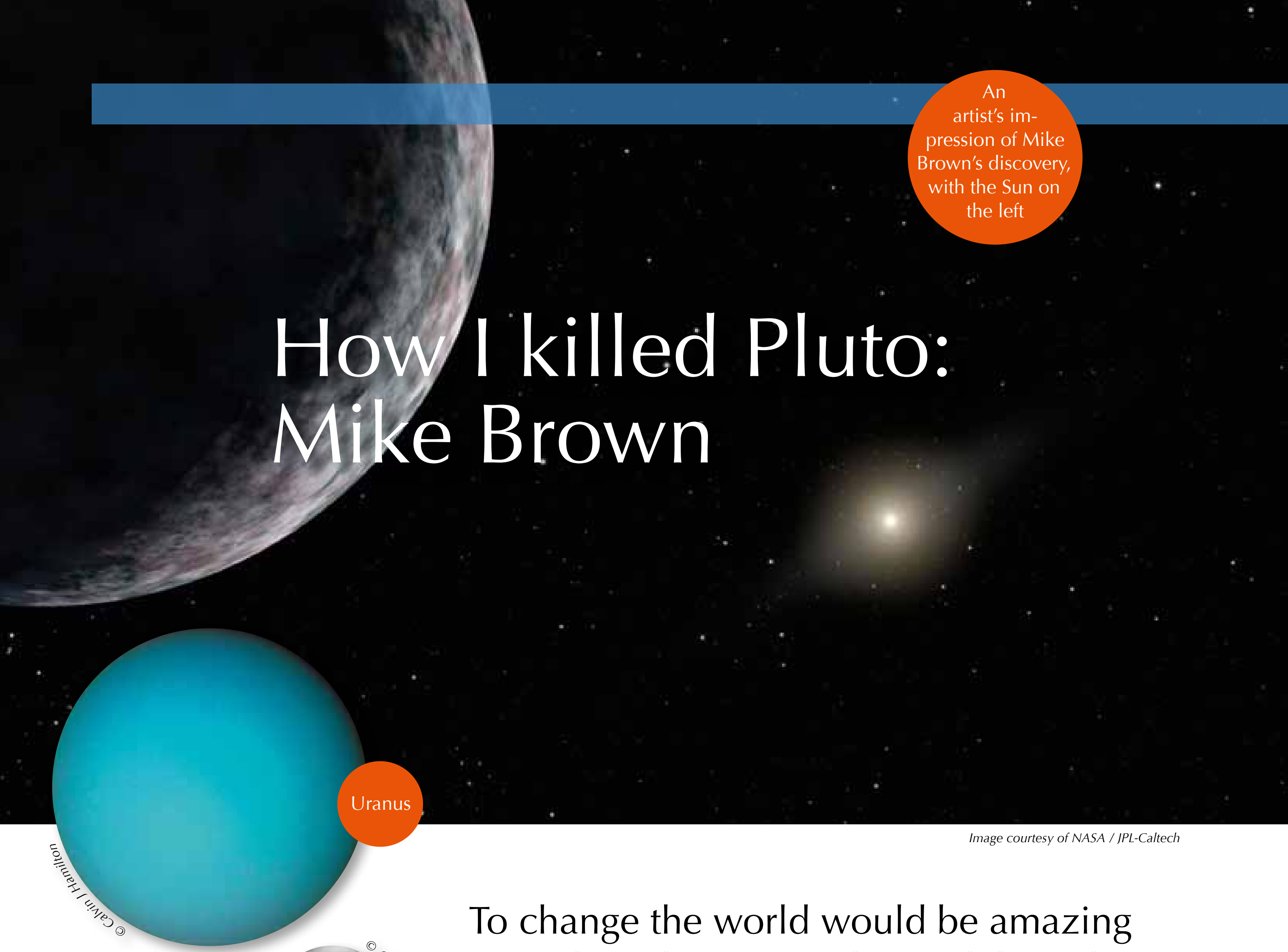
EIROforum

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 65.



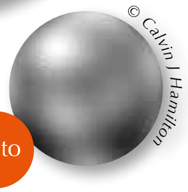
An artist's impression of Mike Brown's discovery, with the Sun on the left

How I killed Pluto: Mike Brown

Image courtesy of NASA / JPL-Caltech

Uranus

© Calvin J Hamilton



Pluto

© Calvin J Hamilton

To change the world would be amazing enough. Mike Brown changed the Solar System. **Eleanor Hayes** explains.

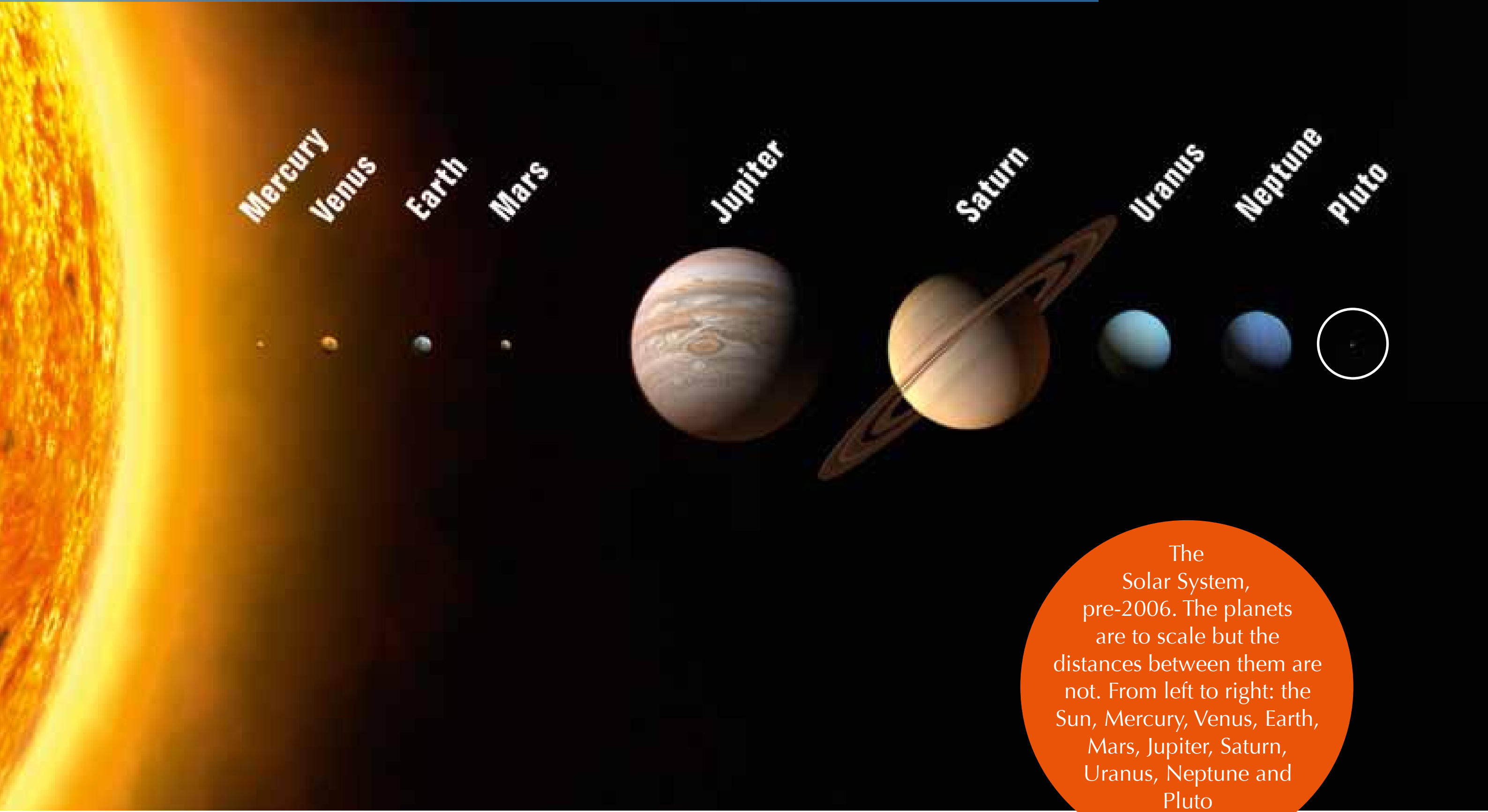
Until 2006, most non-astronomers probably thought that these days, the Solar System was unchanging and unchallenged. Until, that is, it was decided that Pluto was no longer a planet. Meet Mike Brown, who unintentionally sealed Pluto's fate and triggered our new understanding of what is – and what is not – a planet.

The story began in the late 19th century, with the search for Planet X, the ninth planet in the Solar System. In 1846, astronomers had noticed that Uranus's orbit around the Sun was being perturbed by something; this 'something' was found to be the massive gaseous planet Neptune. When it seemed (incorrectly) that the orbit of Neptune was itself being perturbed, astronomers hypothesised the existence of another massive planet, even further from the Sun: Planet X.

For such a huge planet, Planet X proved remarkably difficult to find. When Clyde Tombaugh finally discovered it in 1930, it became clear why. Named Pluto, at the suggestion of an 11-year-old schoolgirl, the newly discovered planet was tiny, with a diameter only three-quarters that of our Moon. As Mike Brown, professor of planetary astronomy at California Institute of Technology (Caltech)[w1], USA, says, "Most people seem to think Pluto is a fairly major body in the Solar System – it's often depicted about the same size as Mercury. But that's so wrong!"

Although in 1930, Pluto was thought to be somewhat larger and more massive than it actually is, even then, astronomers recognised that its orbit was odd. The other planets travel around the Sun on circular orbits, their orbits forming a flat disc. Pluto's orbit, in contrast, is elongated and tilted at about 20° to the disc of the other planets' orbits. From the time of its discovery, "Pluto was seen as the weird planet at the edge of the Solar System", states Mike.

Some 60 years later, though, "Pluto suddenly started to make sense, because with the development of digital cameras and bigger telescopes, astronomers got better at finding objects in the outer part of the Solar System, beyond Neptune." The first



The Solar System, pre-2006. The planets are to scale but the distances between them are not. From left to right: the Sun, Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, Neptune and Pluto

Image courtesy of the International Astronomical Union / Martin Kornmesser

of these objects was found in 1992, and within a decade there were 500 of them – all discovered in the same way that Clyde Tombaugh used to find Pluto – taking repeated pictures and looking for movement. This band of objects beyond Neptune is what is now known as the Kuiper Belt. All had orbits similar to Pluto's – elongated and tilted – and although in 2002, Pluto was still far larger than any of these objects, "it was clear that Pluto was part of the Kuiper Belt rather than part of the planetary system, but many people were desperate to keep calling it a planet."

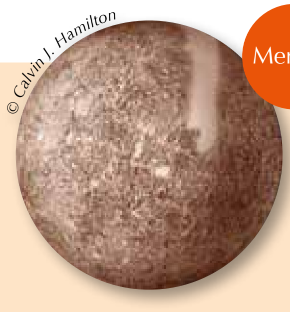
Pluto might have remained a planet, if it weren't for a frustratingly cloudy night in December 1999. Unable to use the telescope, Mike claimed to a colleague, "I think there's another planet out there, beyond Pluto." He pointed out that the small objects in the Kuiper Belt were being discovered with very small, targeted searches. If only astronomers could work out how to look at the whole sky, he believed that they were bound to find something larger than Pluto.

"I bet her that within five years, someone would find a planet beyond Neptune. I was convinced that someone was going to find it, but mostly, I was convinced it was going to be me!"

Determined to win his bet, Mike set about devising the best combination of telescope and camera to monitor the whole sky. "Astronomers had actually got a lot worse at covering large patches of sky over the previous 50-60 years. Clyde Tombaugh used photographic plates attached to the tel-

REVIEW

- Physics
- Geography
- Biology
- History
- Astrophysics
- Ages 10-19



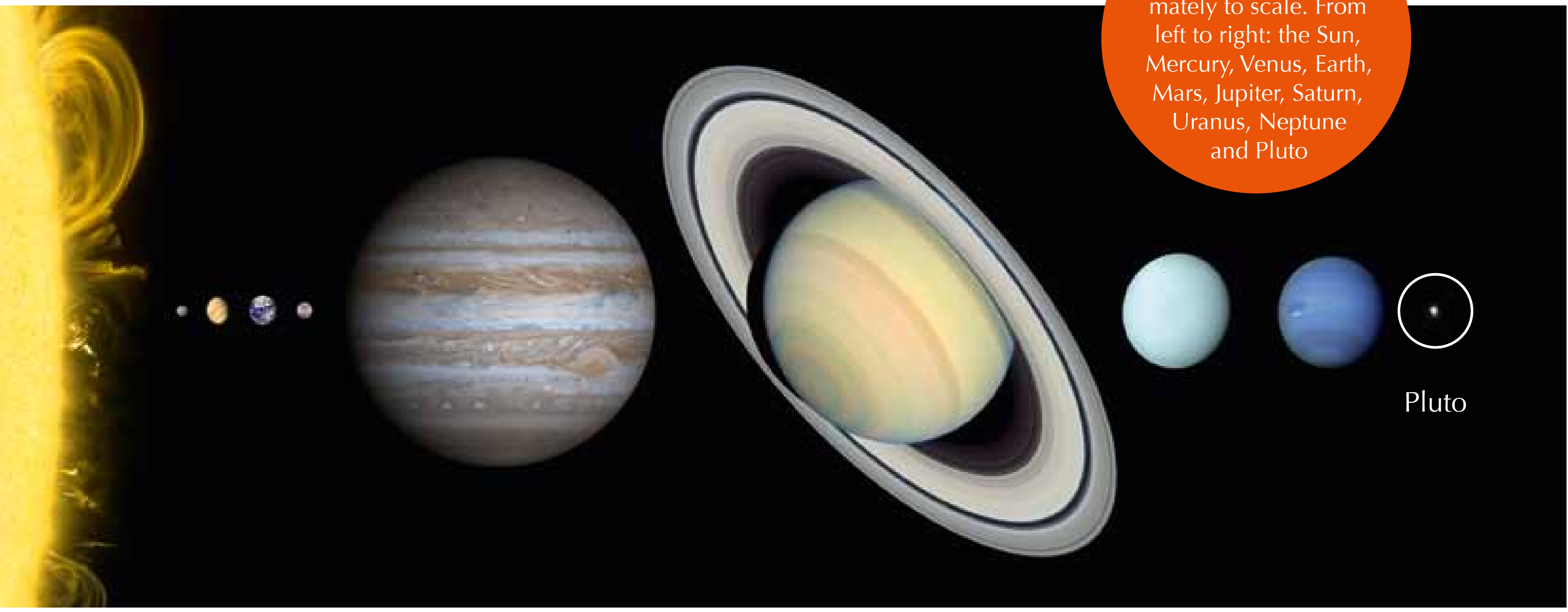
Mercury

The story describes the work of Professor Mike Brown, his hunt for the tenth planet in our Solar System – and the unexpected result. It is based on a lecture given by Professor Brown, so the style is pleasant, like an exciting adventure story.

The article could be useful in physics, astrophysics or geography lessons, but also in language, biology or even history lessons. Each teacher can find a way to use the article to raise interest in science – even those teachers without much knowledge of physics.

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

© Calvin J Hamilton (www.solarviews.com)



The Solar System, pre-2006, approximately to scale. From left to right: the Sun, Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, Neptune and Pluto

escope but by the late 1990s, astronomers were using digital cameras. They were more sensitive but not good at seeing large swathes of sky."

One digital camera may not have covered much sky, but 112 digital cameras stuck together gave Mike the biggest digital camera in the world at that time. He attached it to the wide-field telescope at Caltech's Palomar Observatory in California, and – via a microwave link – could operate it robotically from his computer. That cable is one of Mike's favourite pieces of equipment. "In the ten years that I worked on this telescope nearly every single night, I never had to go to Palomar – a three hour journey from my home. Instead, I could do things that normal people do like getting married and having a kid."

Night after night, Mike and his colleagues Chad Trujillo and David Rabinowitz would point the telescope at a little patch of the sky and take three pictures over the course of three hours. A bank of computers would then compare the images, to identify anything that was moving. "The computer is OK, but your eye is better at filtering out noise – little blips that the camera produces. Every morning, the computer would have picked out one or two hundred potential moving things, and I would flip through the images, searching for any that really moved."

"You can tell a lot about an object from these images. Everything in the Solar System is moving – so you can tell that it's in the Solar System by the fact that it moves, but you can also tell how far away it is by how fast it moves. The closest things to us move the fastest. You can also tell about how big it is by how bright it is. These objects don't have any of their own light; they only shine by reflected sunlight so to reflect more sunlight, they have to be bigger."

"It's exciting to go to work each morning thinking 'this morning, you might see something moving across the sky, and you will be the first human to have ever seen it.' It made walking into the office, sitting down and looking through those hundred things the best part of my day."

"It made walking into the office and looking through those hundred things the best part of my day."

"So you will understand my reaction when, on 5 January 2005, I was flipping through the images and I came to this one." Unlike 60 or so previous objects that Mike and his colleagues had found, it was moving very slowly, which meant it was a long way away. "It was well beyond the Kuiper Belt, more distant than anything we had ever seen before, and it was also the brightest thing we had ever discovered. This combination told us immediately that this thing had to be really, really, big."

"We knew it was at least the size of Pluto and, if you remember the bet that I made back in December 1999, that was our criterion for a planet. So I had won the bet, except it was 5 January 2005 and the bet expired on 31 December 2004. Fortunately, my friend kindly gave me a five-day extension."

What about its orbit? Did the object have a circular orbit like the massive

planets do? Or did it have an elongated and tilted orbit like Pluto and the objects in the Kuiper Belt? Fortunately, over the decades, astronomers had taken many pictures of the sky. By sifting through this data back to 1950, Mike Brown and his colleagues were able to establish the orbit: even more elongated than that of tiny Pluto, and tilted at 45° to the orbits of the eight massive planets of the Solar System.

They then returned to the question of size. The fact that it was bright – reflecting a lot of sunlight – suggested it was big. "But you can reflect a lot of sunlight in two very different ways: you can be a massive body covered in dirt, or you can be smaller and covered in snow or frost, and you'll reflect the same amount of sunlight." To determine which was the case, Mike and his colleagues used the Hubble Space Telescope. The results were a big surprise: their newly discovered object was only about the same size as Pluto. How then, could it be so bright?

They realised it was probably a question of the atmosphere. "Pluto has an atmosphere when it is closest to the Sun; our object probably would have too but it is so far from the Sun right now that the atmosphere is frozen on the surface. We thought the atmosphere was probably nitrogen, like Pluto's atmosphere and our atmosphere, and it is frozen in a thin layer, making the object incredibly reflective. The same thing would happen to Earth, if you moved it that far from the Sun – only we'd have layer of nitrogen ice 10 metres thick, instead of 0.5 millimetres."

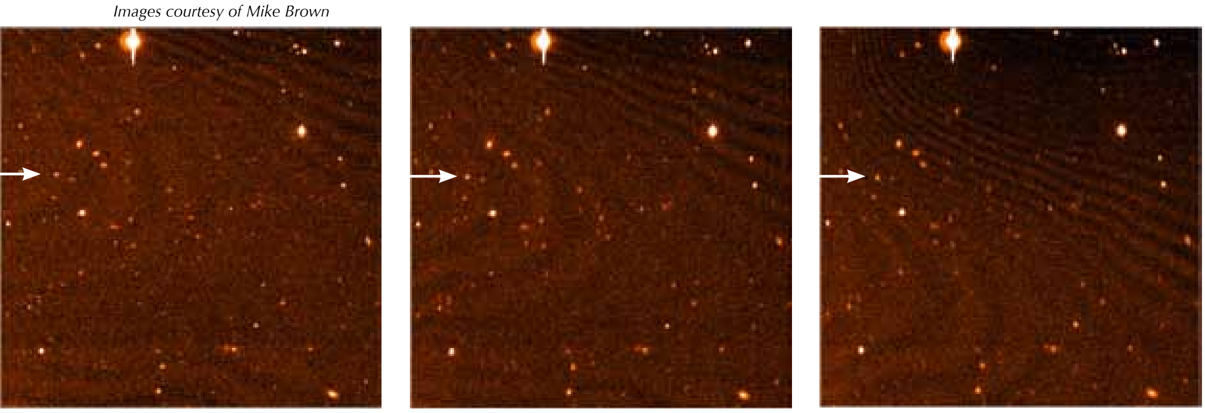
So what was the significance of the discovery of this 'new' object? In a sense, says Mike, nothing. "It's still exactly the same Solar System, just with a little bit of noise at the edge." But it brought the debate about Pluto to a head: if the newly discovered object was classed as a planet, where do you draw the line?

After lengthy and agitated discussions, on 24 August 2006, the International Astronomical Union (IAU) decided to return the number of planets to eight: Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus and Neptune. Pluto, Ceres (previously known as an asteroid) and the newly discovered object were reclassified as dwarf planets (see box).

Mike believes the decision was the right one – and he's not even too disappointed about the loss of his planet. "My original goal in 1999 had been to find the tenth planet, but I think having forced the world into a new appreciation of the Solar System is even better. The Solar System is a beautiful and profound place, and it is made richer by the realisation that the eight planets are the foundation throughout which countless smaller bodies continuously swirl."

Another consequence of the final classification was that Mike and his

Images courtesy of Mike Brown

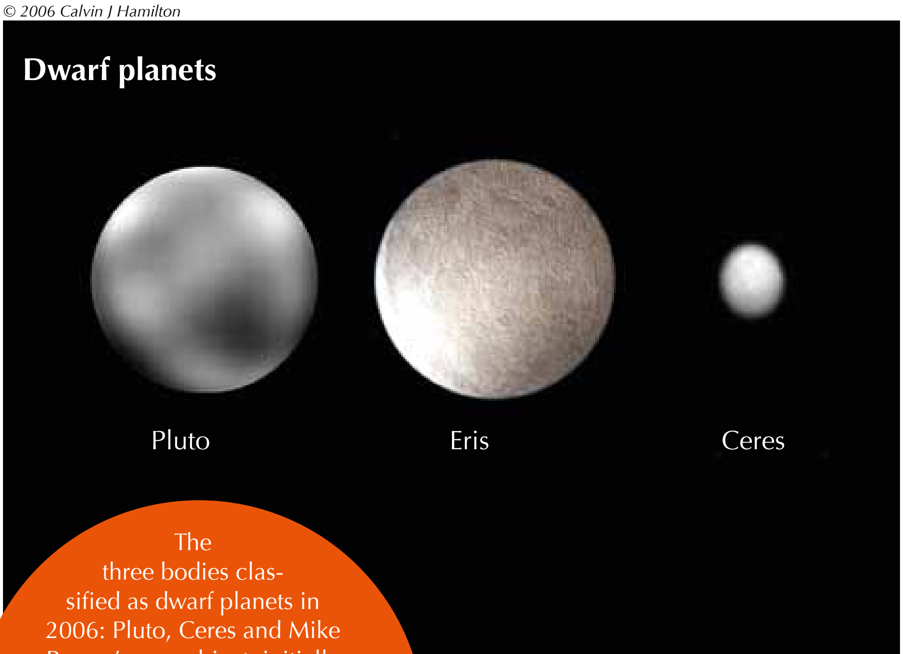


The images that led Mike Brown to discover a new potential planet

BACKGROUND

The story continues

Even today, the story is not complete. Until early 2011, explains Mike, "I would have said the composition of Eris was more or less like that of Pluto, with a core of rock and a big mantle of ice on the outside. Sort of like Earth, which has an iron core and a rocky mantle." Recent research[w2] (Sicardy et al., 2011), however, has made astronomers revise their view. They now know that although Eris is small – about the same size as Pluto – it is 27% more massive. How do they explain this? "Pluto and Eris are much more different than I would have guessed," says Mike Brown. "Eris is almost entirely rock, with only a thin layer of water ice around it. And on the very outside, like the water on Earth, it has frozen gases – methane, and probably nitrogen and carbon dioxide."



The three bodies classified as dwarf planets in 2006: Pluto, Ceres and Mike Brown's new object, initially known as 2003 UB313.

The image of Pluto was rendered from a map created from a series of Hubble images. The image of 2003 UB313 is an artist's impression and the image of Ceres is from the Hubble Space Telescope

colleagues finally got to name the object they had found. Appropriately, "we called it Eris, after the Greek goddess of discord and strife."

Acknowledgements

This article is based on a lecture given by Professor Brown, as part of the Silicon Valley astronomy lectures[w3], with permission of Professor Brown and the Astronomical Society of the Pacific.

Reference

Sicardy B (2011) A Pluto-like radius and a high albedo for the dwarf planet Eris from an occultation. *Nature* **478**: 493-496: doi: 10.1038/nature10550

Download the article free of charge on the *Science in School* website (www.scienceinschool.org/2011/issue21/pluto#resources), or subscribe to *Nature* today: www.nature.com/subscribe

Web references

w1 – To learn more about Mike Brown's work, visit his university web page: www.gps.caltech.edu/~mbrown

w2 – To learn more about the recent measurements made of Eris, see the ESO press release: www.eso.org/public/news/eso1142

w3 – Mike Brown's lecture and many others in the Silicon Valley astronomy lecture series can be listened to, downloaded or subscribed to as podcasts via the website of the Astronomical Society of the Pacific: www.astrosociety.org/education/podcast

Resources

The full story of Mike Brown's involvement in the demise of Pluto can be found in his book:

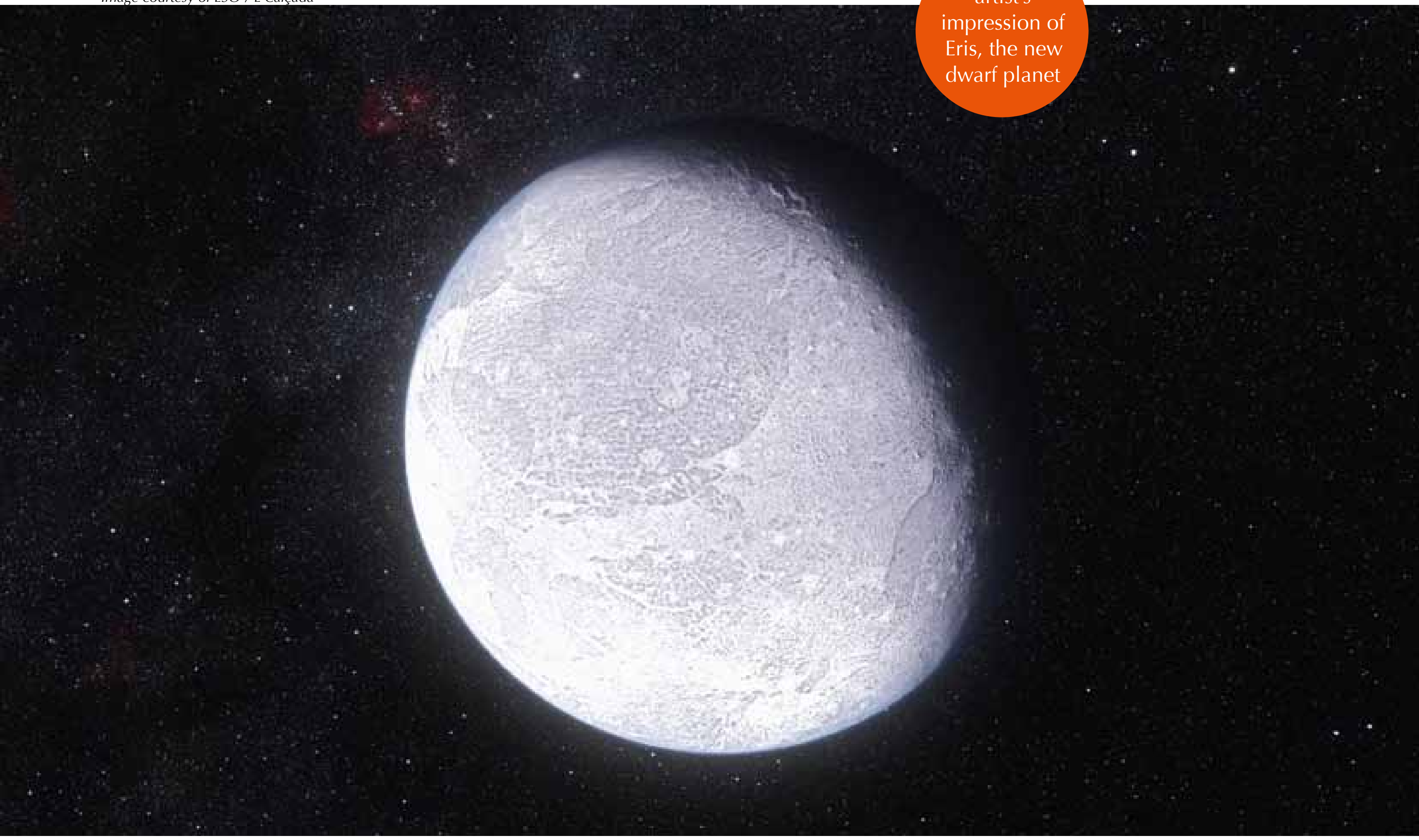
Brown M (2010) *How I Killed Pluto and Why it Had it Coming*. New York, NY, USA: Spiegel & Grau. ISBN: 978-0385531085

You're unlikely to find a new planet yourself, but to learn how to detect asteroids in the classroom, see:

Newsam A, Leigh C (2011) Hunting for asteroids. *Science in School* **20**: 30-35. www.scienceinschool.org/2011/issue20/asteroids

To browse all feature articles in *Science in School*, see: www.scienceinschool.org/features

Image courtesy of ESO / L Calçada



BACKGROUND

Reclassifying the Solar System

On 24 August 2006 in Prague, Czech Republic, the general assembly of the IAU resolved that that planets and other bodies in our Solar System, except satellites, should be defined into three distinct categories.

(1) A planet is a celestial body that (a) is in orbit around the Sun, (b) has sufficient mass for its self-gravity to overcome rigid-body forces so that it assumes a hydrostatic equilibrium (nearly round) shape, and (c) has cleared the neighbourhood around its orbit.

(2) A dwarf planet is a celestial body that (a) is in orbit around the Sun, (b) has sufficient mass for its self-gravity to overcome rigid-body forces so that it assumes a hydrostatic equilibrium (nearly round) shape, (c) has not cleared the neighbourhood around its orbit, and (d) is not a satellite.

(3) All other objects, except satellites, orbiting the Sun shall be referred to collectively as small Solar-System bodies.

Source: www.iau.org/public_press/news/detail/iau0603

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, initially for a bioinformatics company and then for a learned society. In 2005, she moved to the European Molecular Biology Laboratory to launch *Science in School*.

To learn how to use this code, see page 65.

Image courtesy of John Carnemolla / iStockphoto

Birds on the run: what makes ostriches so fast?

What makes ostriches such fast runners? **Nina Schaller** has spent nearly a decade investigating.

When admiring a soaring seagull or a diving penguin, we rarely consider that these feathered animals have something very rare in common with us: whereas most other animals move on four, six or more legs, birds and humans are the only true bipeds. Evolution has solved the challenge of moving on two legs in two ways: humans are plantigrade (we place our entire foot on the ground when we walk or run), whereas birds are digitigrade (they walk on their toes, or *digits*).

Some avian species can run more quickly not only than humans run, but even faster than their flying counterparts fly. The fastest long-distance runner is the African ostrich (*Struthio camelus*). At a steady 60 km/h with top speeds exceeding 70 km/h, it could cover the 42 km Olympic marathon in 40 minutes rather than the two hours needed by a human. This remarkable combination of speed and endurance allows the ostrich to cover great distances to find fresh grazing pasture or to outdistance hungry hyenas.

Scientists have long explored the challenges of terrestrial locomotion, particularly the running abilities of dogs and racehorses. However, studies on avian locomotor modes have typically explored flight dynamics while paying less attention to *cursorial* species (those that are specialised for running).

After finishing my degree in biology in 2002, I volunteered at Frankfurt Zoo in Germany, where I became fascinated by the ostrich's racing ability and decided to investigate it. The hypothesis of my PhD research was that the ostrich locomotor system transmits power to the ground with a high degree of efficiency, maximising energetic output (speed and endurance) while minimising energy demands (muscular and metabolic work).

To test my idea, I decided to study both form and function of the ostrich locomotor system. Using dissection, I explored ostrich anatomy, searching for specialised limb structures that might reduce the metabolic cost of locomotion. Simultaneously, I studied the biomechanics of live ostriches: how physical forces acted on their

10-week-old ostrich chicks in their new home

Image courtesy of Jürgen Gass

anatomy when they moved.

To enable close observation of natural motion sequences, I hand-raised three ostriches in a large outdoor enclosure and, over four years, habituated them both to me and their experimental racetrack. Mutual trust was crucial: a kick from an ostrich can kill a lion.

Maximising speed: long, light legs

In a running animal, higher speeds are achieved by increasing both the length and frequency of steps. Longer legs can swing further, and if the leg's muscle mass is located proximally (close to the body), the leg can then swing faster, in the same way that moving the adjustable weight of a metronome closer to the pivot increases the tempo.

To investigate this principle, I compared leg segment lengths (Figure 1) and muscle mass distribution of fast-running, ground-dwelling bird species. Of all cursorial birds, the ostrich possesses the longest legs relative to its size and has the longest step length when running: 5 m. In addition, to a greater degree than other bird species, it has the majority of its leg musculature located very high on the thigh bone and hip, whereas the lower swinging elements of its leg are comparatively light, moved by long, mass-reducing tendons (Figure 2). This arrangement optimises the os-

REVIEW

- Biology
- Physics
- Biomechanics
- Evolution
- Motion
- Ages 10+

The surprising yet obvious statement that 'birds and humans are the only true bipeds' introduces the account of the research that Nina Schaller has been doing for nearly a decade. She offers us a picture of the multidisciplinary approach to a complex phenomenon – the outstanding speed and endurance of the ostrich – investigating the biomechanics and efficiency of the bird's performance by means of anatomy (dissection) and physiology (functional study). The listed resources, in addition, provide a wealth of information and teaching materials on ostrich and human locomotion.

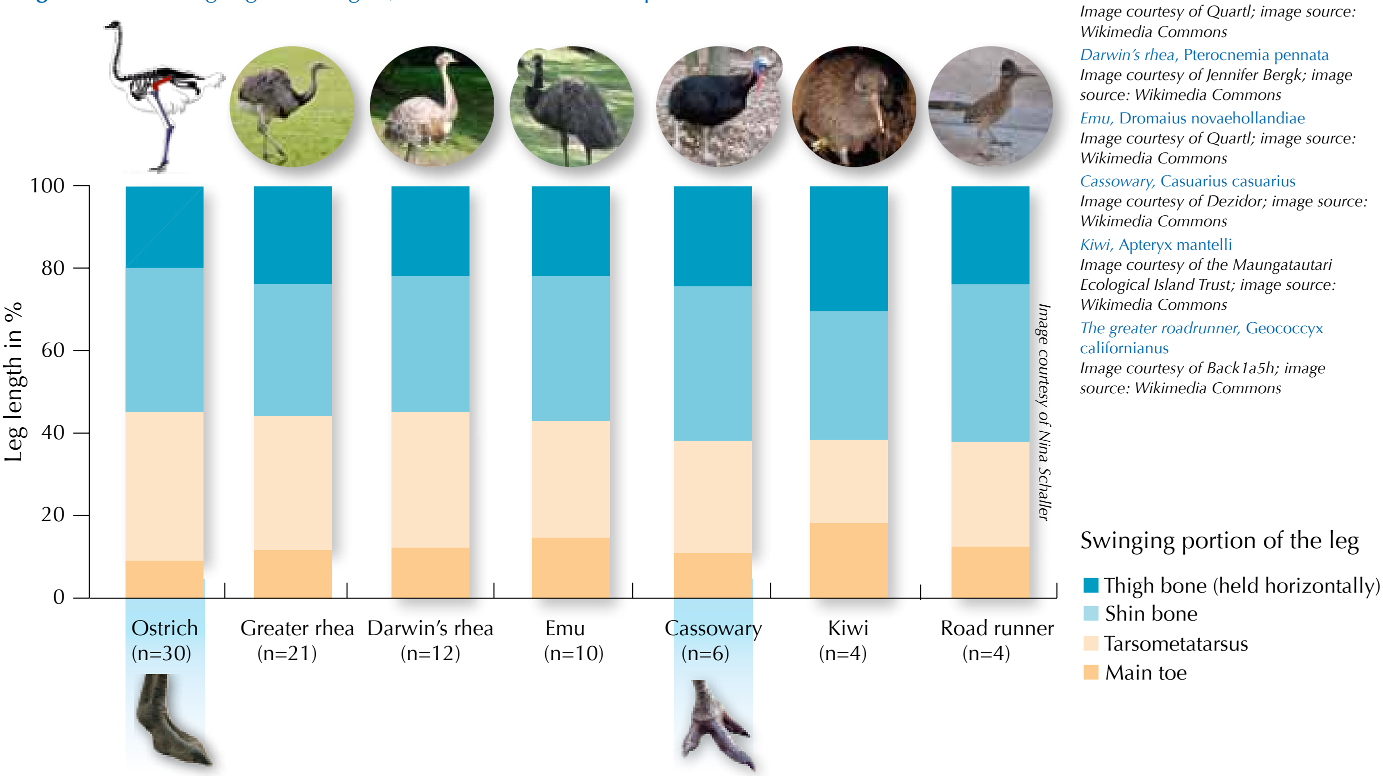
The article would be an interesting and useful means to address topics in biology (biomechanics – bones, muscles, tendons and ligaments; evolution – homology and analogy) and physics (efficiency, forces, speed, springs and motion) at both upper- and lower-secondary school. For example, it could be used to address the biomechanics of walking and running in different species, the evolution of bipedal locomotion in birds and humans, and the functional aspects of lower limb prostheses (for instance those used by the sprint runner Oscar Pistorius). It could also provide valuable background reading before a visit to a natural history museum or zoo, or to a robotics lab.

Suitable comprehension questions include:

1) The hypothesis of Nina Schaller's research was that the ostrich's locomotor system:
   a) maximises energetic output and energy demand
   b) minimises energetic output and maximises energy demand
   c) maximises energetic output and minimises energy demand
   d) minimises energetic output and energy demand.
2) Ostrich legs have
   a) musculature located high on the thigh bone and short tendons
   b) musculature located high on the thigh bone and long tendons
   c) musculature located low on the thigh bone and short tendons
   d) musculature located low on the thigh bone and long tendons.

Giulia Realdon, Italy

Figure 1: Linear leg segment lengths; n indicates number of specimens examined



Greater rhea, Rhea americana
Image courtesy of Quartl; image source: Wikimedia Commons

Darwin's rhea, Pterocnemia pennata
Image courtesy of Jennifer Bergk; image source: Wikimedia Commons

Emu, Dromaius novaehollandiae
Image courtesy of Quartl; image source: Wikimedia Commons

Cassowary, Casuarius casuarius
Image courtesy of Dezidor; image source: Wikimedia Commons

Kiwi, Apteryx mantelli
Image courtesy of the Maungatautari Ecological Island Trust; image source: Wikimedia Commons

The greater roadrunner, Geococcyx californianus
Image courtesy of Back1a5h; image source: Wikimedia Commons

Nina and an ostrich displayed at the Royal Ontario Museum, Toronto, Canada

trich leg for high-velocity locomotion, giving it both a long step length and a high step frequency.

Maximising endurance: stable joints

A wide range of joint motion allows humans to climb trees or ballet dance, but this flexibility has a cost. When we run, muscle power is used for propulsion but also to prevent sideways joint movement, thereby increasing our energy requirements over a given distance. I suspected that ostriches had a more efficient approach.

Unlike energy-consuming muscles and their tendons, ligaments can act as a 'joint corset', limiting sideways motion without consuming energy. To demonstrate that this mechanism was present, I filmed my running ostriches from various angles to record the range of motion of their legs. I then repeated these measurements with an intact dead ostrich, and finally with a dissected ostrich leg that had had all muscles and tendons removed, leaving only the skeleton and joint ligaments. The range of sideways motion in live and dead ostrich specimens was nearly identical. In contrast, a similar comparison in humans would reveal a huge difference in sideways motion range, especially at the hip joint, which is stabilised by muscle action. My measurements showed that ligaments are the main elements that guide an ostrich leg through the stride, allowing muscle power to be devoted almost exclusively to forward propulsion.

When manipulating the dissected ostrich legs, I made a further new discovery. When trying to flex the ankle joint, I had to overcome some resistance – an unexpected finding in a lifeless limb devoid of muscles. When I released the joint, it snapped back to an extended position, suggesting that ligaments were passively keeping the bird's leg extended. To test this theory, I exerted pressure from above on the standing, dissected leg until the ankle joint collapsed into a flexed position (Figure 3). It required 14 kg

Image courtesy of Nina Schaller

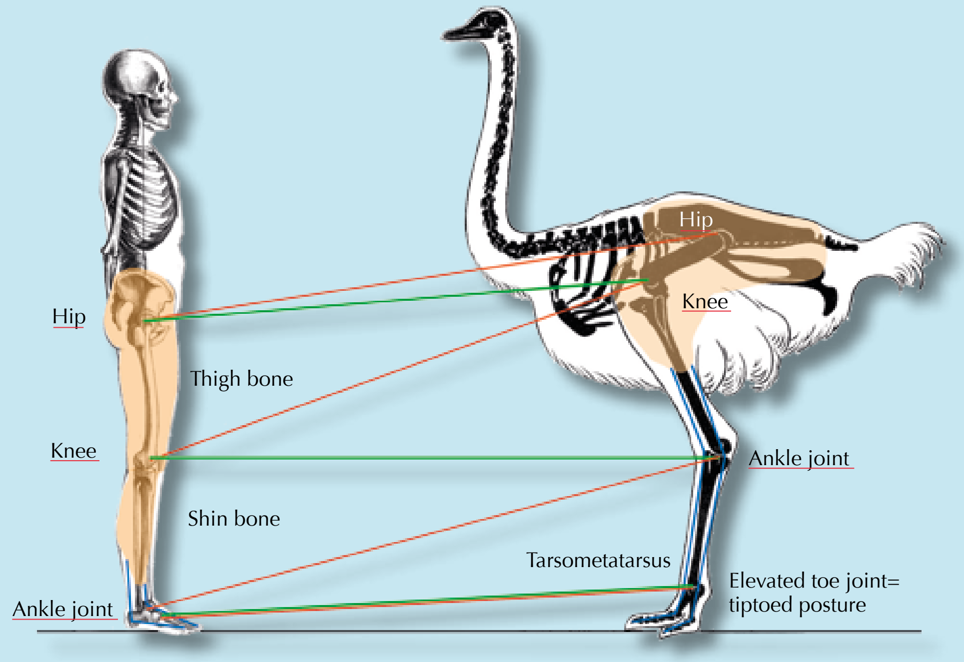


Figure 2: Comparative anatomy of human and ostrich legs: in birds, the bone between ankle and toes, the tarsometatarsus, is much longer than in humans, and serves as a functional equivalent to our upright shin bone. The bird's ankle joint is at our knee level, which explains why a bird appears to flex its 'knee' backwards. Its actual knee joint, hidden under plumage, is permanently flexed and connects to the hip joint through a short, horizontal thigh bone. Red lines connect anatomically equivalent joints; green lines connect functionally equivalent joints.

In the ostrich, muscle mass is concentrated at the top of the leg, while long tendons prevail in the lower regions. Shaded areas show major muscle mass distribution, blue lines indicate location of major tendons

of downward force — 28 kg of weight that an ostrich standing on two legs would not be required to actively support when walking or running. This experiment showed that saving metabolic energy by using ligaments as a passive leg-stabilising mechanism is an excellent locomotor endurance strategy.

Making ground contact

We have seen that light limbs are a precondition for fast, efficient locomotion and that one way in which the ostrich achieves this is by concentrating the leg muscle mass close to the hip joint. A further strategy for reducing lower-leg mass involves specialised toe morphology and positioning. This can also be observed in other cursorial animals; modern horses, for example, have evolved from five-toed ancestors to gallop on the toenail of their middle toe – the hoof. The ostrich has undergone a similar evolution: whereas most birds have four toes and the majority of large flightless birds possess only three, the ostrich is unique among birds in walking on only two toes (Figure 1). Furthermore, it is the only bird to walk on the tips of its toes.

I wondered how this, the largest and heaviest living bird, manages to balance and grip at high-speed on tiptoe. Since there is no established method for investigating toe function in live birds, I used a pressure plate, commonly used by orthopaedists to analyse pressure distribution in

Image courtesy of Nina Schaller

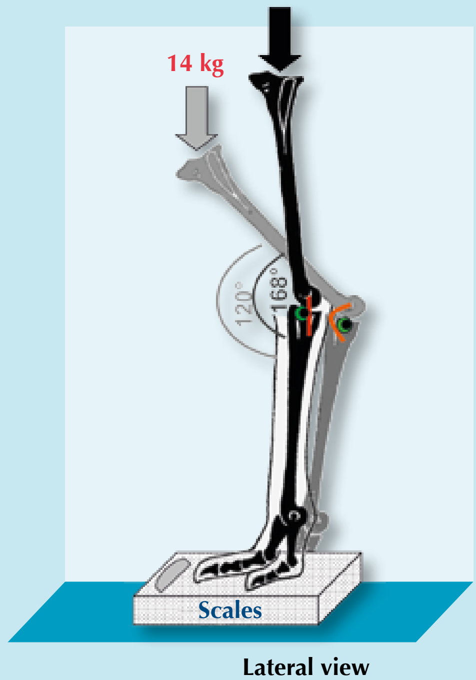


Figure 3: Experiment showing the ability of the ankle joint ligaments to passively support weight from above (only the left side of the left leg is shown). The ankle joint has contoured bone protrusions (in green) on either side. When the joint is fully extended (168°), the ligaments on either side (in red) are tensed because they pass over this protrusion, thereby stabilising the joint. When the ostrich lifts its toes off the ground, the ankle joint is flexed below 140° and the ligaments (in orange) are free to slide around the protrusions: the stabilising mechanism is relaxed

Image courtesy of Nina Schaller

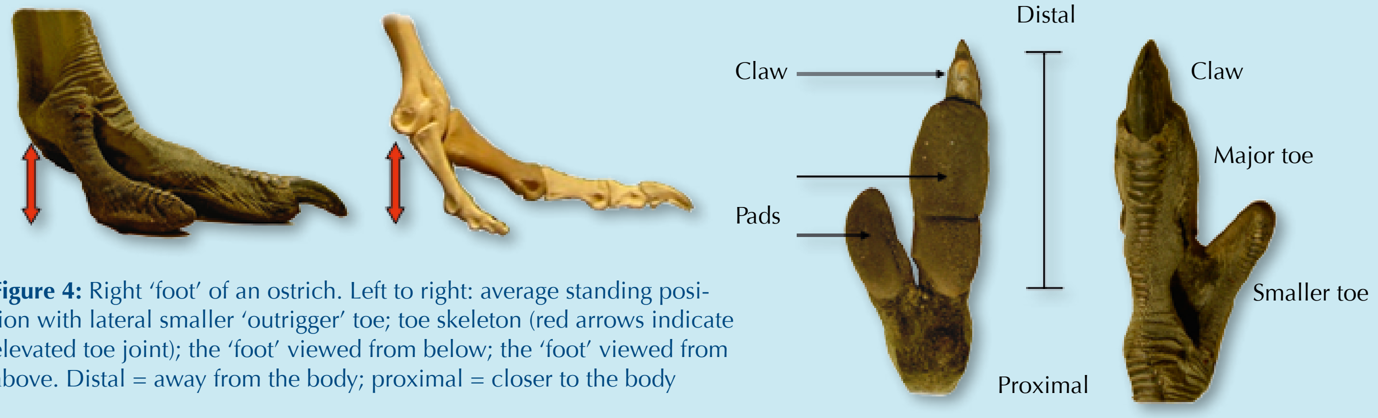


Figure 4: Right 'foot' of an ostrich. Left to right: average standing position with lateral smaller 'outrigger' toe; toe skeleton (red arrows indicate elevated toe joint); the 'foot' viewed from below; the 'foot' viewed from above. Distal = away from the body; proximal = closer to the body

human feet. I trained my ostriches to walk and run over the plate, capturing high-resolution real-time data of ostrich 'foot' pressure during ground contact. This showed that the big toe supports the majority of the body mass while the smaller toe prevents the ostrich from losing its balance by acting as an outrigger, especially during slow walking.

At high speeds, the toes' soft soles dampen impact stresses, while the spring-loaded tiptoed posture acts as an additional shock absorber (red arrows in Figure 4). The claw barely contacts the ground during walking, but exerts pressures of up to 40 kg/cm² when the bird runs. The claw penetrates the ground like a hammered spike to ensure reliable grip

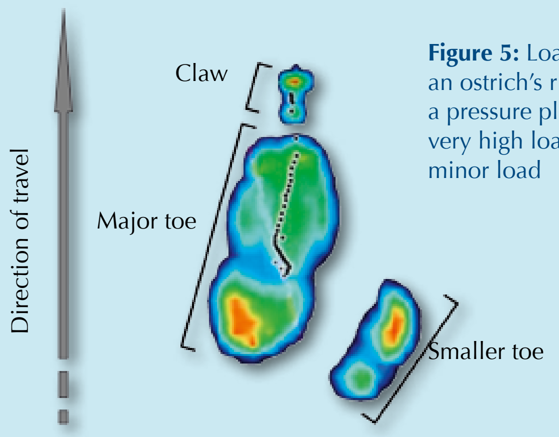


Figure 5: Load-distribution profile of an ostrich's right 'foot' recorded with a pressure plate. Areas in red indicate very high load; dark blue indicates minor load

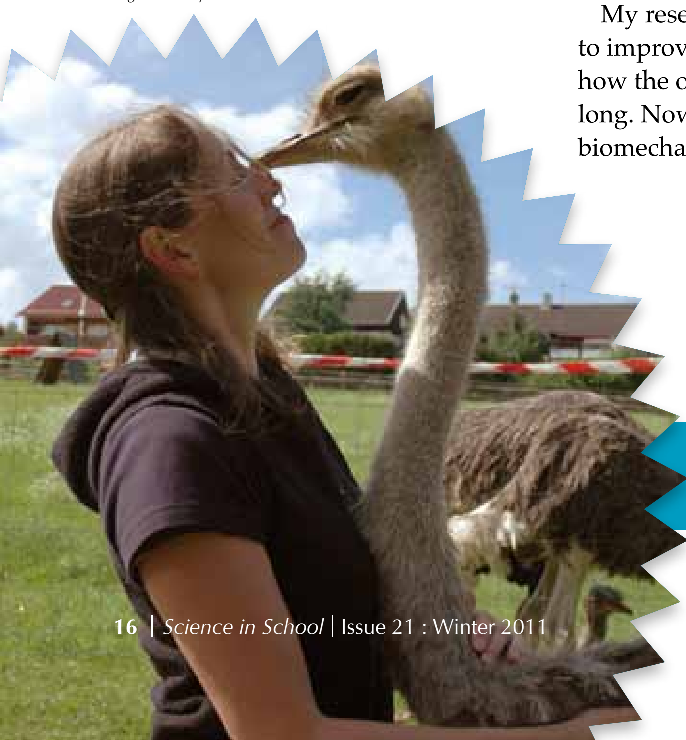
Image courtesy of Nina Schaller

at 70 km/h – maximum speed with minimal energy, ideal for endurance running on the level ground of the African savannah (Figure 5).

Practical applications

My research has gone a long way to improve our understanding of how the ostrich runs so fast for so long. Now that we understand these biomechanical strategies, perfected over 60 million years of evolution, we may be able to adapt them in modern technologies such as bipedal robotics, suspension systems, and joint-stabilisation engineering. Already, some of my findings have inspired developers of 'intelligent' human prostheses to adapt features of ostrich legs and toes, which may allow amputees a wider range of function and manoeuvrability.

Image courtesy of Gisela Löffler for Bild der Wissenschaft



Nina and one of her full-grown co-workers, Tiffy

Resources

The 'Confessions of an ostrich' give the ostrich's point of view, and include links to other resources. See: http://tolweb.org/treehouses/?treehouse_id=3303

This introductory lesson on ostriches consists of an essay and a quiz for the students. It is suitable for lower secondary-school level. See: www.lessonsnips.com/lesson/ostriches

A similar activity for primary-school students can be found here: www.enchantedlearning.com/subjects/birds/printouts/Ostrichquiz.shtml

The National Geographic Kids website has a multimedia 'Creature Features' page on ostriches. See: http://kids.nationalgeographic.com/kids/animals/creaturefeature/ostrich

For an introduction to the biomechanics of walking, see: www.pt.ntu.edu.tw/hmchai/BM03/BMClinic/Walk.htm

The Society for Integrative and Comparative Biology's activities on bone and joint biomechanics were developed for university students, but can easily be adapted for older secondary-school students. To build models of joints, see: www.sicb.org/dl/biomechanicsdetails.php3?id=19

For a slide show overview of human locomotion and its biomechanics, with links to sport, see: http://tinyurl.com/c2yrxca

To download the slide show, you will need a Google email account.

If you enjoyed reading this article, you might like to browse the full collection of cutting-edge science articles published in *Science in School*. See: www.scienceinschool.org/cuttingedge

---

After finishing her biology studies at the University of Heidelberg, Germany, Nina Schaller volunteered at the Frankfurt Zoo where an exceptionally friendly ostrich sparked her interest in this unique terrestrial vertebrate. For the past nine years, she has studied the unparalleled running performance of the largest living bird. She hand-raised ostriches and collaborated with universities and research institutions in Antwerp, Belgium; Vienna, Austria; Frankfurt and Munich, Germany; and Toronto, Canada. Nina's interdisciplinary approach led to the discovery of energy-conservation strategies that explain how the ostrich manages life in the fast lane.

To learn how to use this code, see page 65.

Image courtesy of Lutz Langbein, German Cancer Research Center (DKFZ)

Breast cancer cell

Cancer stem cells – hope for the future?

Cancer and stem cells are both topical issues. But have you heard of cancer stem cells? As **Massimiliano Mazza** explains, this concept may revolutionise the treatment of cancer.

Public domain image; image source: Wikimedia Commons

The Edwin Smith papyrus, the world's oldest surviving surgical document, was written in hieratic script in ancient Egypt around 1600 BC. It is believed to be a copy of an older work attributed to Imhotep. Plate 6 and 7 of the papyrus, pictured here, discuss facial trauma

Cancer: an evolving concept

If thou examinest a man having tumours on his breast, (and) thou findest that swelling have spread over his breast (…) thou shouldst say concerning him: "One having tumours. An ailment against which I will fight."

This first known reference to a tumour, on an Egyptian papyrus[w1], is attributed to Imhotep – vizier, architect, physician and astronomer to Pharaoh Djoser, in 2500 BC.

A tumour (from Latin *tumor*, meaning swelling) is a tissue mass caused by the abnormal proliferation of cells, but it is not always associated with cancer. Tumours that are confined to a

Image courtesy of the National Institutes of Health; image source: Wikimedia Commons

Rudolph Ludwig Karl Virchow (1821-1902), referred to as 'the father of modern pathology'

specific region of the body are known as benign – they may cause health problems but are not necessarily life-threatening. In contrast, a tumour that spreads within the body, invading adjacent tissues and often metastasising (spreading to tissues and organs elsewhere), is called malignant; this is cancer. Although humans have been aware of cancer for more than 4000 years, our understanding of it has only improved significantly in the past 200 years.

An important contribution to the study of cancer was made in the 19th century by German physiologist Johannes Müller and his student Rudolf Virchow. Benefitting from recent advances in microscopy, they understood that cancer is an aberration of cell behaviour, rather than being generated *de novo*. Virchow was the first to realise that this happens through a combination of genetic predisposition and chronic irritation, such as that caused by smoking or ultraviolet radiation. As we know today, cancer begins with a single cell that loses control over its growth as it accumulates genetic mutations – both spontaneously and as a result of environmental factors – sometimes over a period of many years.

Cancer heterogeneity and cancer stem cells

The microscopic dissection of tumours in the 19th century also revealed that the morphology of even a single tumour may be remarkably heterogeneous. A tumour always originates from a single cell, so how can its daughter cells vary so much? There are two reasons: first, as they divide, the cancer cells accumulate further mutations that make them genetically different from one another; and second, the *microenvironment* varies across the tumour and this influences how each cancer cell behaves.

Let us take a look at the genetics first. In certain types of skin cancer, for example, an epithelial cell accumulates mutations, often over many years, and becomes cancerous – proliferating to form a group of epithelial cancer cells. Just like a population of animals, this population of cells evolves as it accumulates further mutations. Those mutations that give a cell a competitive advantage over other cells will result in a *clone* of similar cells, whereas other mutations will be disadvantageous and may even kill off the cell. By the time a tumour is detected, the different clones of cells that make up the lump may have become distant relatives.

The second influence is the microenvironment of a cancer cell: the cells, structures and molecules around it. As the epithelial cancer cells proliferate and the tumour grows, it incorporates cells from the surrounding tissue, until it consists not only of cancer cells but also of many different types of non-cancerous cells. These can include supporting cells of the connective tissue, blood vessels that supply the tumour with nutrients, and immune cells that enter the tumour from the bloodstream

REVIEW

- Biology
- Medicine
- Cancer
- Stem cells
- Medical physics
- Ages 15-19

This article puts forward the current theory that there are cancer stem cells in much the same way as there are other stem cells. The article could make a good basis for a general discussion of the topic of cancer, including cancer research and treatments, diagnosis and survival rates. Why are some cancers more treatable than others? Differences between bone marrow transplants, chemotherapy, immunotherapy, radiotherapy and vaccination can be researched and discussed. Why is there no vaccine for cancer? How does the vaccine for human papilloma virus work to prevent some cervical cancers (it has to be remembered that this is not a vaccine against the cancer itself)? Some cancers involve chromosomal rearrangements – this would lead on to the topic of cytogenetics. Most students have encountered someone with cancer and they will be able to engage with the topic.

Shelley Goodman, UK

Image courtesy of The Yorck Project: 10.000 Meisterwerke der Malerei; image source: Wikipedia

Bathsheba at Her Bath, by Rembrandt Harmenszoon van Rijn (1606–1669). The model is believed to be Rembrandt's second wife Hendrickje, and the dimpled discolouration on her left breast is thought to be breast cancer

and provide it with cell-signalling molecules and soluble factors. Plus there are normal epithelial cells that are not cancerous, along with the extracellular matrix – structural protein fibres that hold the cells together – and the fibroblasts that synthesise it. A tumour is therefore a complex tissue.

Is this the whole story of why cancer cells vary so much within a single tumour? Is this variation solely due to the mutations that the rapidly dividing cancer cells inherit and accumulate, plus the influence of the tumour's microenvironment? According to the *stochastic model* of cancer formation, it is. This model predicts that all cancer cells within a tumour are equal in their ability to initiate a new tumour if transplanted into a suitable host (Figure 1).

Experiments in the mid-20th century, however, showed that although a single cell can initiate a tumour, it has to be the right cell; this suggested that there are different types of cancer cells within a tumour, each with diverse roles. Indeed, in the 1960s, two distinct groups of cancer cells were identified among tumour cells of leukaemia patients: a larger subset that divided every 24 hours, and a smaller, slow-cycling subset that did not proliferate for weeks or months.

To account for these findings, a second model – the *hierarchical* or *cancer stem cell model* – was proposed, according to which the cancer cells are hierarchically organised, as are the cells of normal tissues. The model predicts at least two distinct subpopulations: a small population of cancer stem cells (CSCs) that divide slowly and are responsible for maintaining the tumour, and the vast majority of other cancer cells, which divide more quickly and are not capable of initiating a new tumour (Figure 1). The name 'cancer stem cells' was chosen because, like stem cells in normal body tissues, they can either produce more cells like themselves, or differentiate to form different cell types.

Image courtesy of the National Institutes of Health

Breast cancer, as shown in a mammograph

Scientists are still debating which of the two models (stochastic or hierarchical) best fits the experimental results, but there is mounting evidence from studies of several cancer types that a small subset of cells are responsible for tumour maintenance and initiation. If so, these are CSCs.

Cancer stem cells in cancer therapy

Currently, despite treatment with chemo- and radiotherapy, many cancers recur and metastasise to other organs – these are the circumstances of the majority of cancer patients that

Image reproduced and edited courtesy of American Society of Hematology, from Dick JE (2008) Stem cell concepts renew cancer research. Blood **112**(13): 4793-4807. doi:10.1182/blood-2008-08-077941; permission conveyed through Copyright Clearance Center, Inc

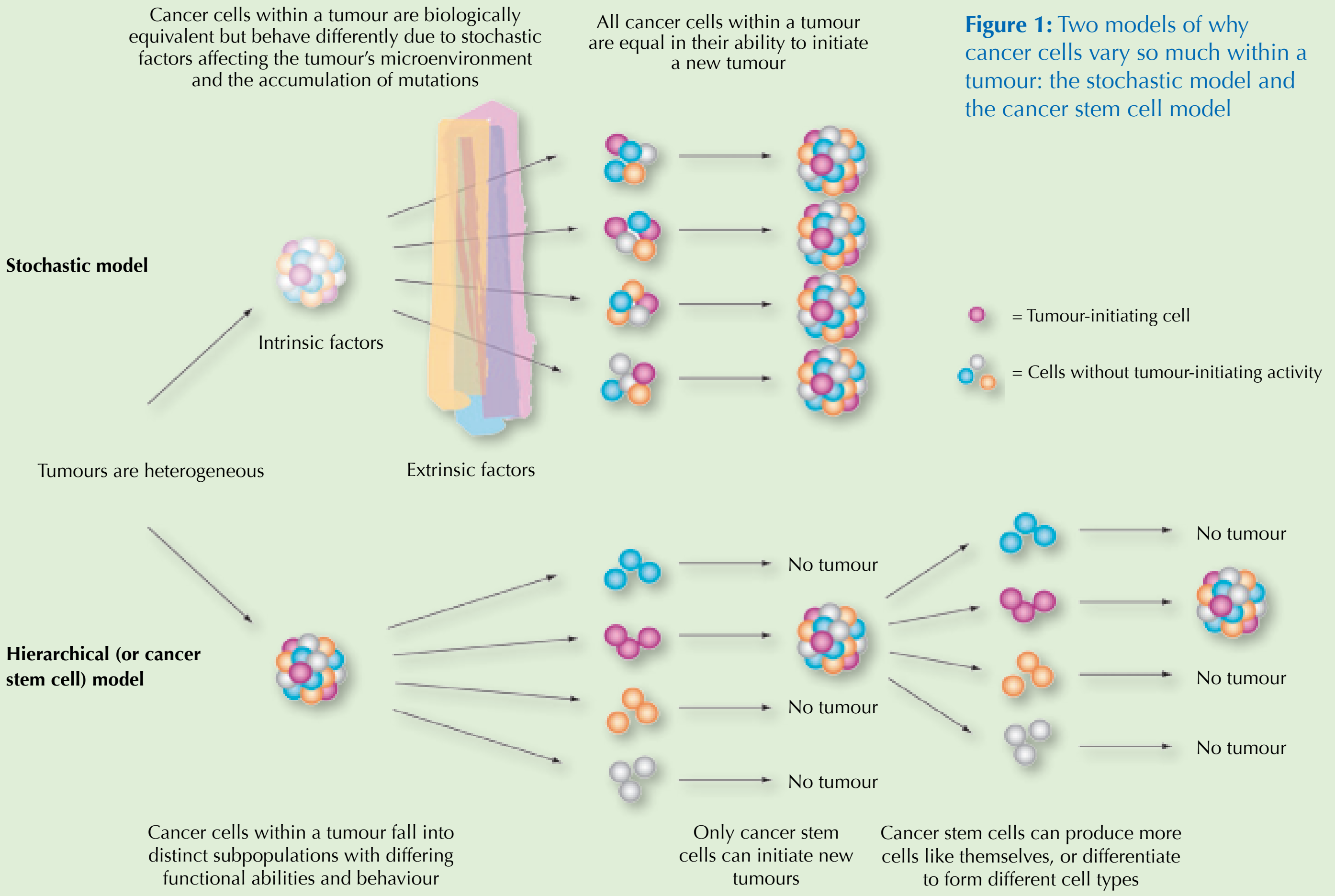


Figure 1: Two models of why cancer cells vary so much within a tumour: the stochastic model and the cancer stem cell model

die. Why is this? The reason could be CSCs. Because of their slower cell cycle, they might survive the treatment, allowing the tumour to regrow later.

Conventional chemo- and radio-therapies for cancer specifically target fast-dividing cells, because most cancer cells proliferate much faster than normal cells. The treatments are designed not to harm slowly dividing cells, such as normal stem cells and most other cells in our body. After patients with acute myeloid leukaemia are treated with these therapies, their haematopoietic (blood-forming) stem cells begin to proliferate to replenish the pool of blood cells. However, scientists have found that the CSCs that have survived start proliferating then too, regenerating the bulk of the tumour with cells even more aggressive and treatment-resistant than before.

The obvious solution, then, would be to develop therapies to specifically target CSCs. This is not easy though, because scientists are still struggling to find reliable methods to detect which cells in a tumour are the CSCs. The idea, however, is for those types of cancer where the CSC model holds true – such as brain, breast, colon, ovarian, pancreatic and prostate cancers – to combine therapeutic strategies that target the fast-dividing cells with strategies that make the slowly dividing CSCs proliferate faster, so that they can be killed off, too.

Over the next few years, scientists hope to find out whether the CSC theory is a real breakthrough for cancer treatment, or if a more accurate model of cancer is still required.

Web reference

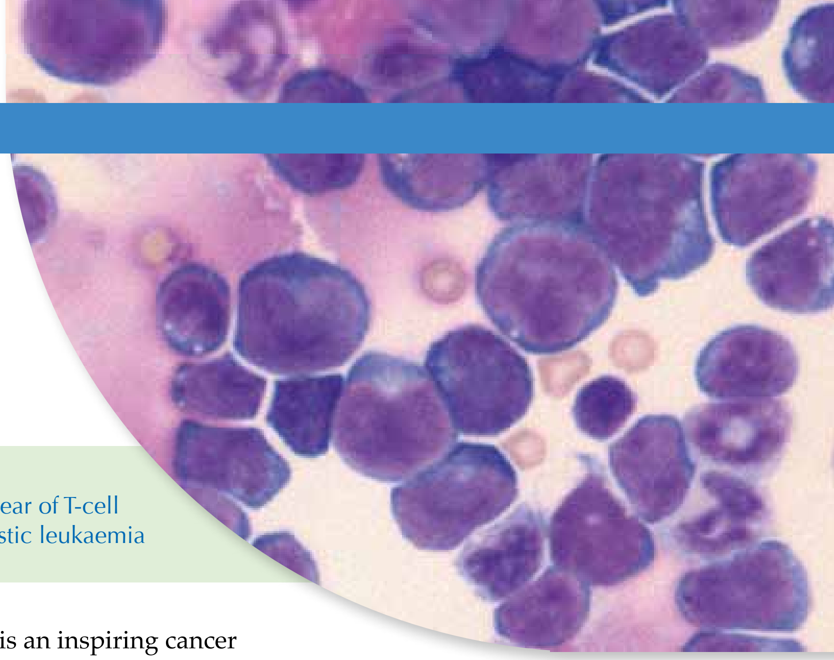
w1 – For translations of the Edwin Smith papyrus in English and German, see: www.touregypt.net/edwinsmithsurgical.htm and www.medizinische-papyri.de/Papyrus-Smith

Resources

The University of Rochester Medical Center has produced a lesson plan for an upper secondary-school activity on cancer stem cells. See the university website (www.rochester.edu) or use the direct link: http://tinyurl.com/633jfds

Harvard scientists have recently discovered that CSCs may be generated from other cancer (non-stem) cells – so that eradicating the CSCs

Image courtesy of Hind Medyouf, German Cancer Research Center (DKFZ)



Bone marrow smear of T-cell acute lymphoblastic leukaemia

would not eradicate the cancer. See 'Cancer stem cells made, not born' on the university website (www.harvard.edu) or use the direct link: http://tinyurl.com/6h9fyng

Nature has compiled a resource section on CSCs, including a podcast, links and current research articles. See: www.nature.com/nature/focus/cancerstemcells

For a teaching activity to spot cancer mutations, see:

Communication and Public Engagement team (2010) Can you spot a cancer mutation? *Science in School* **16**: 39-44. www.scienceinschool.org/2010/issue16/cancer

Joan Massagué is an inspiring cancer researcher. For an interview with him, see:

Sherwood S (2008) On the trail of a cure for cancer. *Science in School* **8**: 56-59. www.scienceinschool.org/2008/issue8/joanmassague

If you enjoyed reading this article, why not browse the full list of articles on medical topics published in *Science in School*? See: www.scienceinschool.org/medicine

Massimiliano Mazza has been doing post-doctoral work in the Experimental Oncology Department at the Istituto Europeo di Oncologia (European Institute of Oncology) in Milan, Italy, since September 2007. He works on models of acute myeloid leukaemia in mice, and is particularly interested in CSCs.

To learn how to use this code, see page 65.

The physics of crowds

Crowding affects us almost every day, from supermarket queues to traffic jams. **Timothy Saunders** from EMBL explains why this is interesting to scientists and how to study the phenomenon in class.

The physics of crowds is an active area of research in many fields, from public safety to protein interactions. Crowds occur in many places: people entering stadia, traffic jams, animal migrations (e.g. wildebeest or salmon), and molecular crowding inside cells.

The reasons for crowding are as manifold as their occurrences, and include the density of people, animals or molecules; narrow streets; road works; accidents; lack of visibility; social pressure (when people are uncertain, they tend to follow others); avoidance of danger (groups of animals avoiding predators); limited exit points (wildebeest crossing rivers at shallows during migration); panic (escaping from fire); and rapid velocity changes (traffic-jam formation).

Crowds are a real problem for which the application of physics can be helpful. Crowds have intriguing dynamics: both the behaviour of the individual members of the crowd and of the crowd as a whole must be considered – and this can change rapidly or become unstable. Crowd behaviour can even be counterintuitive. In a traffic jam, for example, the position of the vehicle at the front of the jam often moves further back over time, against the flow of traffic, as the jam propagates through a stream of vehicles[w1].

For more details of the physical phenomena in crowds, see the supplementary online information[w2].

Image courtesy of Hani Nabulsi

A crowd at the Hajj

Image courtesy of Fraz Ismat; image source: Flickr

- Biology
- Physics
- Geography
- Environmental studies
- Mathematics
- Ages 13+

REVIEW

Studies of fluid movement and molecular motion inside cells are presented in a completely innovative way. The concept of crowding is extended to different situations, both at the macro level, such as in human crowding, and the micro level, as when discussing molecules.

The activities, which can be carried out using only basic equipment, are supported by illustrations and websites giving historical information on crowding, pictures and simulations, making them easy to replicate. The development of the lesson plan follows a bottom-up approach, considering initially the experiences of the students and then building upon their experiences to evolve into more detailed analysis of crowding. If the noise might disturb other classes, the activities could be carried out in the playground or sports hall.

Crowding activities are relevant in biology when discussing molecular flow and protein interactions. In physics, they are applicable to fluid movement, velocity changes of traffic flow, and public safety when designing open areas such as stadia and shopping centres. Though it is mainly a scientific concept, crowding could also be used in geography or environmental studies to consider density of people, social pressure and animal migration.

The article and its activities could then be followed up by an individual or group assignment. Students could be asked to design a public stadium, a communal area or even a recreational area for their own school, justifying their arrangements for public safety.

Addressed in different ways, these activities would be suitable for students aged 13 and older. Advanced mathematics students (aged 17+) could use the activity to begin modelling physical processes.

Giulia Realdon, Italy

Teaching crowd formation

The proposed lesson introduces students aged 14 and above to some of the underlying principles of crowds and crowding. In particular, it highlights the need for multiple areas of physics to be used together to tackle such complex phenomena. The lesson can be used to teach phases of matter (because crowds can be both solids and fluids), properties of fluids, forces and interactions, and dynamics. A lesson plan is available online[w2].

Introduction

1. Introduce the topic[w2] and remind the class that crowds do not necessarily involve humans.
2. In groups of 2-5, students should collect examples of crowding and the reasons for crowd formation.
3. Mediate a class discussion to collect the results and reduce the reasons for crowd formation to more general concepts such as those mentioned above (e.g. narrow spaces and panic).

Image courtesy of Rainbirder; image source: Flickr

Wildebeest risking strong currents and crocodiles to cross the Mara river, Kenya

4. Introduce the physical phenomena displayed in crowds[w2]. You can use videos[w3, w4] to help demonstrate these points clearly and refer to the list of examples collected by the class to motivate the discussion. The class should draw analogies between interactions in crowds and other physics concepts (such as electron–electron repulsion, shock / travelling waves and fluid flow).

The following experiments build an intuitive understanding of how different factors affect crowds. They require students to behave sensibly and avoid danger. Stress that students should avoid physical contact during the experiments and that experiments should always be done at a walking pace.

Experiment 1: Leaving the room

This experiment explores how limited access can induce crowding (this is particularly important when designing fire exits) and demonstrates that crowding can be relieved by forcing the crowd into streams.

1. For a class of around 20-25 students, clear an area in the classroom in front of a door: 3-4 m from the door and about 3 m wide (Figure 1A). Adjust the size depending on space and student numbers (allow roughly 0.5 m^2 per student).
2. One student stands outside the door with a stopwatch. The rest line up inside, around the cleared space.

Image courtesy of Rainer Sturm / pixelio

A flock of sheep

Images courtesy of Timothy Saunders

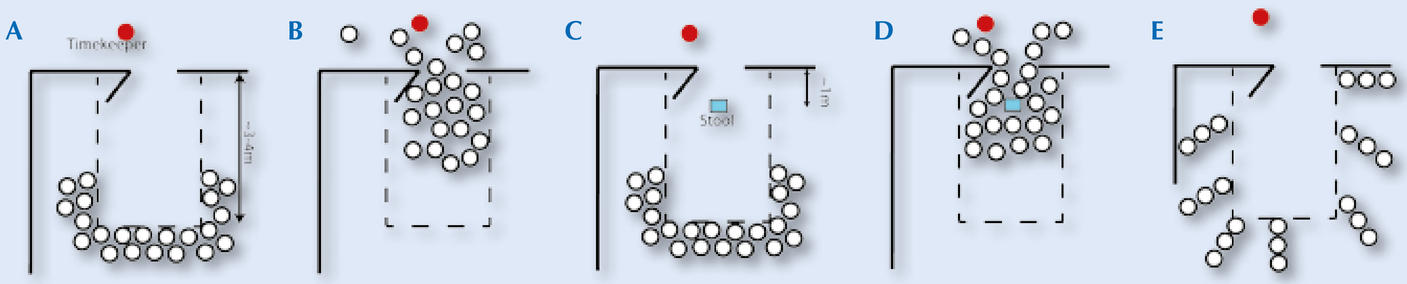


Figure 1: Experiment 1. **(A)** The red spot represents the timekeeping student; black circles represent remaining students. **(B)** Students leave the room together; the timekeeper records how long this takes. **(C)** Repeat **(B)**, but with a stool 1 m from the door. **(D)** The stool causes two streams to form, decreasing exit time. **(E)** Repeat **(B)** with a different initial configuration

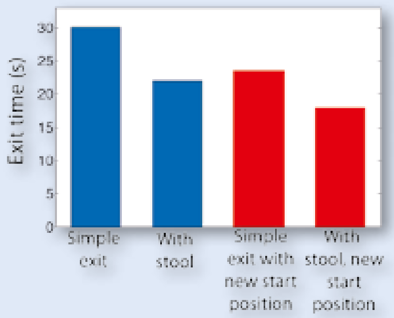


Figure 2: Example distribution of measured times

3. Once ready, the students all start walking at the same time and exit the room.
4. The student outside records starts the stopwatch when the first student leaves the room and stops it after the last student has come through (Figure 1B).
5. Repeat the experiment twice more and record the average exit time over the three repetitions.
6. Next, place a stool 1 m from the door, inside the cleared space (Figure 1C). The students again exit the room, without touching the stool (Figure 1D). Record the average time over three repetitions.
7. The initial configuration of students plays a role in determining the exit time. Ask the students to discuss different initial conditions and how these may reflect more realistic situations (such as people at a fire escape). The class should choose a new initial condition (such as in Figure 1E) and repeat the above experiment.
8. Plot the recorded average times (Figure 2) and discuss reasons for differences in these times in class.

The exit time should be shortest when the stool is present. It breaks the flow of people into two separate streams, which reduces the chance of two people coming very close to one another and makes a blockage less likely. This is an example of counterintuitive physics – an object in the way speeds up the exit rate. Simulations of the above scenarios and a discussion of the underlying physics are available online[w3, w5].

What do these results mean for fire-exit design and fire-safety rules? Should obstacles be put in front of fire exits? This may not always be practical. What would happen if running were allowed? Although this could decrease the exit time, it also increases the chances of an accident – and an injured person at a door would block others from escaping (Figure 3).

Image courtesy of maureenlafleche; image source: Flickr

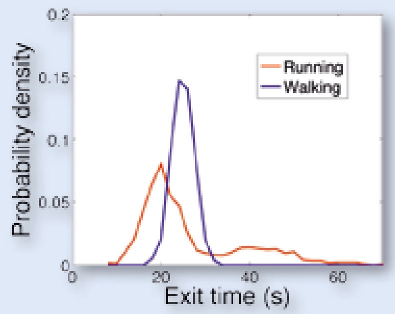


Figure 3: Qualitative comparison of exit times for walking versus running. The mean exit times are similar, but the spread in exit times is much larger for running, a scenario that should be avoided in fire-exit design

Experiment 2: Walking in narrow places

This experiment reveals how space constraints can alter the flow of people or lead to traffic jams. This is particularly relevant in situations where the crowds are densely packed, such as pilgrims to Mecca (on the Hajj)[w2] or in molecular crowding (large proteins in the cytoplasm of cells have a higher folding rate when more densely packed, to save as much space as possible; see McGuffee & Elcock, 2010). Although the experiment is a considerable simplification of such systems, it highlights how crowding can alter collective behaviour.

1. For a class of around 25 students, delimit a 5 x 3 m corridor of clear space, for example using 1 m rules on the floor (Figure 4A). Allow roughly 0.5 m^2 per walker (see Step 2).

Image courtesy of Luke Robinson; image source: Flickr

A crowd at the entrance to a London Underground station

2. Five students are timekeepers (red dots, Figure 4A), each positioned along a 1 x 3 m section of the corridor (chalk can be used to separate the corridor into these regions for clarity) with a stopwatch set to zero. The remaining students are walkers (Mars or Venus symbols), of which one is the target (green filled symbol). Walkers initially position themselves randomly within the area defined by the metre rules, facing one end of the corridor (chosen randomly).
5. Each walker then heads towards the end of the corridor. Once there, they turn and walk to the other end of the corridor, avoiding other walkers.
6. After 30 s (to ensure good mixing), the timekeeper whose area contains the target starts his / her stopwatch. When the target leaves the area, the timekeeper stops his / her stopwatch (but does not reset it!) and the neighbouring timekeeper, whose area the target has just entered, starts his / her stopwatch (Figure 4B). Continue for 2 min and then record the cumulative time on each timekeeper's stopwatch.
7. Next, reduce the width of the corridor by 1 m and repeat the experiment. Continue until the corridor is only 1 m wide (Figure 4C).
8. Plot the recorded times taken by each timekeeper for the different corridor widths (Figure 5).

At low densities (i.e. wide corridor) the target spends roughly the same amount of time in each of the five areas (though slightly longer at the ends, as stopping and turning takes some time). As crowding increases, a traffic jam is likely to form at the centre because this is where velocities are (initially) highest and the narrower corridor makes avoiding other students more challenging – so they are more likely to stop to avoid a collision, thus causing an obstruction. Therefore, for more restricted corridors, the target spends most time in the central regions.

This is an example of how behaviour changes from a free to a restricted system. This is similar in principle to traffic jam formation when the number of lanes is restricted (though obviously the cars are not going in opposite directions in the same lane!). Students may also notice that streams form, akin to streams of pedestrians on the high street[w5]. This happens because it becomes more efficient for someone to follow another person's path rather than forming a new route through the crowd.

Conclusions

Summarise the key results:

- Crowds are dynamic entities, well described by concepts from physics.
- Streaming can relieve crowd pressure. In particular, artificially inducing streaming (using obstacles) can decrease the exit time from crowded areas.
- High initial velocities can induce crowding – it does not always pay to be fast. This is relevant in spatially reduced regions, such as areas with road works or a cell cytoplasm.
- Using the above ideas, physicists have been able to assist in dealing with a number of real-world problems. For example, the annual Hajj has new systems for relieving crowd pressure to attempt to avoid further crowd problems[w2].
- Such solutions require the combination of different physics disciplines (such as fluid mechanics, particle interactions, fluctuations and the role of boundaries) and non-intuitive thinking.

Optional extension

You could have your students write an essay about a particular form of crowding, how physics can explain the observed crowding, and (if appropriate) what can be done to relieve

Image courtesy of Timo Newton-Syms; image source: Flickr

Image courtesy of Timothy Saunders

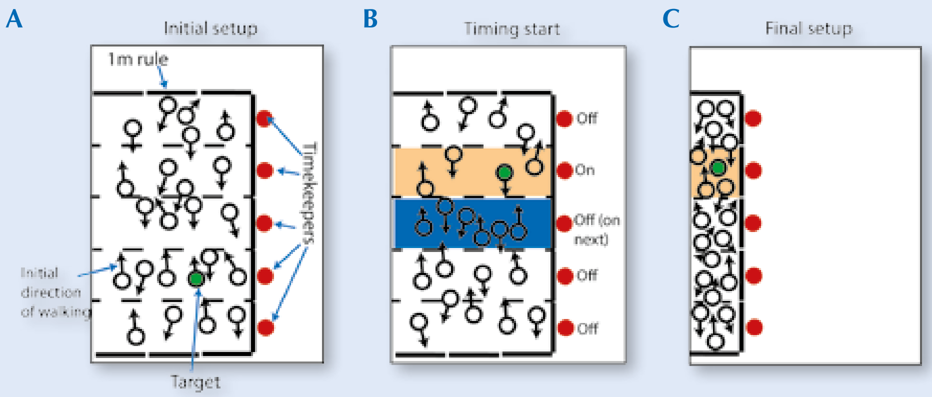


Figure 4: Experiment 2. (**A**) Red dots are timekeepers, the green dot is the target and black circles represent walkers. (**B**) After 30 s of mixing, the timekeeper whose area contains the target starts the stopwatch (orange area). When the target leaves the orange area (into the blue area), the orange timekeeper stops the watch whilst the blue timekeeper starts his / hers. (**C**) Repeat with narrower corridor until the corridor is only 1m wide

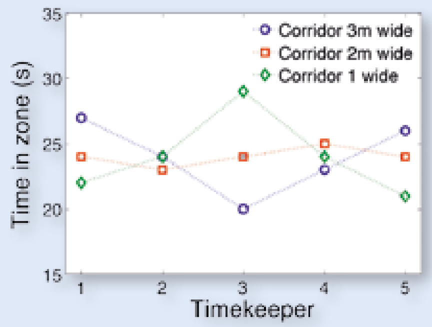


Figure 5: Example of the time distributions measured by the timekeepers

the crowding. Possible examples include the Hajj pilgrimage; design of fire escapes; highway building; town planning; animal migration; diffusion of molecules in cells; or macromolecular crowding in solution.

For mathematically advanced students, the intelligent driver model is a good example of how crowds can be modelled[w6].

Reference

McGuffee SR, Elcock AH (2010) Diffusion, crowding & protein stability in a dynamic molecular model of the bacterial cytoplasm. *PLoS Computational Biology* **6(3)**: e1000694. doi: 10.1371/journal.pcbi.1000694

Web references

w1 – A team of US scientists has set up an informative website to present their simulation data on the formation of traffic jams. It includes a good explanation of their research and results, as well as a number of videos showing how *phantom* traffic jams form. See: http://math.mit.edu/projects/traffic

w2 – For background information on the physics of crowding, including links to online tools, as well as for the lesson plan, see the *Science in School* website: www.scienceinschool.org/2011/issue21/crowding#resources

w3 – Following several stampedes with serious outcomes, scientists from Germany and Saudi Arabia have investigated crowding during the Hajj, which led to changes in the way the crowd is now organised. Their website contains background information and short videos of their analyses, as well as a list of links to other crowd-analysis and simulation studies. See: www.trafficforum.ethz.ch/crowdturbulence

One of the scientists, Dirk Helbing, has since moved to the ETH Zürich, Switzerland. His homepage provides a good collection of videos, links and simulations of crowding and other mass social behaviour such as synchronised clapping. See: www.soms.ethz.ch/research/Videos

w4 – A team of German and Hungarian scientists has simulated escape panic in a computer model. Their free website offers their article published in *Nature* in English and Hungarian, videos simulating various escape scenarios with and without panic or herd effect, a list of major crowd disasters and background information. See: www.panics.org

w5 – For a simulation of how lanes of uniform walking direction form in a street, see: www.trafficforum.org/somsstuff/pedapplets/Corridor.html

w6 – For an explanation of the intelligent driver model, see: www.vwi.tu-dresden.de/~treiber/MicroApplet/IDM.html

Resources

If you found this article useful, you might like to browse the rest of the teaching activities in *Science in School*. See: www.scienceinschool.org/teaching

---

Timothy Saunders is a post-doctoral researcher at the European Molecular Biology Laboratory in Heidelberg, Germany. His work involves applying concepts from physics to biological problems. Over the past six years he has taught mathematics, physics and biology to students of a range of age groups and abilities. This article grew out of a series of lessons given to adult learners resitting their school biology exams.

To learn how to use this code, see page 65.

Polymers in medicine

The topic of polymers is often limited to chemistry lessons. The **Establish project** offers some hands-on activities to investigate these materials and some of their medical applications.

Polymers are used in everyday products such as disposable nappies, shampoo and paper

Image courtesy of Kerry Lannert; image source: Flickr

Image courtesy of Roger Walch; image source: Flickr

Image courtesy of SCA Svenska Cellulosa Aktiebolaget; image source: Flickr

We use polymers every day, for example in the form of plastics, coatings and paper, and in products such as nappies and shampoos. Polymers consist of large molecules made up of repeating structural units. The following activities have been developed to help students to make links between the macroscopic world of materials that we can see and the sub-microscopic world of particles (atoms and molecules) that we cannot see, using real applications. They use the approach of inquiry-based learning, whereby the students are encouraged to develop their ideas based on their observations of the practical activities and then to test them in new contexts.

In the first activity, students aged 13-15 investigate the diffusion of liquids through different types of polymer membrane (Worksheet 1). They then move to a consideration of membranes in medicine: how the human kidney works and how its functions can be taken over by a dialysis machine (Worksheet 2). The particular focus is to understand why some molecules are removed from the blood during dialysis and others are not. The students should also predict what would happen if the dialysis fluid were water, leading them towards an understanding of osmosis.

In the second activity, students aged 15-17 create membranes of polyvinyl chloride (PVC) and investigate their physical and chemical behaviour. They then create and test an antibacterial PVC membrane (Worksheet 3). As extensions of this activity, the students can investigate membranes made with different plasticisers, or determine the antibacterial effectiveness of membranes containing different metals or different quantities of metals.

Membranes with invisible holes

In this activity, students are asked to think about the invisible world of atoms and molecules and, through their understanding of the activity, will develop an understanding of the particulate nature of matter. These activities can be used to show both the existence of molecules and that molecules have different sizes. The students investigate the diffusion of particles through different types of membranes, then apply what they have learned to a consideration of the kidney and of dialysis[w1].

Tube number	Membrane
1	No membrane
2	Jam-pot cover
3	Plastic bag or cling film
4	Latex glove

Table 1: Possible membranes for investigation of 'holes'

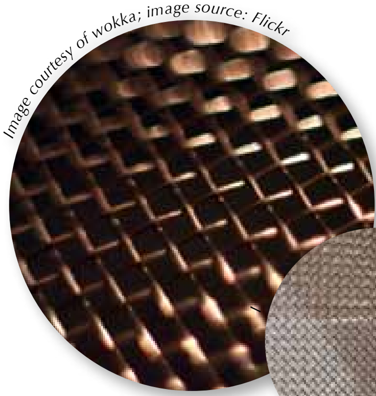


Image courtesy of wokka; image source: Flickr

Image courtesy of Peter Asquith; image source: Flickr

The students will already have encountered the use of sieves to separate mixtures and the need to use a sieve with appropriately sized holes. The teacher can use the context of wrapping food to introduce plastic membranes, after which the students can carry out the investigation below with different membranes. The teacher should encourage a discussion of possible explanations for the results. If necessary, encourage the development of the idea that there are particles of different sizes and membranes with holes of different sizes.

The idea is to use a variety of films / membranes, e.g. cheap plastic bags, food wrapping or food bags, to investigate the movement of iodine particles through different membranes. The students should set up several experiments, as suggested in Table 1. The teacher should try them out in advance, to make sure that they give sufficiently different results.

The students should learn to:

- Draw conclusions from observations
- Explain the phenomenon through the existence of invisible holes and the movement of particles
- Distinguish alternative explanations and debate with peers.

BACKGROUND

The Establish project

These activities are among the teaching units being developed by the Establish project, an EU-funded project to encourage the widespread use of inquiry-based science teaching for secondary-school students (aged 12-18). A group of more than 60 partners from 11 European countries are working together to develop and adapt teaching units for use in classrooms across Europe.

The activities in this article are taken from the teaching unit entitled 'Exploring holes'. At the time of going to press, units are also available on sound and on disability, and further units are planned on cosmetics, chitosan, forensic science, photochemistry, renewable energy and medical imaging. To learn more and download the completed units, visit the Establish website[w5].

REVIEW

- Biology
- Chemistry
- Osmosis and diffusion
- Polymerisation
- Excretion
- Ages 13-18

Have you ever wondered how a dialysis membrane works? Can plastics be used to filter unwanted substances from your body? How about antibacterial plastics? This article introduces the role of polymers in dialysis machines used for blood filtration and for the treatment of wounds.

The experiments for younger students that are described in this article will help them to understand the science of polymers and how they are used in dialysis. In the activities for older students, the class actually get to make their own PVC – one of the most common polymers used today – and investigate its antibacterial properties.

The activities would be appropriate in both chemistry and biology lessons, addressing the topics of polymerisation, osmosis, diffusion and excretion. It could be followed by a discussion of the wider uses of polymers, of selectively permeable membranes or of excretion.

Andrew Galea, Giovanni Curmi Post-Secondary School Naxxar, Malta

Student worksheet 1: membranes with invisible holes

Materials

- Iodine solution (approximately 0.05 M)
- Starch solution (approximately 0.12% w/v)
- A selection of different plastic films

Procedure

Investigate the movement of iodine particles through different membranes. Make a small bag out of each membrane and place it in a tube of starch solution, as shown in Figure 1. Pour some iodine solution into each bag and observe what happens.

1. Record your observations in Table 2.
2. Can you explain what is happening?
3. Can you match each of your tubes (1-4) to one of the diagrams (A-D) in Figure 2?
4. What would happen in each tube if the solutions were reversed: if at the start, the solution of smaller molecules was in the tube and the solution of larger molecules was in the membrane (Figure 3)? Enter your predictions in Table 3.

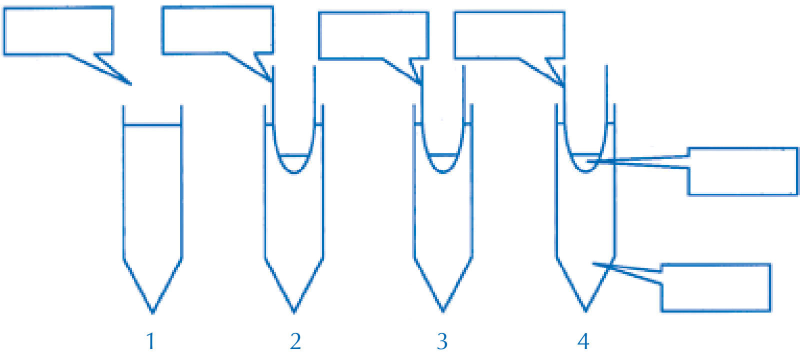


Figure 1: Experimental set-up

		1	2	3	4
Colour at start	In small bag				
	In tube				
Colour at end	In small bag				
	In tube				

Table 2: Results of your experiment

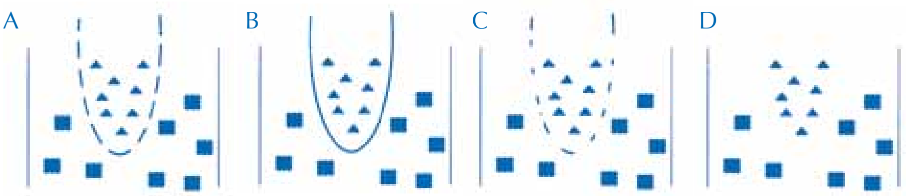


Figure 2: Which situation corresponds to each of your test tubes?

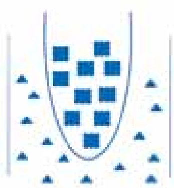


Figure 3: What would happen if the solutions were reversed?

		1	2	3	4
Colour at start	In small bag				
	In tube				
Colour at end	In small bag				
	In tube				

Table 3: Your expectations if the solutions were reversed

Student worksheet 2: kidneys and dialysis

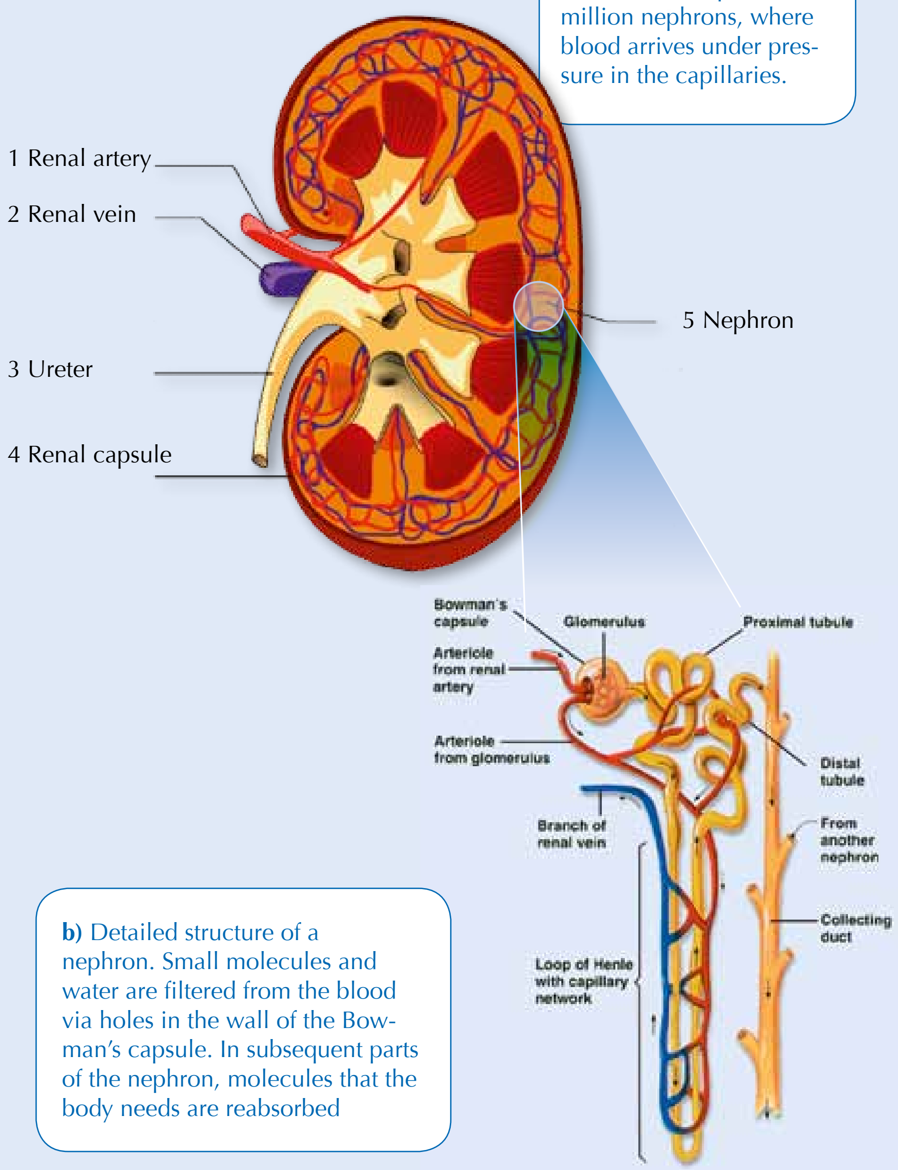
The human kidney is an amazing organ, with two essential functions: the maintenance of water balance in the body, and the excretion of urea, salts and water. Each day, the kidneys filter 180 l of fluid out of the blood – most of which is reabsorbed, together with all the nutrients that the body still needs, such as glucose and amino acids. From the 180 l of fluid that they filter, the kidneys produce about 2 l of urine containing waste products such as urea, which is toxic to the body. The urine is then stored in the bladder before being excreted.

1. Why do you think there are normally no plasma proteins in the urine even though they are in solution in the blood plasma?
2. As a result of certain injuries or diseases, blood cells appear in the urine. What may have happened to cause this?

If a person's kidneys fail, death will follow in about four days because urea builds up and the body loses control of its water balance. The person's life may be saved with the help of *dialysis*; this typically involves attending hospital three times a week. During dialysis, which takes about six to eight hours, the blood is taken from the patient's body in a tube and flows into a machine where it passes next to a filter called a dialysis membrane. A specialised dialysis solution flows on the other side of the membrane. The composition of this solution ensures that urea passes through the membrane from the blood into the dialysis fluid, but glucose and amino acids do not. The blood – minus urea – is then returned to the body.

1. Why are red blood cells and plasma proteins not removed from blood during dialysis?
2. Urea, glucose and amino acids are similar-sized molecules. Why does urea pass across the dialysis membrane but glucose and amino acids do not?
3. What would happen if water were used as the dialysis fluid?
4. How could dialysis be used to remove excess salts?

How the kidney works



a) Overview of the kidney. Filtration takes place in 3 million nephrons, where blood arrives under pressure in the capillaries.

b) Detailed structure of a nephron. Small molecules and water are filtered from the blood via holes in the wall of the Bowman's capsule. In subsequent parts of the nephron, molecules that the body needs are reabsorbed

Image courtesy of Piotr Michał Jaworski; image source: Wikimedia Commons

Image courtesy of quecojones; image source: Flickr

A patient undergoing dialysis

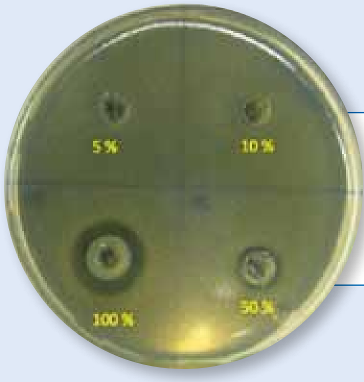
Antibacterial PVC

In this activity, students create PVC membranes and investigate the effect of a plasticiser on the physical and chemical properties of the membrane (these membranes can also be used in the first activity). The students then create a PVC membrane containing silver particles, and test its antibacterial properties by incubating it overnight.

As a more advanced investigation, the students could get a better understanding of the antimicrobial property of the membrane by incorporating different concentrations of silver in membranes and examining the effect of concentration on the zones of inhibition that they observe. Typical examples are shown on the right.

Non-pathogenic *Escherichia coli* can be obtained from the American Tissue Culture Collection (ATCC)[w2]. BAA 1427 in particular is a non-pathogenic surrogate strain suitable for use in this experiment.

Image courtesy of James Chapman, Dublin City University



Silver-impregnated PVC films showing difference in zone of inhibition with silver (Ag) loading

Student worksheet 3: synthesising and investigating antibacterial PVC

The polymer polyvinyl chloride (PVC) is a cheap and durable plastic used in pipes, signs and clothing. Plasticisers are often added to it to make it more flexible and easier to manipulate. In this activity, you will make a membrane of PVC both with and without a plasticiser, then compare their physical and chemical properties.

Antimicrobial membranes are used in many medical technologies, and are produced by incorporating nanoparticles or microparticles of silver or other metals into polymers. In the presence of oxygen (in air) and water, the elemental silver particles react to form silver ions (Ag^{2+}), which can break down cell walls, inhibit cell reproduction and disturb metabolism in some bacteria, viruses, algae and fungi[w3, w4].

Materials

Solvent: oxolane (tetrahydrofuran, $(CH_2)_4O$)
PVC powder
Dibutyl sebacate or other plasticiser
Silver nitrate ($AgNO_3$)
Tri-sodium citrate ($Na_3C_6H_5O_7$)
Nutrient agar
Bacterial culture (e.g. *E. coli* in a nutrient broth)
A hotplate
A magnetic stirrer
75 ml beakers
A glass substrate (e.g. beaker, watch glass or glass slide)
A graduated cylinder
A Pasteur pipette
A spatula
Petri dishes
Inoculation loops

Procedure

Safety note: All steps should be carried out under the fume hood. Tetrahydrofuran is a highly flammable liquid and vapour that can cause serious eye irritation. Handle with care under the fume hood only and wear gloves when using it.

1) Making PVC without a plasticiser

1. Using the hotplate and a magnetic stirrer, warm 20 ml solvent.
2. Slowly add 1.5g PVC powder, while stirring.
3. After about 10 min, the solution should become more viscous. Remove the beaker from the heat.
4. Remove the magnetic stirrer and pour a few millilitres of the PVC solution thinly and as evenly as possible over the glass substrate (inside or outside the beaker, or on the glass slide or watch glass). To ensure a thin layer, rotate the glass substrate carefully while the solution is still hot.
5. Leave the substrate and PVC under the fume hood to allow the solvent to evaporate; this takes about 15 min. The PVC membrane can then be easily removed from the glass substrate.

2) Making PVC with a plasticiser

Repeat the steps above to create four more membranes of PVC, each with a different amount of plasticiser added to the heated solvent (see Table 4).

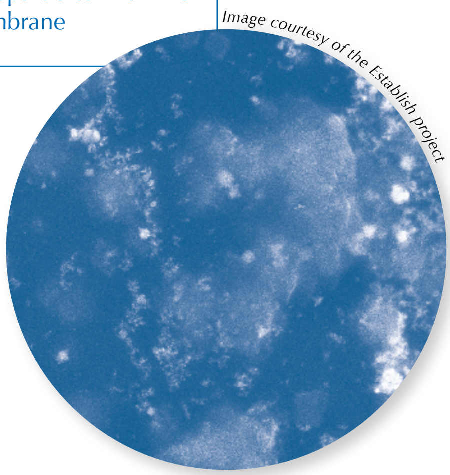
1. Compare your five samples of PVC membrane. What effect does the plasticiser have on the plastic?
2. What do you think happens to the plastic when more plasticiser is added?
3. Referring to the scanning electron microscopy (SEM) images on page 34, was your answer to Question 2 correct?
4. These membranes can be used in the previous activity ('Membranes with invisible holes') to investigate the relative size of the 'holes'.

3) Making antibacterial PVC

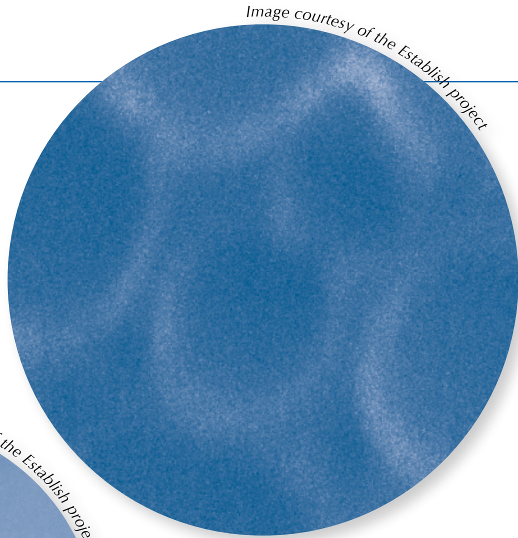
The preparation of PVC containing silver particles requires the membrane to have large holes, which is why we use a plasticiser. The silver itself is added in the form of silver nitrate, which is then reduced using sodium citrate.

1. Using the hotplate and a magnetic stirrer, warm 20 ml solvent.
2. Add 2.5 ml plasticiser, then slowly add 1.5 g PVC powder.
3. Add 2.5 ml 10 mM silver nitrate and stir for 1-2 min.
4. Divide the solution between two 75 ml beakers. Quickly rotate each beaker so that the inside is coated with solution, forming a membrane in the shape of the beaker. Ensure that there are no gaps, as the membrane must be capable of holding water.
5. Leave the beakers under the fume hood to allow the solvent to evaporate, then carefully remove the membranes. (This is quite difficult; by making two, you increase your chances of success.)
6. Make a 5 mM solution of sodium citrate and pour this carefully into one of the beaker-shaped membranes. It should pass through the membrane (hold it over a beaker), reacting with the silver nitrate, giving silver nano- or microparticles.
   Note the colour change to the membrane.
7. Allow the membrane to dry under the fume hood. Typical

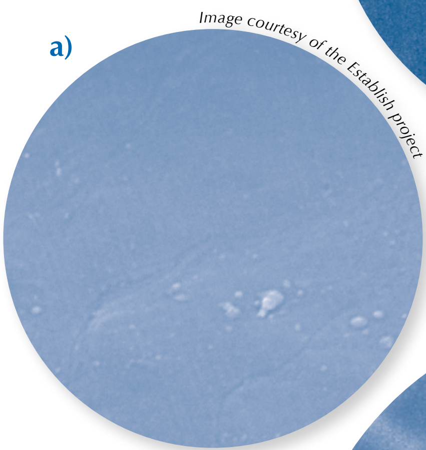
Silver micro- and nanoparticles in a PVC membrane



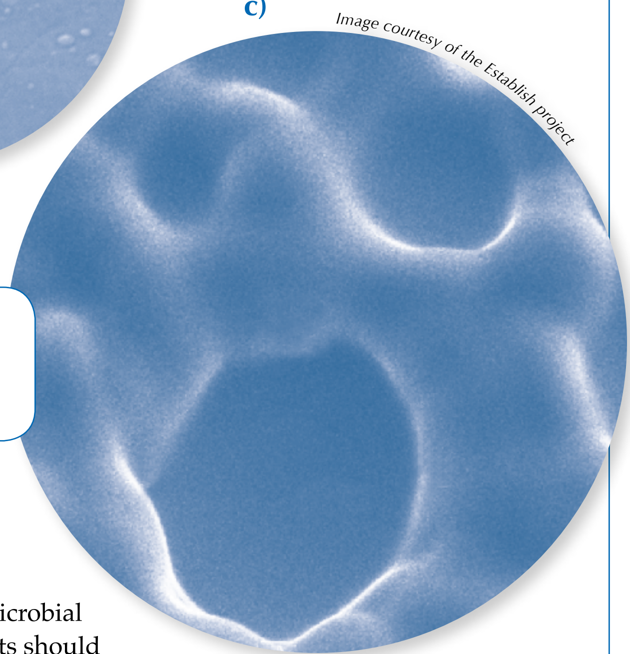
b)



a)



c)



SEM images of PVC: a) unplasticised, b) with 0.5 ml plasticiser and c) with 2 ml plasticiser

SEM images (page 34) show the presence of elemental silver dispersed in a PVC membrane.

Next, you can investigate the antibacterial properties of the prepared membranes.

1. Prepare an agar plate with a bacterial colony: on a Petri dish containing nutrient agar, deposit about 100 μl of your bacterial culture (e.g. *E. coli* in a nutrient broth) and use an inoculation loop to spread it evenly across the plate.
2. Place approximately 1 cm^2 of your silver-impregnated PVC membrane on the plate.

   Alternatively, to provide a comparison, place three pieces of PVC membrane on the plate, one of which is untreated with silver.
3. Incubate the plate overnight at 37 °C, then measure the zone of inhibition around each piece of membrane.

Safety note: As with all microbial studies, sterilised implements should be used at all times (either sterilised in an autoclave or pressure cooker, or dipped in ethanol and then flamed). This includes the scissors that you use to cut the membrane. To prevent cross-contamination, wash the inoculation loops with antibacterial wash before use.

Sample no.	PVC (g)	Solvent (ml)	Dibutyl sebacate (ml)
1	1.5	20	0.5
2	1.5	20	1
3	1.5	20	2
4	1.5	20	3

Table 4: Creating membranes of PVC with different amounts of plasticiser

The antibacterial property of these membranes makes them useful for treating wounds and burns, as well as infections with bacteria such as methicillin-resistant *Staphylococcus aureus* (MRSA) and *E. coli*.

1. Why are antibacterial PVC membranes particularly useful in the treatment of MRSA infections?
2. What other applications of antibacterial PVC membranes can you find?

Acknowledgements

The activities described in this article are based on information in Wilms et al. (2004; Worksheet 1), from Alison Graham at Dublin City University, Republic of Ireland (Worksheet 2), and from Laura Barron and James Chapman at Dublin City University (Worksheet 3).

Reference

Lewis DJ et al. (2010) Intracellular synchrotron nanoimaging and DNA damage / genotoxicity screening of novel lanthanide-coated nanovectors. *Nanomedicine* **5(10)**: 1547-1557. doi: 10.2217/nnm.10.96

Wilms M et al. (2004) Molekulares Sieben: Mit Einmachfolie ins Diskontinuum. *Chemkon* **11(3)**:127-130. doi: 10.1002/ckon.200410011

Web references

w1 – The Merlot Health Sciences portal has a useful animation of dialysis. See: http://healthsciences.merlot.org/images/18loop.gif

w2 – ATCC is a global non-profit bioresource centre and research organisation that provides biological products, technical services and educational programmes. See: www.atcc.org

w3 – Silver nanoparticles may be killing beneficial bacteria in wastewater treatment. *Science Daily*. www.sciencedaily.com or use the direct link: http://tinyurl.com/4mq4pv

w4 – Surface modification of silver nanoparticles and their interactions with living cells. *Nano Werk*. www.nanowerk.com or use the direct link: http://tinyurl.com/68fojm9

w5 – To learn more about the Establish project and download the completed units (more will be added over time), see: http://establish-fp7.eu

w6 – An international research centre in Grenoble, ESRF produces high-brilliance X-ray beams, which serve thousands of scientists from all over the world. See: www.esrf.eu

w7 – To find out more about EIROforum, see: www.eiroforum.org

Resources

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

In this, the International Year of Chemistry, why not browse the full collection of chemistry articles in *Science in School*? See www.scienceinschool.org/chemistry

To learn how to use this code, see page 65.

@ EIROforum

EIROforum

Nanoparticles in medicine

ESRF

The use of nanoparticles is very important in new health care applications. Understanding the impact of nanoparticles on cells and tissues is crucial for safety, reliable diagnosis and treatment of diseases. Many medical nanoparticles are based on metals, and X-ray techniques at the European Synchrotron Radiation Facility (ESRF)[w6] are well suited to monitor, for example, the interaction of a single nanoparticle with a cryopreserved cell at the nanoscale (Lewis et al., 2010).

ESRF is a member of EIROforum[w7], the publisher of *Science in School*.

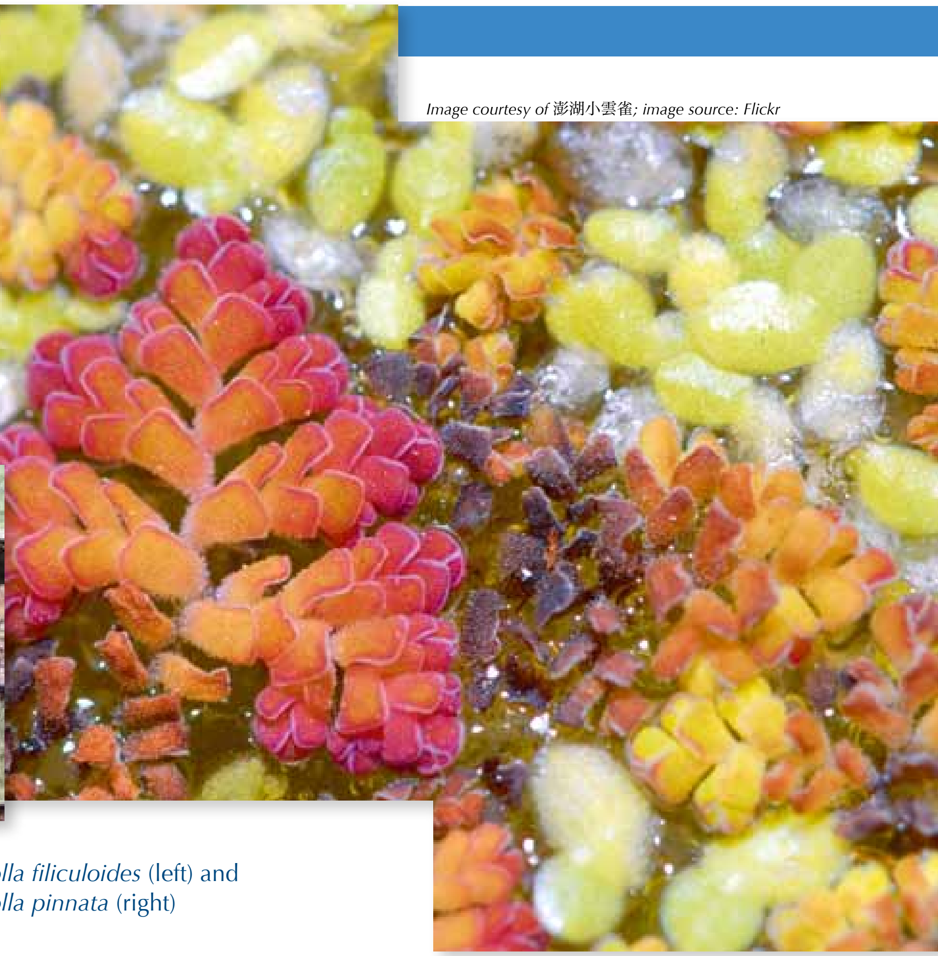


Image courtesy of 澎湖小雲雀; image source: Flickr

Azolla filiculoides (left) and *Azolla pinnata* (right)

Image courtesy of eyeweed; image source: Flickr

Bioremediation in the classroom

Vered Yephlach-Wiskerman introduces a classroom project to investigate the bioremediation powers of the aquatic fern *Azolla*.

When soils or aquatic bodies are contaminated, for example with heavy metals, solvents or oil, one important cleaning option is bioremediation: the use of micro-organisms or plants that will take up the contaminants and either metabolise them into less harmful compounds or accumulate them, allowing them to be removed. Common applications include cleaning up abandoned mining sites or oil spills. Phytoremediation (from the Greek *phyto* – plant) uses a plant's natural ability to contain, degrade or remove toxic chemicals and pollutants from soil or sludge, sediment or ground water.

Azolla is one such plant: this genus of floating freshwater ferns accumulates heavy metals such as nickel, cadmium and mercury (Arora et al., 2006); its biomass is easy to harvest and desiccates very fast (Wagner, 1997). These characteristics make it a perfect candidate for bioremediation systems (Cohen et al., 2004), although it is always important to assess the potential impact of introducing a new species into an ecosystem[w1, w2]. *Azolla* lives in symbiosis with the cyanobacteria *Anabaena azollae*, which can fix atmospheric nitrogen. This independence of a further external source of nitrogen allows the fern to double its biomass every two to three days at room temperature and is the reason that it has been used in China as a biofertiliser in rice paddies for centuries.

Azolla in the science classroom

The plant is a great tool for interdisciplinary school projects involving ecology, environmental studies, biology, chemistry and biotechnology. During such a project, students can develop essential skills for scientific work: formulating a problem and a hypothesis, planning an experiment, writing up the results and drawing conclusions.

In the lesson, introduce the topic of bioremediation and have the students collect information about *Azolla*[w1, w3, w4, w5, w6, w7] (Arora & Saxena, 2005), such as the morphology of water plants as op-

REVIEW

- Chemistry
- Biology
- Applied science
- Environmental science
- Earth science
- Ages 16-18

Keeping the environment clean and pollution free as well as monitoring the environment are now major concerns, and these subjects are studied in school science. Natural ways of cleaning up the environment, such as bioremediation by plants and microbes, are ideal and have been studied for many years. This article shows how a common aquatic plant, *Azolla*, can be used to demonstrate bioremediation in the classroom. The activities foster scientific thinking skills, an essential part of the 'how science works' element of the curriculum. A simplified version of this activity could be used with younger students.

The experiments could be linked to chemistry – in tests for cations and anions and titrations. The activity also has links to microbiology and biotechnology, as the students could learn the basics of how microbiological water quality can be monitored. As an extension activity, students could use the Internet find out how microbes can be used to clean up oil spills and how micro-organisms can be selected or genetically engineered to deal with particular contamination problems.

Shelley Goodman, UK

posed to land plants, the importance of symbiosis, the nitrogen cycle, the use of *Azolla* in agriculture (Pabby et al., 2004), and *Azolla*'s ability to absorb heavy metals.

Help the students to formulate the research questions and hypotheses that they would like to investigate. Possible topics include measuring the gain in biomass depending on growth conditions (e.g. CO_2 level, iron level in the water, amount of light), or the effect of *Azolla* on water quality.

Teams of two to three students work well, and each experiment should be repeated three times for confirmation. Different teams can work on different aspects of the plant or on the same topic to replicate a single experiment.

In the final session, the results can be presented and discussed in class.

Table 1 can help students plan their experiment. The table can also be downloaded from the *Science in School* website[w8].

Next, the students should tabulate their experimental results and represent them graphically. They should consider the most appropriate type of graph to use (e.g. line graph or bar chart).

Below is an example of a project suitable for students in Grades 10-12 (aged 16-18). We used *Azolla filiculoides*, but any of the seven *Azolla* species will do. They can easily be obtained in plant nurseries or garden centres, aquarium shops or online.

The effect of *Azolla* on water quality

Hypothesis / research question: *Azolla* will lower water's conductivity because the plant will absorb available metal ions. Does *Azolla* influence the water quality in other ways?

To test this hypothesis and answer the question, several parameters that indicate water quality will be monitored over the course of 2 weeks. Apart from measuring the conductivity, we also decided to investigate some aspects of water quality that were easy to test and for which the equipment was readily available.

Students should be familiar with basic plant physiology and the use of the instruments / methods.

	Details of the experiment	Your answer
1	Formulate your hypothesis.	
2	What is the biological basis of your hypothesis?	
3	What is the dependent variable you want to measure in your experiment? How is it measured? In what units?	
4	What is / are the independent variable(s) you want to change to study its / their effects on the variable in Step 3? How will you change it / them?	
5	What are the fixed variables in the experiment – those that will not change?	
6	Detail the controls you intend to include and explain their importance.	

Table 1: Planning your experiment

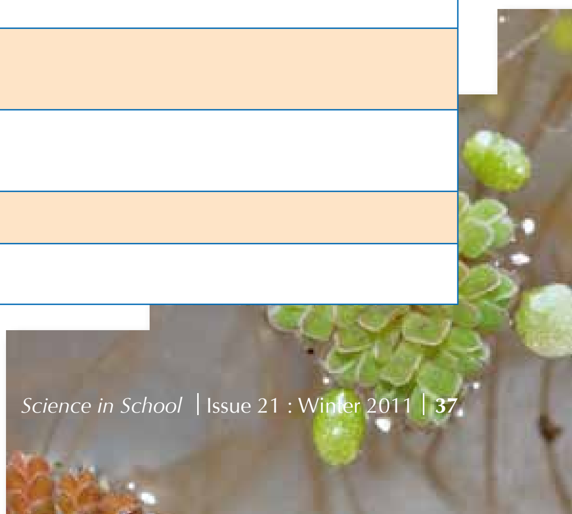
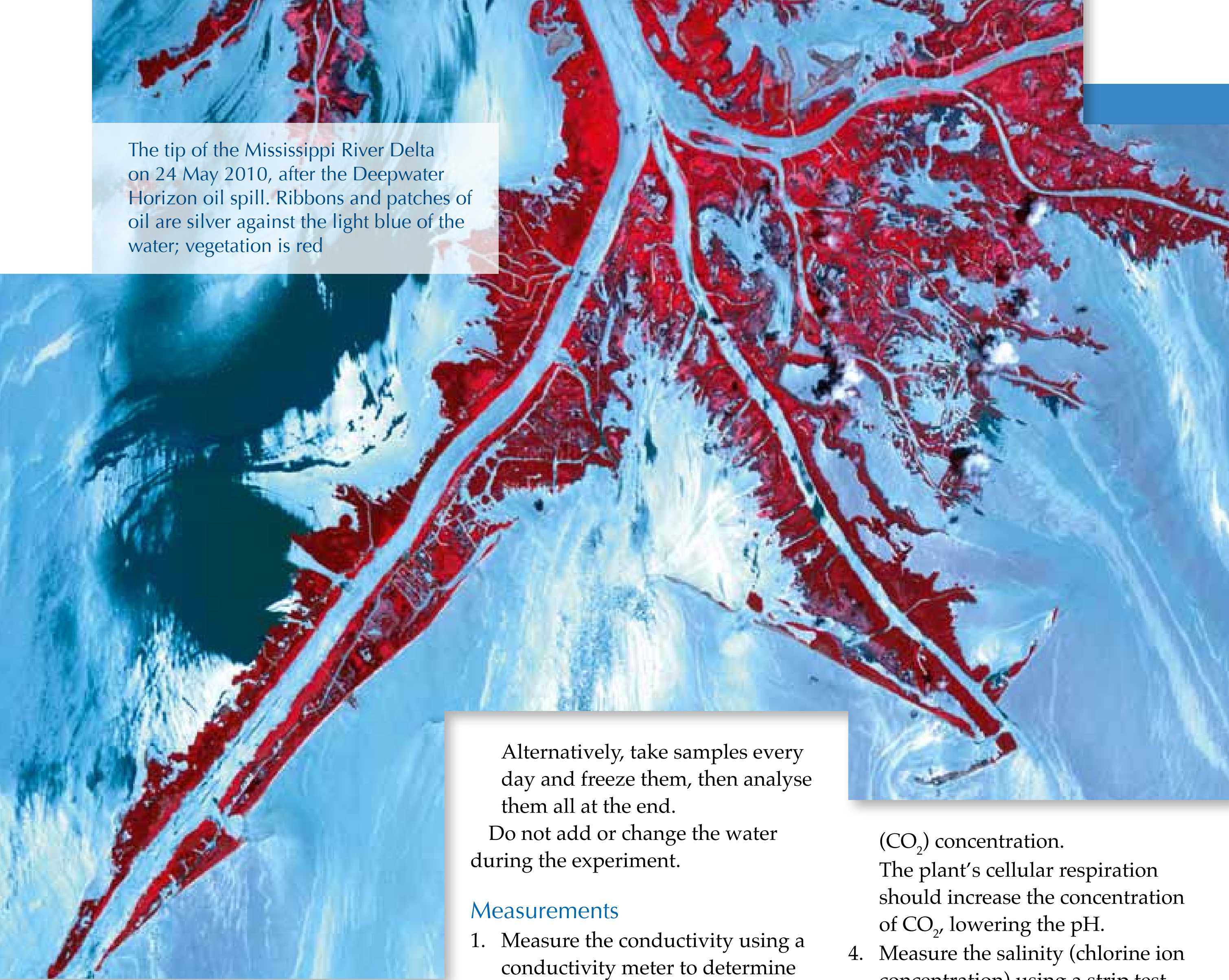
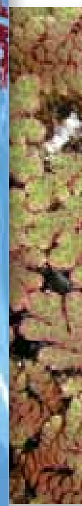


Image courtesy of 澎湖小雲雀; image source: Flickr



The tip of the Mississippi River Delta on 24 May 2010, after the Deepwater Horizon oil spill. Ribbons and patches of oil are silver against the light blue of the water; vegetation is red

Image courtesy of NASA Goddard Space Flight Center



1. Pour 250 ml tap water into each of two glass containers, then place them on the window sill.
   Ideally, we would use contaminated water so that the plant can demonstrate its bioremediation, but this would not be safe. However, you could add metals from the school collection to a sample of tap water, and use this mixture.
2. Measure your parameters in both containers.
3. To one of the containers, add about 50 g *Azolla* (add more if the plant is very wet). The second container should be left untreated.
   To extend the investigation, a third aquatic plant – one that does not absorb heavy metals, such as duckweed (*Lemna spp*.) – could be used in a third container.
4. Repeat your measurements every 1-2 days.
   Alternatively, take samples every day and freeze them, then analyse them all at the end.

Do not add or change the water during the experiment.

Measurements

1. Measure the conductivity using a conductivity meter to determine the concentration of electrolytes.
   Because metal ions are taken up by *Azolla*, the conductivity in the water should decrease over time.
2. Measure the concentration of several specific ions. This can be done easily using commercial strip tests. We tested the nitrate and iron content because we had kits for them.
   Levels of iron should decrease over time as it is absorbed by *Azolla*, because it is an essential element for nitrogenase activity. If the iron supply is too low, *Azolla* fronds will turn yellow and wilt.
   Due to their symbiotic cyanobacteria, *Azolla* can live without a further source of nitrogen apart from the air, but the plant's growth rate will drop. Thus a small decrease in nitrate levels in the water would be expected.
3. Measure the pH using either a pH meter or a strip test, to get an indication of the carbon dioxide (CO_2) concentration.
   The plant's cellular respiration should increase the concentration of CO_2, lowering the pH.
4. Measure the salinity (chlorine ion concentration) using a strip test.
   If the salinity increases, it should do so equally in both water samples – it will be the result of evaporation, because *Azolla* does not take up chlorine ions.

As a control, you could determine bacterial content by measuring turbidity with a spectrometer or turbidity meter, or by measuring the concentration of colony-forming units using the dilution method, seeding isolation, and counting colonies of bacteria on a rich agar medium. Differing levels of bacteria in the initial water samples may influence the water quality and could falsify results, as bacteria may also take up nutrients and metals.

Safety note: The cyanobacteria in *Azolla* produce a neurotoxin, so the plants should not be eaten. In addition, some *Azolla* species are considered a weed and are an invasive species in many countries, so the plants should be disposed of safely after use.

Polluted water

Image courtesy of Chesapeake Bay Program; image source: Flickr

Azolla filiculoides (left) and *A. pinnata* (right)

Image courtesy of eyeweed; image source: Flickr

See also the general *Science in School* safety note on page 65.

References

Arora A, Saxena S (2005) Phosphorus requirements of *Azolla microphylla*. *International Rice Research Notes* **30(2)**: 25-26.

Arora A, Saxena S, Kumar Sharma D (2006) Tolerance and phytoaccumulation of chromium by three *Azolla* species. *World Journal of Microbiology and Biotechnology* **22(2)**: 97-100. doi: 10.1007/s11274-005-9000-9

Cohen MF, Yamasaki H, Mazzola M (2004) Bioremediation of soils by plant-microbe systems. *International Journal of Green Energy* **1(3)**: 301-312. doi: 10.1081/GE-200033610

Pabby A, Prasana R, Singh PK (2004) Biological significance of *Azolla* and its utilization in agriculture. *Proceedings of the Indian National Science Academy* **B70(3)**: 299-333. www.new.dli.ernet.in/rawdataupload/upload/insa/INSA_1/2000c954-299.pdf or use the direct link: http://tinyurl.com/62wq6mp

Wagner GM (1997) *Azolla*: A review of its biology and utilization. *The Botanical Review* **63(1)**:1-26. doi: 10.1007/BF02857915

Web references

w1 – To learn more about *Azolla*, its distribution, its status as invasive species, its biology and its uses, see the UK's Natural History Museum website (www.nhm.ac.uk) or use the direct link: http://tinyurl.com/azolla

w2 – To learn more about *Azolla* as an invasive species, see the website of NOBANIS, the European Network on Invasive Alien Species (www.nobanis.org) or use the direct link: http://tinyurl.com/65hhueu

w3 – The United States Environmental Protection Agency has compiled a wealth of information on remediation technologies in English and Spanish, including citizen's guides with useful background information. See: www.epa.gov or use the direct link: http://tinyurl.com/5rg3yfk

w4 – For a comprehensive overview on bioremediation, see the website of the Earth Sciences Division of the Lawrence Berkeley National Laboratory (http://esd.lbl.gov/research/projects/ersp/generalinfo/primers_guides/03_NABIR_primer.pdf) or use the direct link: http://tinyurl.com/6jchus7

w5 – To learn more about phytoremediation from the Ecological Engineering Group, see: www.ecological-engineering.com/phytorem.html

w6 – For more information on the biology of *Azolla* and its use in agriculture, see Wayne's Word, 'an online textbook of natural history': http://waynesword.palomar.edu/plnov98.htm

w7 – For an overview of *Azolla*'s preferred growth conditions, see the website of the University of Hawaii (www.ctahr.hawaii.edu) or use the direct link: http://tinyurl.com/6gojelj

w8 – To download Table 1 in Word or PDF format, visit the *Science in School* website: www.scienceinschool.org/2011/issue21/azolla#resources

Resources

The World Water Monitoring Day offers a number of resources in English and Spanish on how to monitor a range of water-quality parameters, as well as kits. See: www.worldwatermonitoringday.org

For further resources on testing water quality, see the website of Lifewater Canada: www.lifewater.ca/Section_16.htm

For downloadable water-testing manuals for schools, see the website of the Massachusetts Water Resources Authority (www.mwra.state.ma.us) or use the direct link: http://tinyurl.com/6jerkan

To learn about a school project to test water quality in the local environment, see:

Harwood R, Starr C (2006) Environmental chemistry: water testing as part of collaborative project work. *Science in School* **2**: 34-37. www.scienceinschool.org/2006/issue2/envt

If you enjoyed reading this article, why not browse the full collection of science education projects published in *Science in School*? See: www.scienceinschool.org/projects

Vered Yephlach-Wiskerman teaches biology at Omer High School in Omer, Israel. She is the Excellence Program Coordinator and a lecturer in biochemistry and immunology at the science department of the Kaye Academic College of Education, a professional training college for teachers in Beersheba.

To learn how to use this code, see page 65.

Gladiolus sp

Image courtesy of greenhem; image source: Flickr

Smell like Julius Caesar: recreating ancient perfumes in the laboratory

Even everyday scents have the power to take us back in time, awakening half-forgotten memories. With **Gianluca Farusi's** help, you can take your students 2000 years into the past, recreating and testing Julius Caesar's perfume.

Dictator of the Roman Republic until 44 BC, he invaded Britain and was the first Roman general to cross the River Rhine. He was the lover of Queen Cleopatra, and the month of July is named after him. Julius Caesar is famous for many things – but probably not for his choice of perfume.

Perfumes, however, were an important part of life in ancient Rome: in the form of incense for religious ceremonies; in public areas to mask foul smells – Pliny the Elder (23-79 AD) records rose-scented water being sprinkled in theatres; and for moisturising the skin.

Today, most commercial perfumes are alcohol-based, but Roman perfumes for the skin took the form of *unguents*, or greasy ointments. An unguent consisted of a liquid base and a scented essence, and could also contain preservatives such as salt, and fixatives such as gums or resins – to stabilise the volatile components of the perfume.

One of the most frequent liquid bases used was omphacium, an oil extracted from green olives or unripe grapes. To obtain scented essences, the Romans used many methods to extract scent from flowers, seeds, leaves, bark and other fragrant plant material. Many of these methods are still used today.

REVIEW

- Biology
- Chemistry
- History
- Ages 14+

This article provides an opportunity to link history with practical chemistry. Learners will be swept away into Roman times, to learn why our ancestors extracted scents from plant material and turned them in a form that could be applied onto the skin. It is highly beneficial for students to connect their current scientific knowledge to its roots. Following the path of our scientific forefathers helps us to understand the development of the scientific process as well as how organic substances have been developed into useful materials.

The activity could be used in biology (plant histology; physiology of smell), chemistry (organic chemistry; molecular chemistry) and history (the Romans; the history of chemistry) lessons. It could also be used as the basis for a discussion on the use of natural as opposed to man-made substances in beauty products. How sustainable is the use of natural products for large-scale production?

Information is provided in the article about different methods of extracting scents. As an extension of the project, the students could investigate these methods further – both on the Internet and in the laboratory. Teachers could also extend the activity and bring the scents closer to home by using local plant material to create perfumes: reliving their country's past through plant life. Local universities are usually an excellent source of information on native species. When collecting plant material, attention should be paid to local safety measures, and endangered species should be avoided.

Angela Charles, Malta

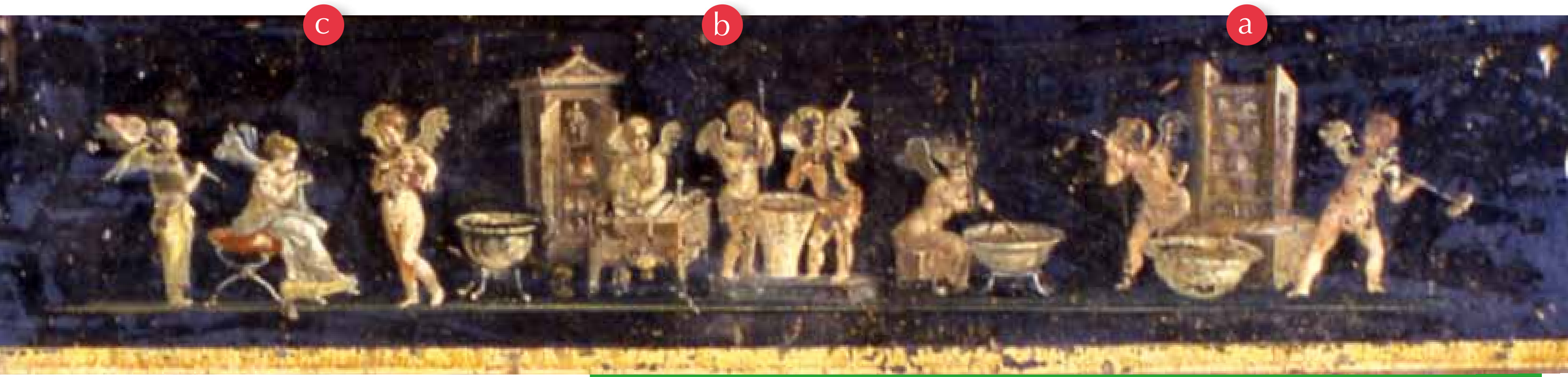


Image courtesy of the Soprintendenza Speciale per i Beni Archeologici di Napoli e Pompei

A decoration of the House of the Vetii in Pompeii, Italy, is extraordinary evidence of how Roman perfumes were prepared and sold. From right to left:

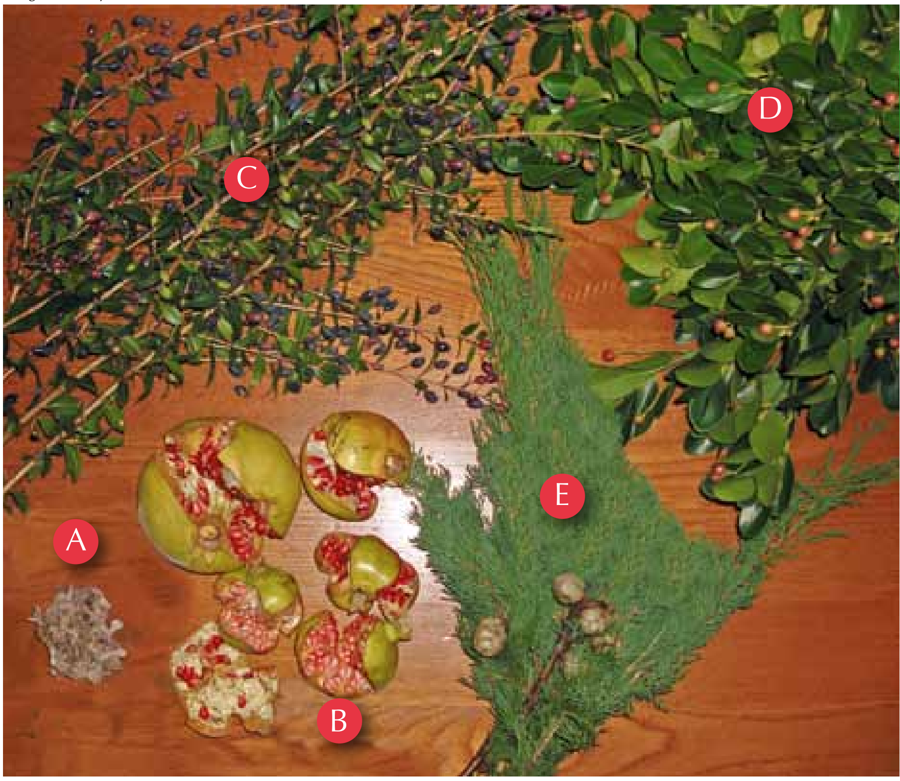
a) Two putti hammer the wedges of a press, to squeeze the oil out of unripe olives. On their left, a psyche stirs a mixture in a cauldron over a fire (probably steeping plants in warm oil).

b) Two putti stir the contents of a deep vessel, which may have to be added to the olive oil. On their left, another putto holds a phial and has both a papyrus scroll and a pair of scales. Behind the putto is a cupboard containing phials and a statue of a deity.

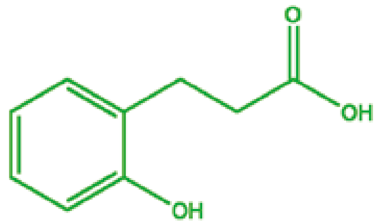
c) The story finishes with the sale: the purchaser tests the perfume on her wrist. Behind her is a slave girl and a putto stands in front of her holding a phial and a spatula

- Enfleurage: petals were placed on suet (the hard fat from around the kidneys) and replaced periodically until the fat was saturated with fragrance.
- Steeping in oil: the scented roots or leaves were crushed, placed in a loose-textured linen bag and left to soak in oil at a moderate temperature.
- Steeping in oil and water: a method common in warm areas such as Egypt. The scented roots or leaves were placed in earthenware jars and covered in a 50% v/v mixture of rainwater and oil. The jars were then buried up to the neck in the hot sand and left open for one to five days. The essential oils released by the plant material mixed with the oil floating on the water. Once the water had evaporated, the fragrant oil was strained off.
- Pressing: to obtain citrus or liquid base oils, citrus skins or olives, for example, were placed in linen bags and pressed.
- Boiling and squeezing through cloth: to extract resins and oily substances from bark.
- An archaeological dig in Pyrgos on

Image courtesy of Gianluca Farusi



The ingredients of the most common and most ancient perfumes, according to Pliny.
A: Calumus (*Acorus calamus*)
B: Pomegranate (*Punica granatum*)
C: Myrtle (*Myrtus communis*)
D: Mastic (*Pistacia lentiscus*)
E: Cypress (*Cupressus sempervirens*)



3-(2-hydroxyphenyl)propanoic acid

Image courtesy of Gianluca Farusi

Cyprus even showed that steam distillation was practised in 2000 BC[w1].

How do we know so much about Roman perfumery? Partly, of course, from contemporary written records – but science can also help. Modern archaeological analyses of perfume traces in ancient pots can help to identify the perfume, the way it was prepared and even what it was used for. By combining chemical data with information from contemporary authors, we can reproduce some of the perfumes of the ancient world.

…Ratio faciendi duplex, sucus et corpus: ille olei generibus fere constat, hoc odorum.… E vilissimis quidem hodieque est – ob id creditum et id e vetustissimis esse – quod constat oleo myrteo, calamo, cupresso, cypro, lentisco, mali granati cortice.… Telinum fit ex oleo recenti, cypiro, calamo, meliloto, faeno Graeco, melle, maro, amaraco. hoc multo erat celeberrimum Menandri poetae comici aetate.

Unguents comprise two elements: the juices and the solid parts. The former generally consist of various kinds of oils, the latter of odoriferous substances.… Among the most common unguents today, and for that reason assumed to be the most ancient, is that composed of oil of myrtle, calamus, cypress, cyprus, mastich, and pomegranate rind.… Telinum is made of fresh olive oil, cyperus, calamus, yellow melilot, fenugreek, honey, marum, and sweet marjoram. It was the most fashionable perfume in the time of the comic poet Menander [around 300 BC].

Pliny the Elder, *Naturalis Historia* (*Natural History*), book XIII, chapter 7, paragraph 9

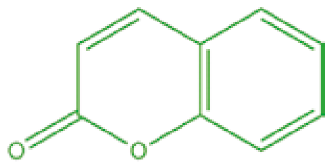
As part of a larger interdisciplinary chemistry project (see box), my students (aged 14-15) and I decided to do just this: recreate the favourite perfume of Julius Caesar. But how did we even know what it was? Thanks to a fragment of poetry attributed to Caesar (‘*Corpusque suavi telino unguimus*’, ‘We anoint the body with fragrant telinine ointment’), it is thought to be the unguent telinum.

However, finding the recipe is no easy task. For one thing, before the introduction of Linnaean taxonomy, there was no consistent naming convention. Thus, for example, the name ‘cyperus’ may refer to the many species of sedge (*Cyperus spp*), to gladioli (*Gladiolus spp*), to lemongrass (*Cymbopogon schoenanthus*) or even to privet (*Ligustrum spp*). Moreover, perfume recipes – then as now – were fiercely guarded by their manufacturers, so even though contemporary writers sometimes recorded the ingredients of a perfume, they seldom mentioned the proportions.

In the case of telinum, we were lucky: in his *Naturalis Historia* (*Natural History*), Pliny the Elder records the ingredients (left) and Pedanius Dioscorides (c. 40-90 AD) records somewhat different ingredients but does mention the proportions in his *De Materia Medica* (*On Medical Materials*).

For our recreation of telinum, therefore, we carried out a series of trials

Image courtesy of Gianluca Farusi



2*H*-chromen-2-one

based on these two ancient recipes, to determine the blend we preferred. How should we interpret 'cyperus', though? We prepared two versions: one with lemongrass oil and one with violet oil (*Viola odorata*) – because the roots of both gladioli and *Cyperus* species smell like violets. Finally, because marum (*Teucrium marum*) is thought to be carcinogenic, we decided to replace it with catmint (*Nepeta cataria*), which smells similar. If not entirely historically accurate, our perfume should at least smell like Caesar's.

Materials and proportions

It is not clear from the historical sources whether dried or fresh materials were used. We used dried materials, as they contain more scent per gram and are easily obtainable: try a chemist or herbalist's shop.

- 100 g omphacium – either use shop-bought olive oil (choose an odourless one) or if you have access to fresh green olives, pick a carrier bag full of them in August, to prepare your own omphacium (see below).
- 56 g fenugreek seeds (*Trigonella foenum graecum*)
- 11 g calamus roots (*Acorus calamus*)
- 5 g dried yellow melilot flower heads (*Melilotus officinalis*)

Fresh green olives

Image courtesy of Gianluca Farusi

Ligustrum sp

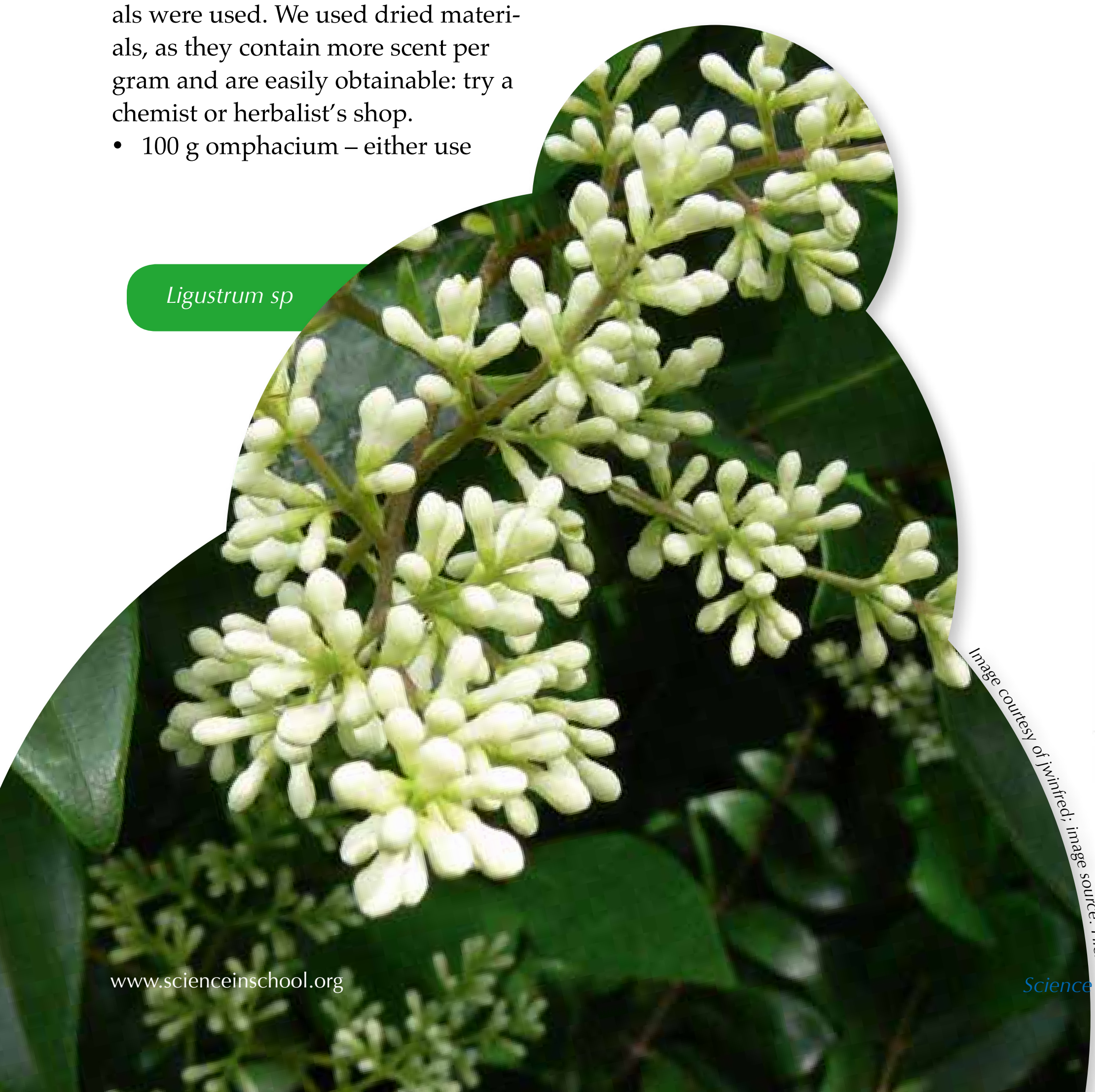


Image courtesy of jwinfred; image source: Flickr

Images courtesy of Gianluca Farusi

The ingredients of our telinum

Images courtesy of Gianluca Farusi

1 Grinding the olives

2 Transferring the ground olives to the tea towel

- 2 g dried catmint leaves (*Nepeta cataria*)
- 3 g dried sweet marjoram leaves (*Origanum majorana*)
- 5-10 drops violet oil or lemongrass oil (depending on the strength of the oil – be careful not to let it dominate the perfume)
- Honey

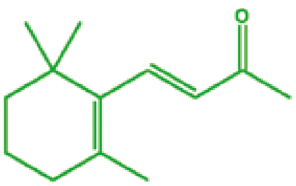


Image courtesy of Gianluca Farusi

(*E*)-4-(2,6,6-trimethylcyclohex-1-enyl) but-3-en-2-one

Image courtesy of Gianluca Farusi

The herb and oil mixture

Preparation

To prepare omphacium for our project, I picked the green olives, ground them in the kitchen mixer, collected the mixture in a tea towel and squeezed the oil into a bowl. I then filtered the oil three times using filter paper, and centrifuged it twice for 5 min each time.

Alternatively, use shop-bought olive oil.

I divided the class into three groups; each group prepared a different historical perfume (instructions for preparing cyprinum and rhodinon can be downloaded from the *Science in School* website[w2]). At the end of the activity, each student had a small sample of perfume to take home.

1. Chop the herbs and spices, and add them to 100 g omphacium.
2. Place the mixture in the oven at 40 °C, and stir several times per day for three days.
3. Strain the scented oil.
4. Add 10% w/w of honey.
5. Add the violet oil.

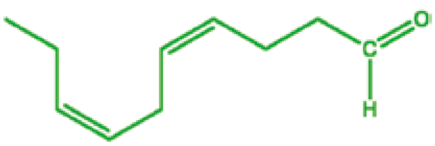


Image courtesy of Gianluca Farusi

(4Z,7Z)-deca-4,7-dienal

The chemistry of scent

Once we had appreciated the perfume of ancient Rome, we returned to the 21st century to investigate which molecules produced the fragrance. Table 1, showing the main aromatic chemicals in our telinum (the structures of some of which illustrate this article) is available for download

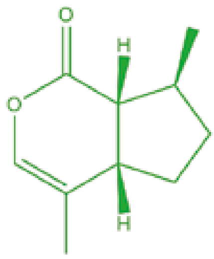


Image courtesy of Gianluca Farusi

(4a*S*,7*S*,7a*R*)-4,7-dimethyl-5,6,7,7a-tetrahydrocyclopenta[c]pyran-1(4a*H*)-one

from the *Science in School* website[w2].

With older students, this activity could be used to investigate organic chemistry in some detail. With my 14- to 15-year-old students, I concentrated on the basics of the chemistry of smell. For example, I asked them:

1. Can you see similarities between the structures of different fragrant chemicals in the perfume?
2. Why is oil effective for extracting these chemicals from plant material?
3. Could we replace oil with something else?
4. Why, once extracted, do the

3 Squeezing the oil through the colander

4 The collected oil

5 Filtering the omphacium

fragrant molecules leave the oil and enter the air, where you can smell them?

5. Rub a drop of telinum onto the back of your hand and smell it from time to time. What do you expect to happen? Does the fragrance change with time? Can you explain what you observe?

Safety note: check your national or local safety guidelines to see if you are allowed to use lab-prepared materials on the skin.

6. Why did ancient perfumers add honey? (Answer: the polysaccharides it contains help to hold the volatile substances in the perfume.)

By the end of the activity, together with some associated experiments, the students had established that:

1. A substance has to be in the gaseous state to be smelled. At first, many students disagreed because they thought that metals had a distinctive smell. They tested this by wearing gloves to lift a copper coin, then smelling it without touching it to their nose. They then did the same without gloves (ideally with sweaty fingers) – and realised that the 'metallic smell' was a volatile substance formed on their skin.
2. The effusion of a substance is in inverse relation to its molar mass (Graham's law).
3. Molecules with the same chemical group have a similar smell. Students prepared different esters in the lab – with the same chemical group and similar fruity smells.

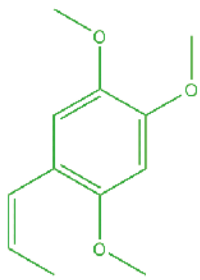


Image courtesy of Gianluca Farusi

(Z)-1,2,4-trimethoxy-5-(prop-1-enyl)benzene

4. The chemical structure is not the only determinant of smell. Students extracted essences of caraway and peppermint using steam distillation and found that they smelled very different. They were amazed when I told them that the structure of the main aromatic molecule is the same. We did not discuss enantiomers at this

BACKGROUND

Studying chemistry with Pliny the Elder

This activity is part of a larger interdisciplinary project, developed together with my 14- to 15-year old students, to meet the curriculum requirements at that age. We began each session (1-4 two-hour lessons) by discussing a passage from Pliny the Elder's *Naturalis Historia*, then worked out how to recreate in the laboratory either the event described in the text or something similar. In this way, the students began in the same pre-scientific state as Pliny and, through laboratory work and discussion, gained modern scientific knowledge on each of the topics. The process motivated even the most unenthusiastic students.

Other activities in the project include extracting indigo from woad, preparing glass tesserae with boric acid, simulating the luminescence of the shellfish *Pholas dactylus*, and preparing iron-gall ink (Farusi, 2007).

Image courtesy of ((o: pattoune :o)); image source: Flickr

Cyperus alternifolius

stage, but the students' curiosity was aroused and they understood that there are several factors that determine scent.

Acknowledgment

The author would like to thank Graziella Zacchini of the Officina Profumo Farmaceutica Santa Maria Novella, who provided plant materials used in the project.

Reference

Farusi G (2007) Monastic ink: linking chemistry and history. *Science in School* **6**: 36-40. www.scienceinschool.org/2007/issue6/galls

Web references

w1 – See the paper 'Cinyra, Cyprus and the notes of music, of wine and perfumes' by Maria Rosaria Belgiorno, which can be downloaded from her website (www.erimiwine.net) or via the direct link: http://tinyurl.com/65623kd

w2 – Instructions for preparing cyprinum and rhodinon, and Table 1, can be downloaded from the *Science in School* website: www.scienceinschool.org/2011/issue21/caesar#resources

Resources

The following books include information about the techniques and the plants used by the ancients in their perfumes:

Belgiorno MR (ed.) (2007) *I profumi di Afrodite e i segreti dell'olio. Scoperte archeologiche a Cipro. Catalogo della mostra* (catalogue of the exhibition 'The perfumes of Aphrodite and the secret of the oil: archaeological discoveries in Cyprus'). Rome, Italy: Gangemi. ISBN: 978-8849212235

Donato G, Seefried M (1995) *The Fragrant Past: Perfumes of Cleopatra and Julius Caesar* (catalogue of the corresponding exhibition in the Emory Museum of Art and Archaeology, Atlanta, GA, USA). Oxford, UK: Premier Book Marketing Ltd. ISBN: 978-0963816931

Pennestrì S (1995) *Aromatica. Profumi tra sacro, profano e magico*. Selcom. ISBN: 9788886553001

The following research articles provide helpful background information:

Colombini MP et al. (2009) An Etruscan ointment from Chiusi (Tuscany, Italy): its chemical characterization. *Journal of Archaeological Science* **36**: 1488-1495. doi: 10.1016/j.jas.2009.02.011

Modugno F et al. (2008) Gas chromatographic and mass spectrometric investigations of organic residues from Roman glass unguentaria. *Journal of Chromatography* **1183**: 158-169. doi: 10.1016/j.chroma.2007.12.090

Pérez-Arantegui J (2009) Colorants and oils in Roman make-ups – an eye witness account. *Trends in Analytical Chemistry* **28**: 1019-1028. doi: 10.1016/j.trac.2009.05.006

Ribechini E et al. (2008) An integrated analytical approach for characterizing an organic residue from an archaeological glass bottle recovered in Pompeii (Naples, Italy). *Talanta* **74**: 555–561. doi: 10.1016/j.talanta.2007.06.026

You may also enjoy other *Science in School* articles on similar topics:

Börsch-Haubold A (2007) Small molecules make scents. *Science in School* **6**: 69-74. www.scienceinschool.org/2007/issue6/scents

Capellas M (2007) Recovering Pompeii. *Science in School* **6**: 14-19. www.scienceinschool.org/2007/issue6/pompeii

Farusi G (2006) Teaching science and humanities: an interdisciplinary approach. *Science in School* **1**: 30-33. www.scienceinschool.org/2006/issue1/francesca

To browse all chemistry-related articles in *Science in School*, see: www.scienceinschool.org/chemistry

---

Gianluca Farusi teaches chemistry at the technical school (Istituto Tecnico Industriale) Galileo Galilei in Avenza-Carrara, Italy, and since 2004, he has lectured in stoichiometry at the University of Pisa, Italy, for the degree program in medicinal chemistry and technology. He is also the regional tutor for the Italian ministerial project 'Insegnare Scienze Sperimentali' ('teaching experimental sciences'). He has been teaching for 15 years and nothing gratifies him more than the delight on his students' faces when they grasp a difficult chemical concept.

To learn how to use this code, see page 65.

Smoke is in the air: how fireworks affect air quality

Did you realise that fireworks cause measurable air pollution? **Tim Harrison** and **Dudley Shallcross** from Bristol University, UK, explain how to investigate atmospheric pollutants in class.

Whether at New Year, on Guy Fawkes Night or at Diwali, most of us have witnessed a firework display – and remembered the explosions and showers of coloured light. What about the sulphurous smoke though? As atmospheric scientists have demonstrated, fireworks leave their mark on air quality for some time after the bangs and glows have passed.

After the annual Guy Fawkes Night in the UK, highly elevated levels of particles (smoke or soot) produced by the fireworks' combustion, as well as high levels of metal ions such as magnesium that originate from the fireworks themselves, have been found. Firework displays have also been linked to elevated levels of other molecules such as nitrogen dioxide (NO_2) and sulphur dioxide (SO_2). Such observations were made during and after a Diwali festival in Hisar City, India, in November 1999; in Mainz, Germany, during New Year celebrations in 2004/2005; during the Lantern Festival in Beijing, China, in 2006; and in Milan, Italy, the night after Italy won the football World Cup in 2006

Image courtesy of Kropsoq; image source: Wikimedia Commons

Fireworks at the Nagaoka festival, Japan

A photomontage of eight images of fireworks from a Guy Fawkes Night display at Roundwood Park in Harlesden, London, UK

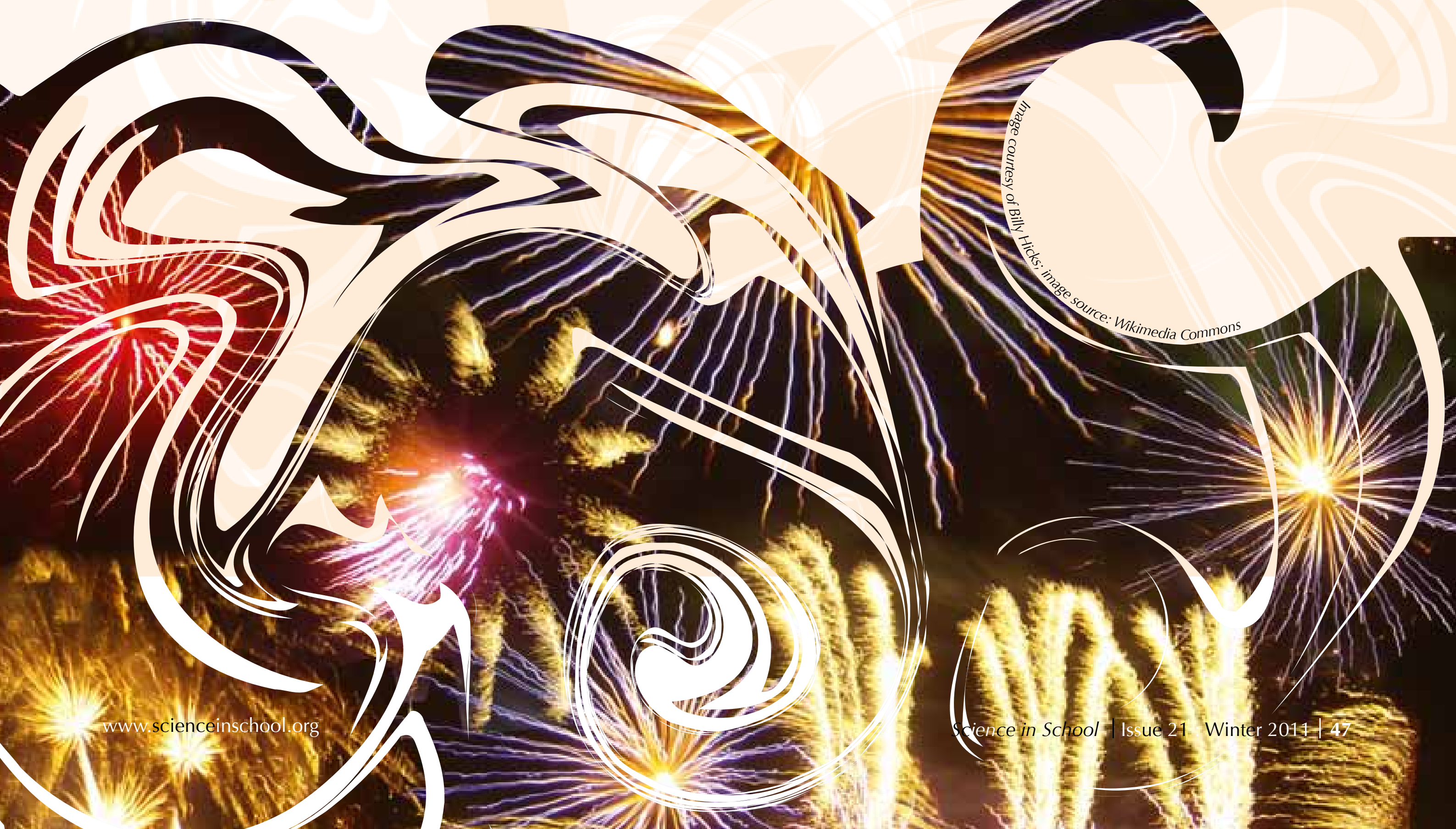
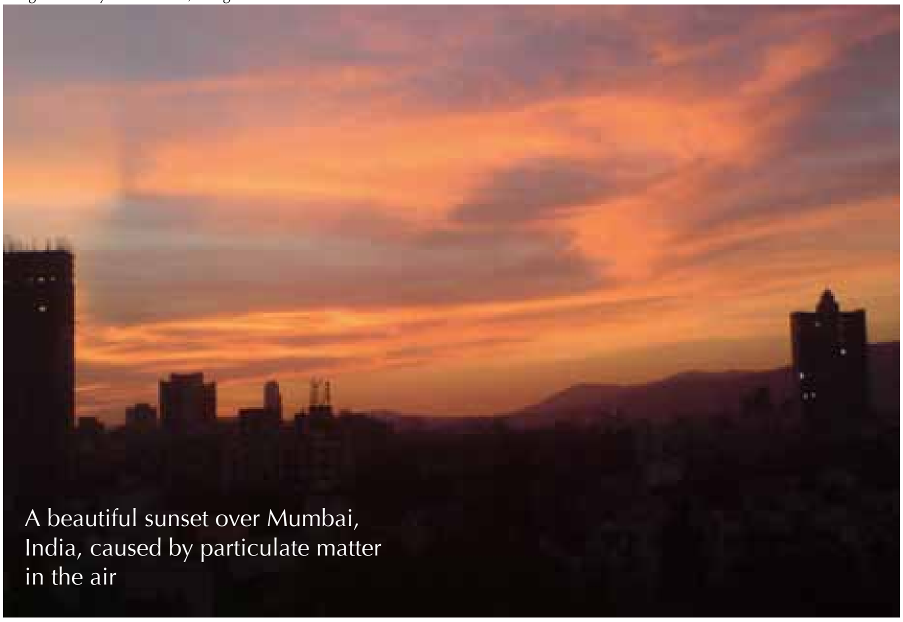


Image courtesy of Billy Hicks; image source: Wikimedia Commons

Image courtesy of Bm1996; image source: Wikimedia Commons



A beautiful sunset over Mumbai, India, caused by particulate matter in the air

(Drewnick et al., 2006; Ravindra et al. 2003; Vecchi et al., 2008; Wang et al., 2007).

Investigating air quality at school

Together with your students, you too can analyse the effect of fireworks on air quality. We worked with UK secondary-school students to investigate the impact of Guy Fawkes Night on air quality (see acknowledgements). The project was an introduction to using air-quality databases – which contain measurements of a wide range of pollutants, a treasure trove of data for use in schools – but also a chance to carry out some real research at school.

Air quality can be linked to many school subjects. The chemistry and physics of fireworks involve a number of interesting topics, such as combustion, sound, light and the pollutants they can release. It can also form the basis of a deeper discussion of the nature of air pollution; what causes it, and effects such as acid rain and climate change. The latter are topics covered in biology, health and geography lessons. The analysis of data has huge potential for enlivening mathematics and IT lessons.

Information about the main pollutants caused by fireworks, as well as details of the chemistry of fireworks, can be downloaded from the *Science in School* website[w1]. Further details on more general causes of air pollution can be downloaded from the UK-AIR website[w2].

Databases

You will need to use a publicly available air-quality database that

REVIEW

- Chemistry
- Physics
- Biology
- Health
- Data-handling techniques
- Global warming
- Ages 14+

All that glitters is certainly not gold. The popular practice of letting off spectacular fireworks, following a football victory or as a full-blown festival spread over several nights, may in fact be contributing to air pollution. This article provides references and ideas for teachers to approach the topic of air pollution by using specific occasions when high levels of gaseous and particulate pollutants are expelled into the air during firework displays. Science students have the opportunity for real-life scientific investigations; rather than confining their experiments to the school laboratory, they are immersed in the scientific community, working to make our environment a better place to live in.

The article could be used in several science subjects: for example, in chemistry (properties and reactions of metallic compounds; burning; stability of compounds; oxidising agents), physics (propulsion; light and sound), or biology or health lessons (the effects of pollution on respiratory diseases, especially asthma). It could also be used interdisciplinarily to consider global warming.

If the school can borrow the necessary equipment – for example, from a university – the school students could even take their own measurements of air quality, which would expose them to the technical analysis of the air, data logging and handling, data comparison and error analysis. They could then perhaps present their findings to the local authority, experiencing for themselves how reliable results of scientific investigations can be used to put pressure on policy makers and potentially bring about improvements.

Angela Charles, Malta

provides at least daily measurements for the location you are interested in studying. The UK air-quality archive[w2] contains hourly data for a range of chemical species; primary pollutants (emitted directly), including NO, NO_2, CO and SO_2; hydrocarbons and particulate matter; and secondary pollutants (formed from primary pollutants), such as ozone. The data are collected from 186 sites around the UK ranging from monitors at the roadside to those in remote regions for measuring background levels. Some sites have been working since the mid-1970s, providing an incredible record of data. The authors are keen to work with any groups of students who wish to interpret aspects of the UK's air-quality data.

For Malta, there is the database of the Malta Environment and Planning Authority[w3] that contains data on CO, NO, NO_2 and O_3.

If you want to analyse data from another European country, you will find AirBase[w4], the air-quality database maintained by the European Environment Agency, a useful resource as it contains measurements for most European countries. Note, however, that the files are large so can take some time to download, and are also less simple to understand than the UK and Maltese data sets.

Image courtesy of Semnoz; image source: Wikimedia Commons

Fireworks at the Lake Annecy festival, France, in 2005

Our results

We analysed particulate matter (PM) levels at all sites where they are measured in the UK around Guy Fawkes Night 2009. PM consists of particles of solid or liquid suspended in a gas. They are categorised according to size as PM_{10} (diameter 10 μm or less), $PM_{2.5}$ (2.5 μm or less), PM_1 (1 μm or less) and ultrafine (0.1 μm or less). Firework combustion produces a range of particle sizes but mainly smaller particles (e.g. $PM_{2.5}$) of soot, whereas bonfires can form larger particles. PM is also produced by the construction industry, and there are natural sources such as pollen, sea salt and wind-blown soil. Increased levels of particles in the air are linked to cardiovascular and respiratory diseases; smaller particles are particularly unhealthy because they can penetrate deeper into the respiratory system. PM also has a significant effect on the climate: soot particles warm the climate, whereas reflecting articles tend to cool it.

As an example, we show $PM_{2.5}$ and PM_{10} levels from the centre of

Image courtesy of Tim Harrison and Dudley Shallcross

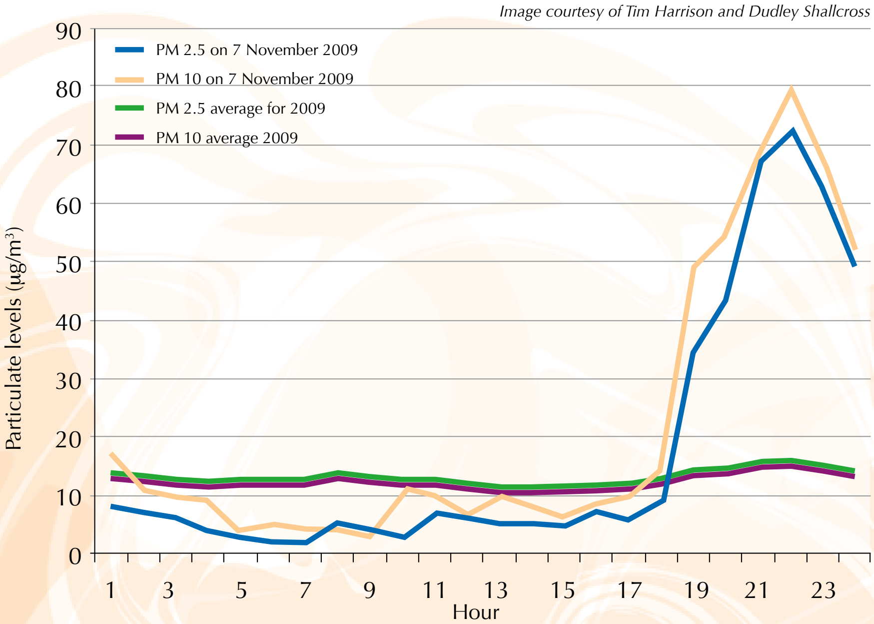


Figure1: PM_{10} and $PM_{2.5}$ levels from Reading town centre, UK: levels on 7 November 2009, and the average levels for 2009

Image courtesy of Karelj; image source: Wikimedia Commons

New Year fireworks, 2010/2011, in Prague, Czech Republic

Reading, a university town in the south of the UK. Although Guy Fawkes Night is actually on 5 November, it is frequently celebrated on the nearest weekend. These data from 5-9 November 2009 show that particle levels peaked on the evening of 7 November (a Saturday). Comparing those data to the all-year average for 2009, we found that the levels on that Saturday were elevated by a factor of up to seven (see Figure 1).

Because $PM_{2.5}$ measures all particles with a diameter of 2.5 μm or less and the PM_{10} and $PM_{2.5}$ levels are virtually the same, most particles produced were small – and particularly bad for the respiratory system. It is very difficult to set safe levels for particle exposure, but at present the limit for PM_{10} in Europe is an annual concentration of 40 $\mu g/m^3$, and a daily concentration of 50 $\mu g/m^3$, which must not be exceeded more than 35 times per calendar year (therefore called the *exceedance*). The average from the night of 7 November was 34.7 $\mu g/m^3$, which is less than the exceedance, but much higher than the 2009 average (mean). At other sites in the UK, we found the PM_{10} level to be exceeded on that day.

Investigations

These databases offer a wealth of possible questions to be considered at school, with examples by no means restricted to firework-derived pollution. For example:

- Plot the levels of several different pollutants before, during and after a firework event (e.g. New Year). Which pollutants peak first? Which take longer to peak? Are the levels of all measured pollutants affected? Why / why not?
- Using data from different sites monitored in the database, compare levels of specific pollutants (e.g. carbon monoxide) between cities and countryside. What explanations can you find for what you observe?
- What differences are there in ozone levels from different locations and at different times of day?
- In Europe the prevailing wind is from the west. Can you detect any pattern in air quality from east to west?

Image courtesy of Kurume-Shimin; image source: Wikimedia Commons

Chikugo river fireworks festival in Kurume, Fukuoka, Japan, 5 August 2011

Acknowledgements

The authors would like to acknowledge the help of the following teachers and students who participated in their UK air-quality study: Dr Oznur Kemal (teacher), Sophie Danby, Marta Tondera, Kelly Lam Ho, Candice Chan Ting Yan, Boni Chau Bo, Jenny Chow Kar Yee, Christine Fong Chi, Sophie Hawkins, Charlotte Hooper, Annabelle Fricker, Siobhan Stewart and Emma Tremewan, from Leweston School Dorset; Naomi Shallcross, Beth Shallcross and Esther Shallcross from Gordano School, Portishead; John Jones (teacher), Beth Jones and Cat Wood from Cheltenham Ladies' College, Cheltenham.

References

Drewnick F et al. (2006) Measurement of fine particulate and gas-phase species during the New Year's fireworks 2005 in Mainz, Germany. *Atmospheric Environment* **40**: 4316-4327. doi: 10.1016/j.atmosenv.2006.03.040

Ravindra K, Mor S, Kaushik CP (2003) Short-term variation in air quality associated with firework events: a case study. *Journal of Environmental Monitoring* **5**: 260-264. doi: 10.1039/B211943A

Vecchi R, et al. (2008) The impact of fireworks on airborne particles. *Atmospheric Environment* **42**: 1121-1132. doi: 10.1016/j.atmosenv.2007.10.047

Wang Y, et al. (2007). The air pollution caused by the burning of fireworks during the lantern festival in Beijing. *Atmospheric Environment* **41**: 417-431. doi: 10.1016/j.atmosenv.2006.07.043

Web references

w1 – For downloadable information on the chemistry of fireworks, see the *Science in School* website: www.scienceinschool.org/2011/issue21/fireworks#resources

w2 – The UK-AIR website hosts an extensive data archive, as well as plenty of information about air pollution. See: http://uk-air.defra.gov.uk

w3 – For air-quality data in Malta, see: www.mepa.org.mt/airquality

w4 – To download air-quality data from the European Environment Agency's AirBase, see: www.eea.europa.eu/data-and-maps/data/airbase-the-european-air-quality-database-3

Resources

Russell MS (2000) *The Chemistry of Fireworks*. Cambridge, UK: The Royal Society of Chemistry. ISBN 0-85404-598-8

If you enjoyed this article, why not browse the full list of articles on chemistry topics published in *Science in School*? See: www.scienceinschool.org/chemistry

---

Dudley Shallcross (d.e.shallcross@bristol.ac.uk) is the professor of atmospheric chemistry at Bristol University, UK. Tim Harrison (t.g.harrison@bristol.ac.uk) is the outreach director for Bristol ChemLabS at Bristol University. They are frequent authors for *Science in School*.

To learn how to use this code, see page 65.

Image courtesy of axstokes / iStockphoto

Just the placebo effect?

When your doctor prescribes you a tablet and you get better, was it really the drug or could it have been the colour of the tablet? **Andrew Brown** investigates the placebo effect.

In 1796, the American doctor Elisha Perkins patented his 'Perkins Tractor', which he claimed could 'draw off the noxious electrical fluid that lies at the root of all suffering'. Consisting of two metal rods, the device was waved over the patient's body. Reports of its curative powers caught the attention of British doctor John Haygarth who, in controlled experiments, showed that although the Perkins Tractor did indeed alleviate symptoms, so did a wooden copy. He was the first to show that a therapeutic response can be achieved by something pharmacologically inert – what we now call the placebo effect.

The placebo effect is often considered to be a psychological rather than a physiological phenomenon – patients only *think* they are better. But it

The Perkins Tractor

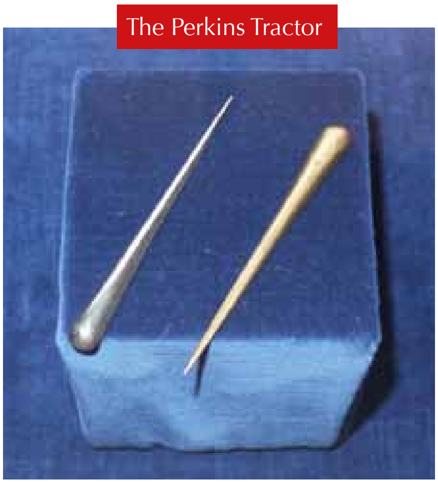


Image courtesy of Geni; image source: Wikimedia Commons

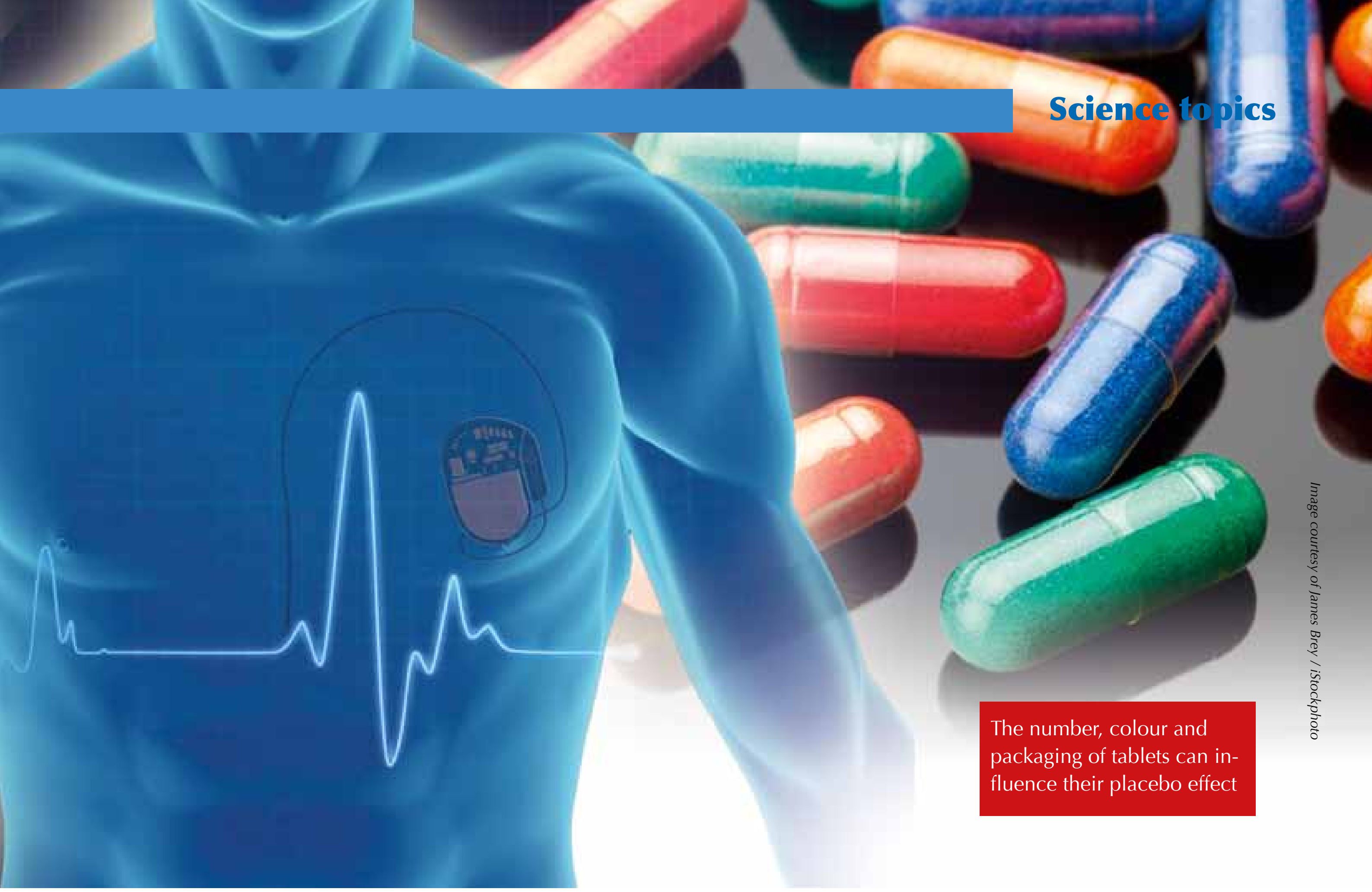
- Biology
- Medicine
- Ethics
- Interdisciplinary
- Ages 16+

Although the word 'placebo' is probably familiar to most people, the chances are that not many really know what it is. The author helps the reader to understand what the placebo effect is and what it does, including the complex ways in which it helps patients get better.

This article will be of most benefit to the study of the nervous system in upper secondary-school biology. The suggested classroom activities will be particularly useful for teachers. The questions provided would be suitable for biology students in whole-class discussion sessions, small-group projects or even individual homework assignments. Since the content of the article is not purely scientific but also touches on ethical issues, it could provide excellent discussion material for psychology and social science classes.

Michalis Hadjimarcou, Cyprus

REVIEW



The number, colour and packaging of tablets can influence their placebo effect

Image courtesy of James Brey / iStockphoto

Image courtesy of angelhell / iStockphoto

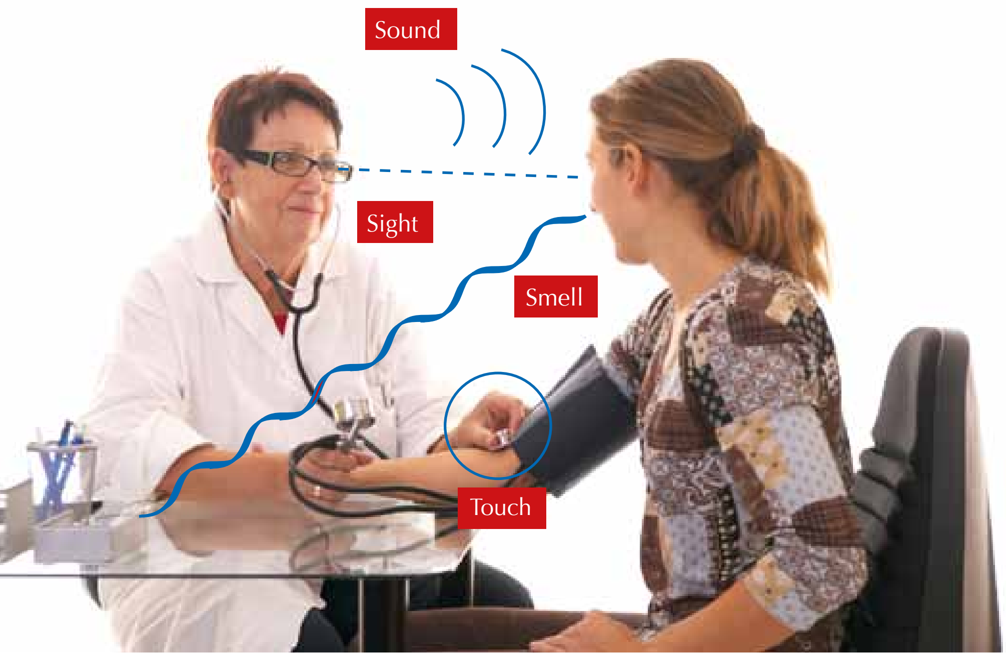


Image courtesy of amriphoto / iStockphoto and Nicola Graf

Figure 1: The psychosocial context consists of a diversity of factors that are symbolic of the fact that a therapy is being performed. A physical placebo (such as a sugar pill) may constitute only one of these factors. In the scene shown here, many of the patient's senses (sight, smell, touch and hearing) are bombarded by stimuli

is far more than that, as clinical trials have testified. In a Swedish trial of heart patients, for example, those in the placebo control group were given an identical pacemaker to those in the treatment group, but unbeknown to them, the device was switched off. After three months, astonishingly, the symptoms of patients in *both* groups had improved. More astonishing still, the researchers were able to measure the improvement in the patients in the placebo control group as an increase in the flow of blood from the heart (Linde et al., 1999).

So what is going on? As Fabrizio Benedetti, professor of physiology and neuroscience and a world authority on the placebo effect, explains: "the placebo effect is a real neurobiological phenomenon, where something happens in the patient's brain". It is triggered not by the ingredients of the placebo itself, but by what it symbolises. In a clinical setting, there are many symbolic factors, which Benedetti refers to collectively as the 'psychosocial context' (Figure 1): "The sight

Reprinted from de la Fuente-Fernández R, Stoessl AJ (2002) The placebo effect in Parkinson's disease. Trends in Neuroscience **25(6)***: 302-306. doi: 10.1016/S0166-2236(02)02181-1. Copyright 2002, with permission from Elsevier*

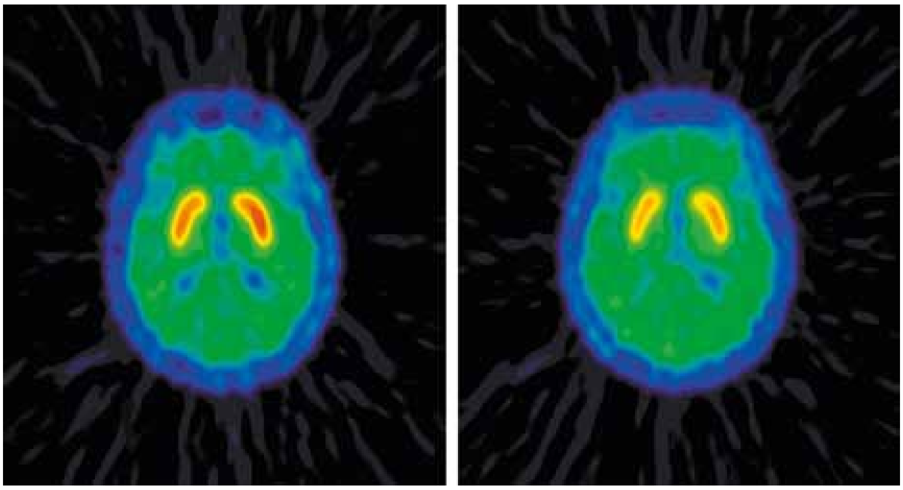


Figure 2: When sufferers of Parkinson's disease, whose brains have low levels of dopamine, are told that their motor function will improve, they release substantial amounts of dopamine in a region of the brain called the dorsal striatum (de la Fuente-Fernández & Stoessl, 2002). The figure shows PET (positron emission tomography) scans of the brain of a Parkinson's patient, showing the amount of radiolabelled raclopride – a compound that competes with dopamine for dopamine receptors – before (a) and after (b) administration of a placebo. The less intense red colour in (b) indicates an increase in the level of dopamine, which inhibits raclopride from binding

and words of the doctor, the smell of the drugs, the hospital machinery: all of these sensory and social stimuli tell the patient that the therapy is being performed." The patient's resulting expectation of a therapeutic effect elicits the placebo effect.

But the psychosocial context can also determine the strength and type of placebo effect. For example, the number, colour and even the packaging of tablets influence their effects (for details of the research behind these observations, see the online supporting information[w1]). In a US study in which half of the participants were given an inert sugar pill and half were given sham acupuncture (the needles did not actually pierce the skin), the sham acupuncture was significantly better at relieving pain than the sugar pill, whereas the pill helped patients sleep (Kaptchuk, 2006).

A 2006 study showed sham acupuncture to have a more powerful placebo effect than sugar pills

So how does the psychosocial context cause neurobiological changes in the brain? When a patient expects a therapeutic treatment, neurotransmitters are released. These bind to their corresponding receptors, prompting the release of further molecules in the brain and other organs, among them hormones, immune mediators and more neurotransmitters, which all cause far-reaching physiological changes that can generate a therapeutic effect.

Benedetti's work on pain and motor-related disorders illustrates that the neurobiological changes can take many forms: "If you expect a reduction in pain, you release endogenous opioids. If you expect a motor improvement, you release a completely different neurotransmitter, dopamine" (Figure 2).

"But the crucial question" explains Benedetti, "is *how* what the brain expects can trigger a specific release of neurotransmitters." At present, he admits that we have no definitive answer to this, but two mechanisms have been studied particularly closely (Figure 3):

1. Classical (or Pavlovian) conditioning: an unconscious mechanism. Benedetti explains: "If you are given a placebo for the first time, usually there is a small response or no response. But if, for example, you inject morphine five days in a row and on the sixth day you replace it with a saltwater placebo, you can bet that one hundred percent of the patients will respond to the placebo." The patients' brains have been conditioned to respond to the injection by producing molecules that interact with the same targets as morphine. A region of the brain called the dorsolateral prefrontal cortex may be crucial in the conditioning response (Figure 4).
2. A two-part conscious mechanism:
   a) The expectation of reward: the patient expects that his or her condition will improve, activating the reward network in a region of the brain called the nucleus accumbens – part of the same region that is activated with the expectation of food, sex, money or even humour (Figure 4; Hayes, 2010).

Image courtesy of YanC / iStockphoto

Image courtesy of filo / iStockphoto, Henrik5000 / iStockphoto and Nicola Graf

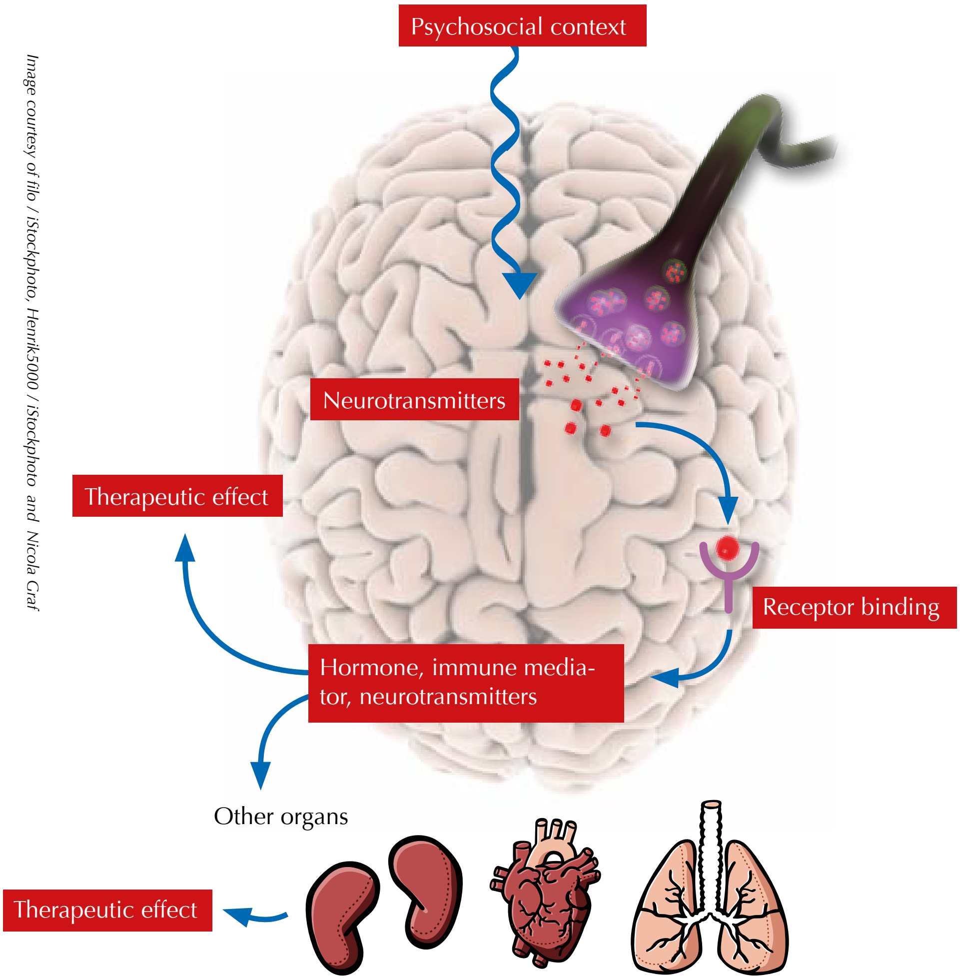


Figure 3: The placebo effect: from psychosocial context to therapeutic response. The psychosocial context tells the patient's brain to expect a therapeutic effect. As a result, neurobiological events occur in the brain via unconscious and / or conscious mechanisms, bringing about the release of effector molecules. These cause physiological changes in the brain and other organs that can generate a therapeutic effect

Image courtesy of Nicola Graf

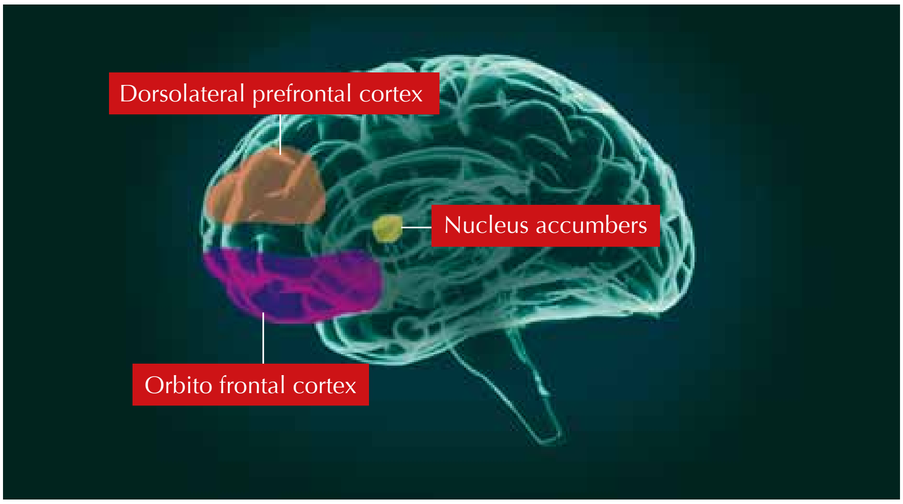


Figure 4: Schematic side-view of the brain showing the regions involved in the conditioning response (dorsolateral prefrontal cortex) and the reward and anxiety response (nucleus accumbens and orbitofrontal cortex, respectively) during the placebo effect

b) Anxiety modulation: this occurs via the brain's anxiety network, which spans many regions, such as the orbitofrontal cortex. "If I give you a treatment and tell you your pain is going to decrease, your anxiety will decrease, triggering the release of neurotransmitters in your brain," Benedetti says.

Both the anxiety and reward networks control many biochemical pathways and associated organs. In the switched-off pacemaker study, the heart condition of the patients in the placebo group is thought to have improved because they were less anxious and produced lower levels of catecholamine stress hormones, known to alter heart function.

Placebo research is still in its infancy; perhaps the most exciting future research will focus on the placebo effect in conventional medicine. Benedetti has already begun, looking at the placebo effect of *real* drugs. For example, in one trial, he found that an injection of the powerful analgesic metamizol was effective in reducing patients' post-operative pain, whereas a hidden administration of the drug (via a pre-laid tube) was completely ineffective (Colloca & Benedetti, 2005). The analgesic effect of the open injection was therefore entirely due to the placebo effect.

This is revolutionary: the idea that the efficacy of drugs can be affected so profoundly by the context in which they are given. For the medical profession, the challenge will be to make the most effective and ethical use of the placebo effect.

Acknowledgement

This article is based on an interview and a lecture[w2] given at the European Molecular Biology Laboratory (EMBL), in Heidelberg, Germany, by Fabrizio Benedetti, professor of physiology and neuroscience at the University of Turin Medical School and at the National Institute of Neuroscience in Italy.

CLASSROOM ACTIVITY

Topics for discussion

- Would it be ethical for doctors to prescribe a placebo for their patients?
- Should conventional medicine make more use of the placebo effect?
- How might the placebo effect give credence to ineffective alternative therapies?
- One of your friends claims to have invented a treatment for spots. How would you design an experiment to test whether the observed improvement is due to the treatment itself or to the placebo effect?
- What can you find out about the negative counterpart of the placebo effect, known as the *nocebo effect*, whereby negative expectations can cause unpleasant symptoms, in the absence of a physical cause?
- Some people are classed as good 'placebo responders' whereas others are not. What might be the evolutionary advantage of being a good placebo responder?

References

Colloca L, Benedetti F (2005) Placebos and painkillers: is mind as real as matter? *Nature Reviews Neuroscience* **6**: 545-552. doi: 10.1038/nrn1705

de la Fuente-Fernández R, Stoessl AJ (2002) The placebo effect in Parkinson's disease. *Trends in Neurosciences* **25(6)**: 302-306. doi: 10.1016/S0166-2236(02)02181-1

Hayes E (2010) The science of humour: Allan Reiss. *Science in School* **17**: 8-10. www.scienceinschool.org/2010/issue17/allanreiss

Kaptchuk T (2006) Sham device versus inert pill: randomised controlled trial of two placebo treatments. *British Medical Journal* **332**: 391-394. doi: 10.1136/bmj.38726.603310.55

Linde C et al. (1999) Placebo effect of pacemaker implantation in obstructive hypertrophic cardiomyopathy. PIC study group. Pacing in cardiomyopathy. *American Journal of Cardiology* **15**: 903-907. doi: 10.1016/S0002-9149(98)01065-0

Web references

w1 – More details of studies on the placebo effect are available to download from the *Science in School* website: www.scienceinschool.org/2011/issue21/placebo#resources

w2 – A video of Fabrizio Benedetti's lecture is available on the EMBL website (www.embl.de) or via the direct link: http://tinyurl.com/3tc4tf5

Resources

For a two-part radio programme by doctor and science writer Ben Goldacre on the placebo effect and its implications for conventional medicine, see: www.bbc.co.uk/radio4/science/placebo.shtml

For mp3 versions, see www.badscience.net

For a review of Ben Goldacre's book *Bad Science*, which includes a fascinating chapter on the placebo effect, see:

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

For a brilliant article about the havoc wreaked by the placebo effect on the pharmaceutical industry, see:

Silberman S (2009) Placebos are getting more effective. Drugmakers are desperate to know why. *Wired Magazine*. Visit the *Wired Magazine* website (www.wired.com/magazine) or use the direct link: http://tinyurl.com/mwlxfp

If you enjoyed this article, why not browse the full collection of articles on medical topics published in *Science in School*? See: www.scienceinschool.org/medicine

---

Andrew Brown recently graduated from the University of Bath, UK, with a degree in molecular and cellular biology. During his course, he took a year out to work for the agrochemical company Syngenta where he specialised in light and electron microscopy. He now works as an intern for *Science in School*, based at the European Molecular Biology Laboratory, in Heidelberg, Germany.

Image courtesy of Yuri Arcus / iStockphoto

To learn how to use this code, see page 65.

More than meets the eye: unravelling the cosmos at the highest energies

Claudia Mignone and **Rebecca Barnes** explore X-rays and gamma rays and investigate the ingenious techniques used by the European Space Agency to observe the cosmos at these wavelengths.

Viewed with the naked eye, binoculars or a telescope, the starry night sky is an overwhelming and tranquil sight. But if we could view the sky in highly energetic X-rays and gamma rays, rather than the visible light perceived by our eyes, we would see a very different picture – a dramatic cosmic light show[w1] (Figure 1).

Some of the most powerful and violent phenomena in the Universe shine brightly at these short wavelengths, such as supernova explosions – the fiery demise of a massive star's life – and black holes, rapidly devouring matter. As a sign of their dynamic nature, many sources of X-rays and gamma rays exhibit distinct changes in their brightness, even over very short periods of time. Gamma-ray bursts, for example, appear as sudden bright flashes that last just a few seconds. These bursts arise from possibly the most extreme explosions in the cosmos (to learn more, see Boffin, 2007). Furthermore, X-rays and gamma rays are released through different physical processes than those responsible for the emission of visible light. This means that galaxies and other astronomical objects look different when imaged at the high-energy end of the electromagnetic (EM) spectrum[w2] (Figures 2 and 3).

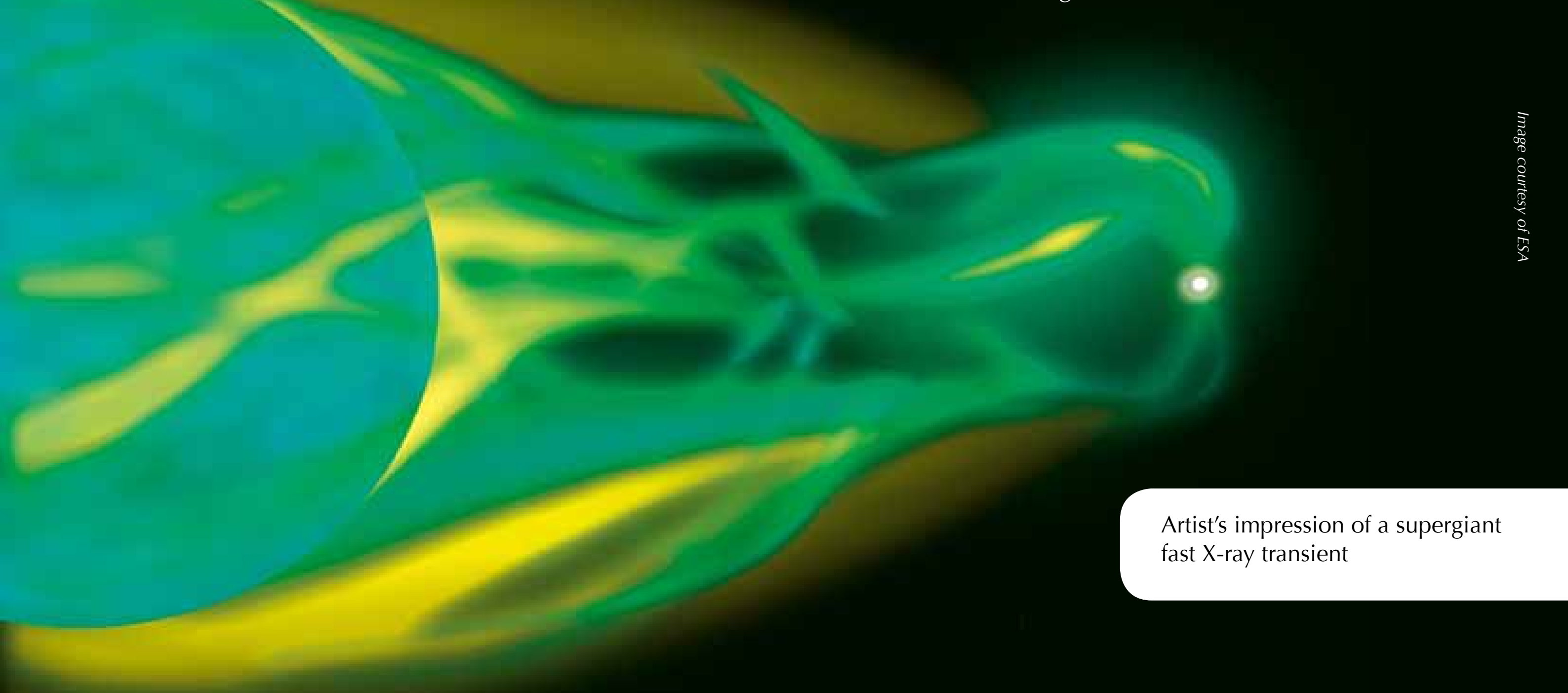


Image courtesy of ESA

Artist's impression of a supergiant fast X-ray transient

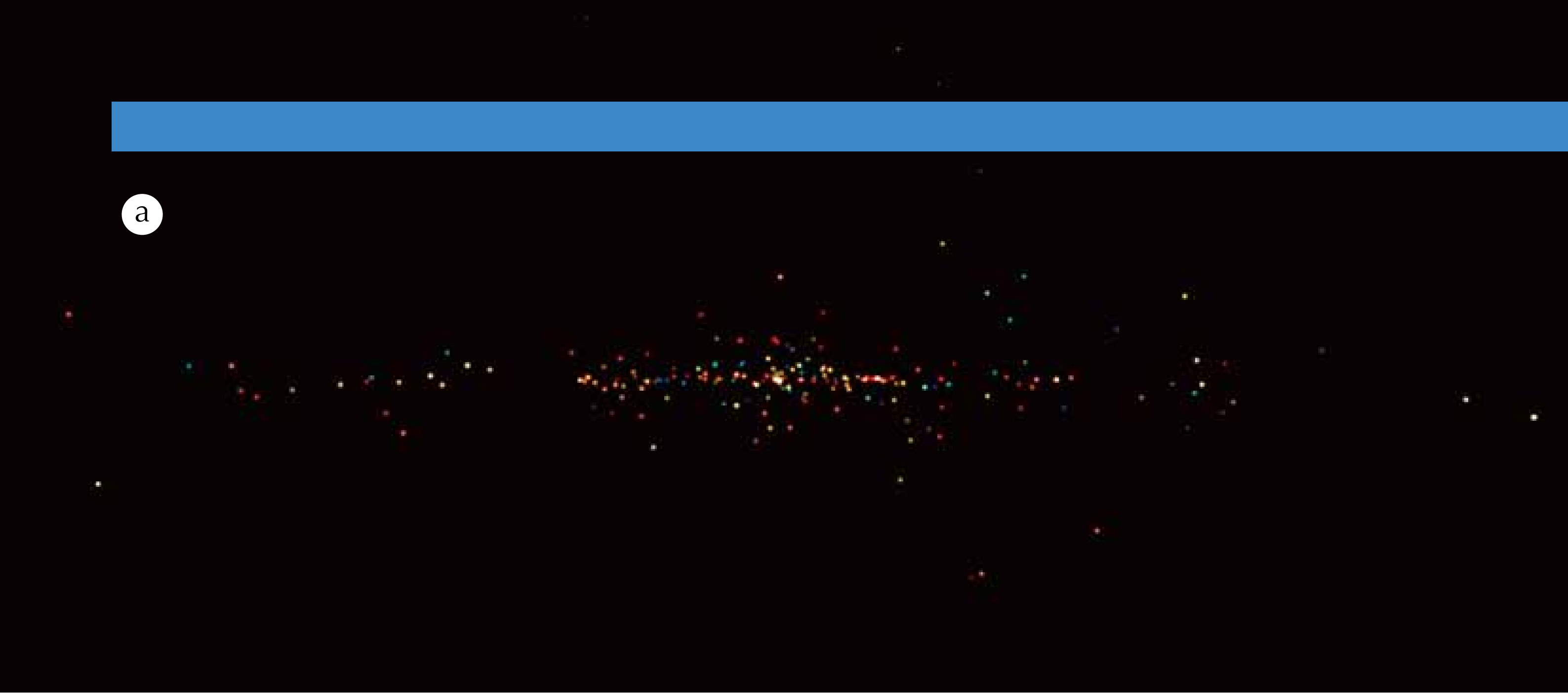


Figure 1: a) An all-sky image at high-energy X-ray wavelengths from ESA's INTEGRAL space observatory, based on data collected in the 18-40 keV energy range (visible light corresponds to 1.65–3.1 eV). **b)** An all-sky image at visible wavelengths

This revolutionary view of the cosmos was revealed to astronomers in the early 1960s, with the beginning of the space age, when rockets and satellites allowed specially developed instruments to be carried beyond the obscuring barrier of Earth's atmosphere[w3]. The European Space Agency (ESA; see box)[w4] soon joined in, with the gamma-ray mission COS-B (1975) and the X-ray observatory EXOSAT (1983). Today, ESA operates two such observatories: the X-ray Multi-Mirror satellite (XMM-Newton), launched in 1999, and the International Gamma-Ray Astrophysics Laboratory (INTEGRAL), launched in 2002.

How do they work? As we explained in an earlier article (Mignone & Barnes, 2011), there is no physical distinction between X-rays, gamma rays, visible light and other types of EM radiation. All are forms of light, differing only in their wavelength (or, as the three are correlated, their frequency or energy; Figure 4). However, depending on their wavelength (or frequency, or energy), they interact very differently with matter. This has major implications for astronomy.

Traditional optical systems, such as our eyes, cameras, microscopes or telescopes, rely on lenses (or mir-

REVIEW

- Physics
- General science
- IT
- Ages 4-19

This article explains simply and comprehensibly how X-rays and gamma rays are collected from cosmic sources using modern space telescopes, and it provides some dramatic images.

For science teachers in primary schools, the article may provide motivation to build a model telescope in lessons, for example using recycled materials – or to use the downloadable satellite models on the ESA website[w4]. The colourful images can also form part of a class exhibit.

Science or physics teachers at secondary school (students aged 11-16) can link to the topic of gamma-ray imaging techniques using a pinhole camera. This would be appropriate in optics lessons, emphasising that both the pinhole camera and coded-mask imaging work without an optical lens.

Images taken by ESA's observatories[w4] would be a useful support for teaching space observation, helping to familiarise students with the different astronomical phenomena (e.g. galaxies, black holes, supernovas, neutron stars, or the annihilation of matter and anti-matter) mentioned in the article. It could also encourage students to do some research of their own on related areas within the curriculum.

For teachers of older school students, it would be interesting to discuss the type of telescopes for high-energy astronomy that are on board the space observatories XMM-Newton and INTEGRAL, and the techniques used to filter the data until the images are fully extracted (this could be linked to IT lessons). Students could compare the structure of telescopes in the high-energy end of the spectrum to that of the optical telescope, and investigate the difficulties encountered when building them.

Stephanie Maggi-Pulis, Malta

Images courtesy of ESA / F Lebrun / CEA Saclay, Service d'Astrophysique (a); ESO / S Brunier (b)

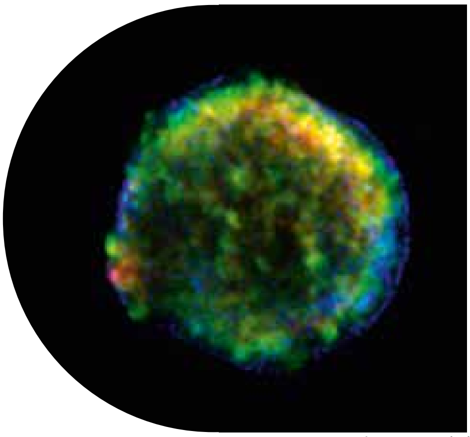


Figure 2: The Tycho supernova remnant as viewed by ESA's XMM-Newton. This remnant is relatively young and is associated with a supernova explosion that was observed in 1572 by the Danish astronomer Tycho Brahe

Image courtesy of Marco Iacobelli (XMM-Newton SOC) and ESA

Figure 3: The Cigar Galaxy (M82), as viewed by XMM-Newton, at visible and ultraviolet (UV) wavelengths (left) and at X-ray wavelengths (right). The central image is a composite of the visible, UV and X-ray wavelength images. The X-ray emission is shown in blue and reveals plumes of very hot gas bursting out of the galaxy's disc

Image courtesy of ESA

Skimming stones

Image courtesy of Killy Ridolis; image source: Wikimedia Commons

rors) that refract (or reflect) light rays and focus them into a single point to produce images. However, this is difficult with some light rays. Because X-rays and gamma rays have wavelengths of a similar size to atoms and sub-atomic particles, respectively, they cannot easily be reflected or focused like visible light, but tend instead to be absorbed when they strike denser materials (Figure 5).

The fact that X-rays and gamma rays are absorbed by dense materials makes them suitable for many applications, including medical scans and investigations of materials[w6]. For astronomers, however, it is a problem: being easily absorbed, these types of radiation are very difficult or impossible to focus; thus obtaining sharp images of their sources is a challenge.

Nonetheless, scientists have developed techniques to detect X-rays and gamma rays coming from the cosmos. They differ greatly from techniques used in traditional optics and that, together with the fact that they operate in space, means that telescopes for high-energy astronomy look nothing like optical telescopes.

X-ray observing techniques

Although it is difficult to reflect X-rays, it is not impossible if they hit the telescope's mirror at a very small angle – think of a pebble skimming across the surface of the water. However, whereas an incidence angle

Image courtesy of ESA / AOES Medialab

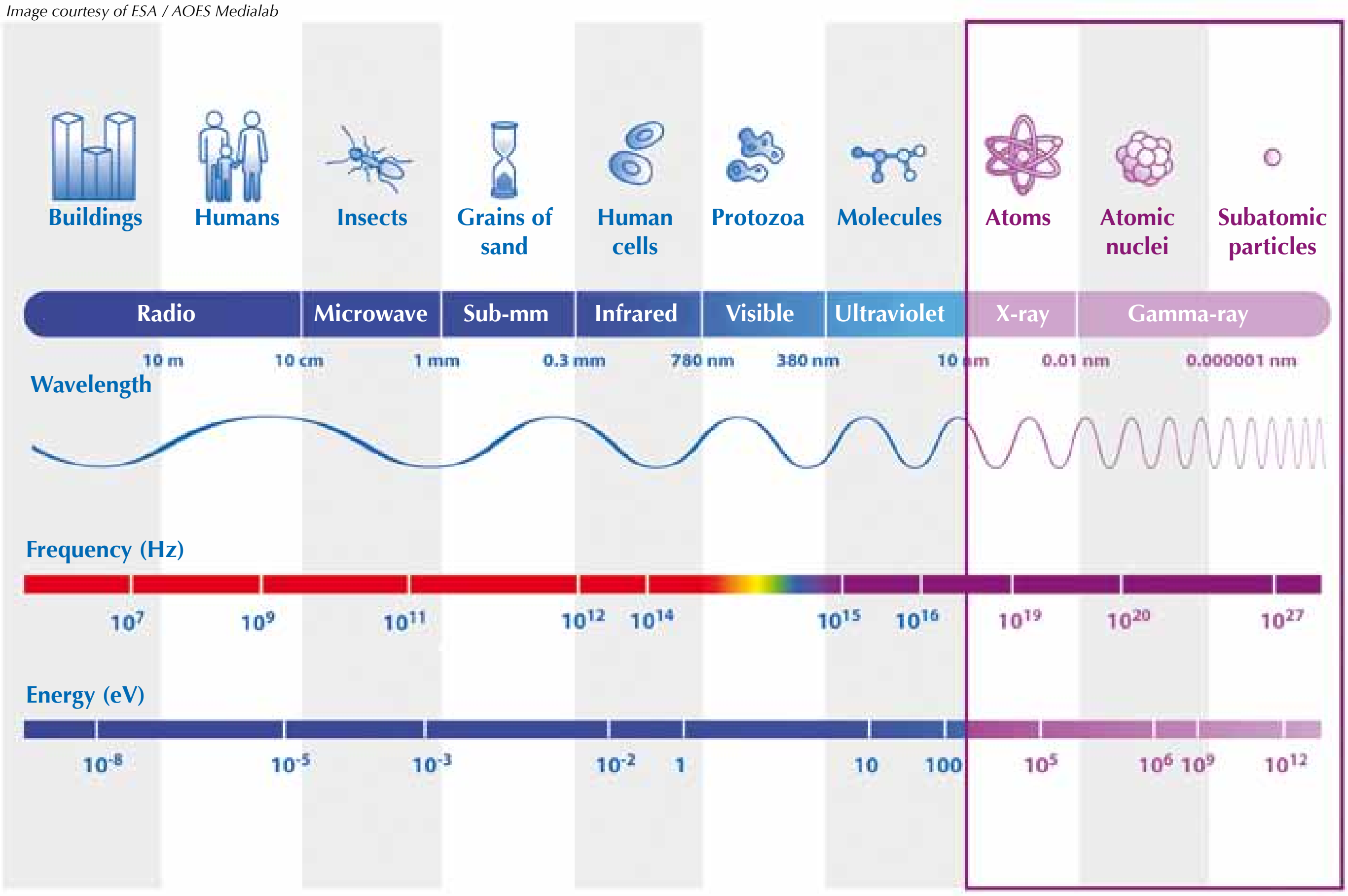


Figure 4: A scheme of the EM spectrum highlighting X-rays and gamma rays, with indications of wavelength, frequencies and energies across the spectrum

Image courtesy of ESA / AOES Medialab

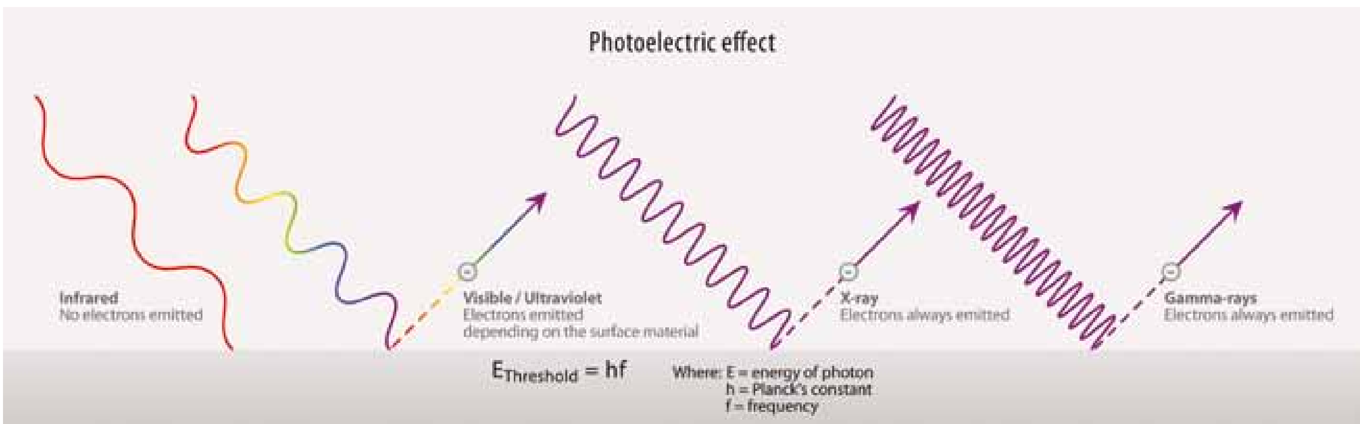


Figure 5: Light rays striking a surface will be absorbed if their energy is higher than a certain threshold value, which depends on the surface material. The energy of the absorbed light is transferred to electrons in the material, which are then emitted. This phenomenon, known as the photoelectric effect[w5], is one of several phenomena that occur when highly energetic radiation interacts with matter. For a dramatic way to teach the subject at school, see Bernardelli (2010)

Image courtesy of ESA / AOES Medialab

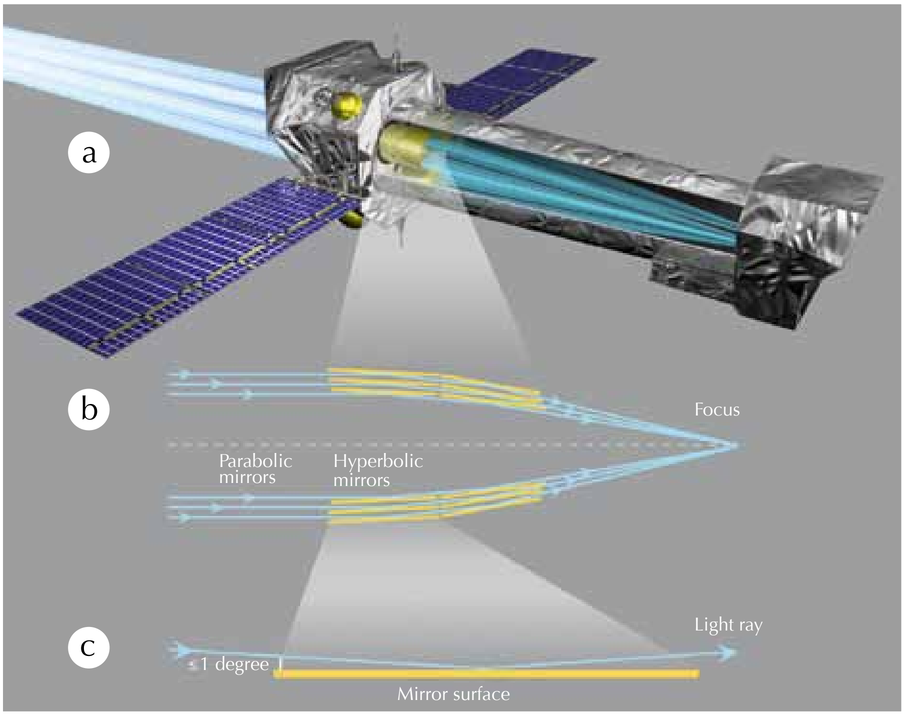


Figure 6:
a) The light path of X-rays through XMM-Newton. The spacecraft carries three telescopes each consisting of 58 nested, gold-coated, tube-like mirrors.
b) The combination of parabolic and hyperbolic mirrors used is shown in cross section through one of the telescopes.
c) X-rays that graze the mirror surfaces are reflected twice and focused onto a detector. The X-rays must graze the mirror at angles of 1° or even less, or they are likely to be absorbed

as large as 20° will allow the stones to bounce, X-rays can be reflected only at much smaller angles: 1° or even less. The X-rays must barely graze the mirror, or they are likely to be absorbed.

To achieve this small angle – and focus the X-rays to a single point – the mirrors used in X-ray telescopes look rather like a funnel (Figure 6). In fact, the mirror shape is a combination of a paraboloid and a hyperboloid, ensuring that the X-rays that graze it are reflected twice. In this way, light is focused onto a detector to form an image of the X-ray source.

This ingenious technique, called grazing incidence optics, has one main drawback: to be reflected and focused, the X-rays must be travelling almost parallel to the tube-like mirrors, so these telescopes collect only limited amounts of X-ray radiation. A powerful telescope is one that collects large amounts of light from distant cosmic sources; this is usually achieved with very large mirrors. In contrast, to maximise their power, X-ray telescopes have several mirrors nested within one another, creating a structure that resembles a giant leek. The three telescopes on board ESA's XMM-Newton space observatory, for example, each consist of 58 nested mirrors (Figure 7)[w7].

Besides their bizarre shape, XMM-Newton's mirrors differ from conventional telescope mirrors in that they are made of gold-coated nickel rather than aluminium-coated glass: the heavier elements are more likely to reflect incoming X-rays (to learn more, see Singh, 2005).

Gamma-ray observing techniques

If focusing X-rays is challenging, focusing gamma rays – the most energetic form of light – is almost impossible. To produce images of cosmic sources in this portion of the EM spectrum, therefore, astronomers had to find alternative methods.

Many instruments for gamma-ray astronomy, including those on board ESA's INTEGRAL space observatory, rely on a technique called coded-mask imaging. This works similarly to a pinhole camera, which has no lens, just a tiny hole through which light rays pass, projecting an inverted image on the opposite wall of the camera.

In place of the pinhole camera's single hole, a coded-mask camera has a mask with a special pattern of holes and opaque spots in front of a detector. Gamma rays that pass through the holes illuminate some pixels on the detector, while others are blocked by the mask's opaque spots and cast shadows on the detector.

The pattern of bright and dark pixels contains information about the location of gamma-ray sources in the sky, and the intensity of the illuminated pixels gives information about their brightness[w8]. Albeit not detailed, the resulting images are useful to

Image courtesy of ESA

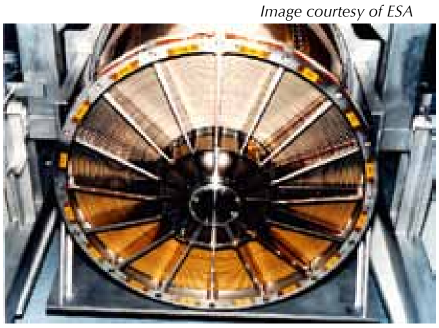
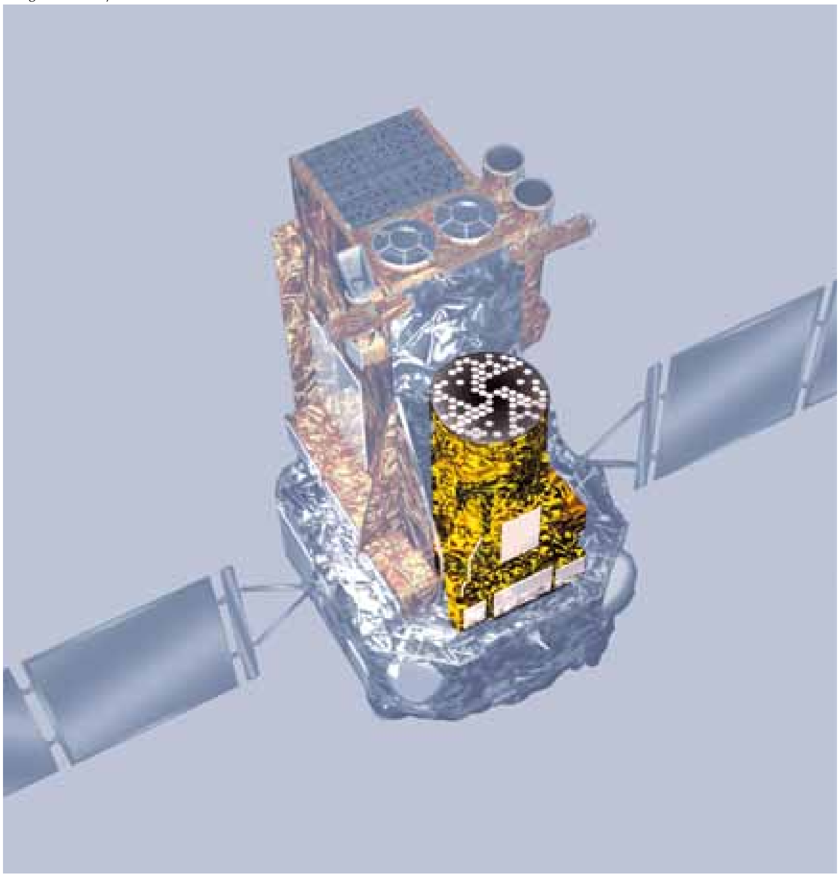
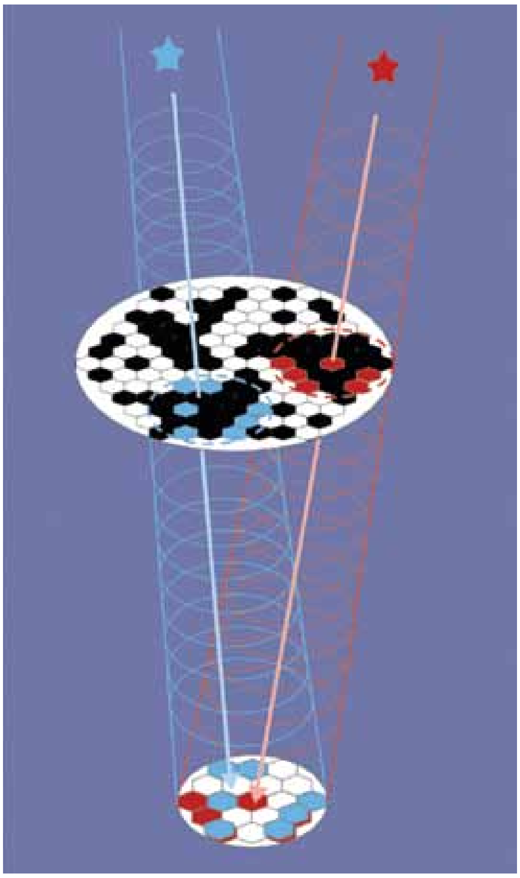


Figure 7: The nested mirrors constituting one of the three telescopes on board XMM-Newton

Images courtesy of ESA / AOES Medialab





b) How the coded-mask camera works: gamma-rays from two different astronomical sources pass through the mask's holes. Some of the incident gamma-rays can pass through the mask and illuminate pixels on the detector below (shown in blue and red, depending on the source), while others are blocked by the mask's opaque spots, casting shadows on the detector (shown in white)

Figure 8:
a) Artist's impression of INTEGRAL highlighting SPI, one of the coded-mask instruments on board the spacecraft.

probe some of the most powerful phenomena in the Universe (Figures 8, 9 and 10).

Coming up…

As you read this article, ESA's XMM-Newton and INTEGRAL observatories are circling Earth, keeping watch over the ever-changing, high-energy Universe and helping to unravel celestial wonders. In our next article, we will explore some of these phenomena, such as the turbulent life and death of stars in the Milky Way, and gigantic black holes at the centres of distant galaxies.

References

Bernardelli A (2010) Stage lights: physics and drama. *Science in School* **17**: 41-45. www.scienceinschool.org/2010/issue17/laser

Boffin H (2007) Fusion in the Universe: gamma-ray bursts. *Science in School* **7**: 61-63. www.scienceinschool.org/2007/issue7/fusion

Mignone C & Barnes R (2011) More than meets the eye: the electromagnetic spectrum. *Science in School* **20**: 51-59. www.scienceinschool.org/2011/issue20/em

Singh KP (2005) Techniques in X-ray Astronomy. *Resonance – Journal of Science Education*. **10(6):** 15-23. www.ias.ac.in/resonance/June2005

Web references

w1 – For a movie based on INTEGRAL data, comparing the appearance of the sky as observed in visible light and in gamma rays, as well as the variability of the gamma-ray emission of sources in the bulge of the Milky Way, see:

Image courtesy of ESA / INTEGRAL / M Fiocchi

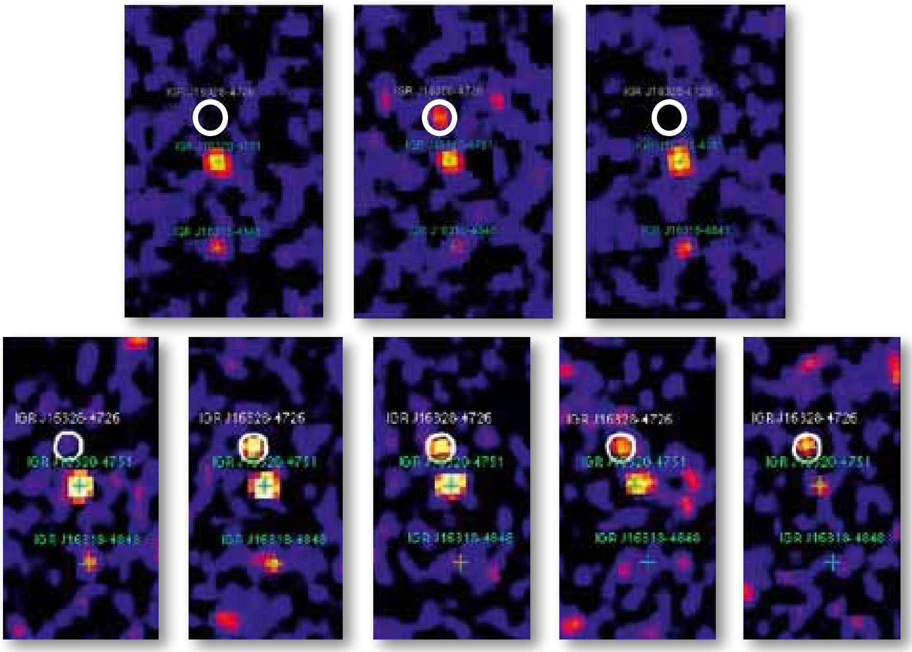


Figure 9: INTEGRAL images of the intermittent source IGR J16328-4726 (encircled). This astronomical source has been monitored over several years with INTEGRAL in the energy range 20-50 keV. As can be seen, the brightness of the source varies significantly over time. Astronomers believe that the source is a supergiant fast X-ray transient: a binary system consisting of a very luminous, supergiant star and a compact object, such as a neutron star or a black hole, orbiting one another. The irregular flow of matter from the supergiant star to the compact object is believed to cause the intermittent nature of these sources

Figure 10: Artist's impression of a supergiant fast X-ray transient

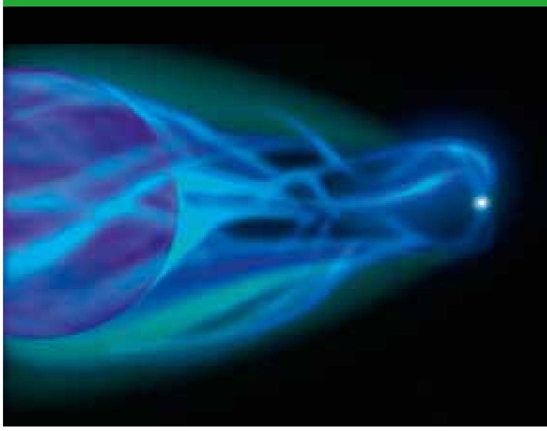


Image courtesy of ESA

http://sci.esa.int/GalacticBulge_video

w2 – To watch an animation showing the different appearance of the galaxy M82 in visible light, ultraviolet and X-rays, see: http://sci.esa.int/science-e-media/img/40/M82Zoom410x354.gif

w3 – To read or listen to Riccardo Giacconi's 2002 Nobel lecture, 'The Dawn of X-ray Astronomy', visit http://nobelprize.org/nobel_prizes/physics/laureates/2002/giacconi-lecture.html

w4 – For more information about ESA, see: www.esa.int

To learn more about the activities of ESA's Directorate of Science and Robotic Exploration, visit: http://sci.esa.int

Education materials produced by ESA are freely available to teachers in the 18 ESA member states. Many are translated into several European languages. See: www.esa.int/educationmaterials

Instructions and patterns for building paper models of many ESA spacecraft (including XMM-Newton and INTEGRAL) can be downloaded here: www.esa.int/classroomtools

The ESA multimedia gallery offers over 10 000 images, videos and animations related to space. See: www.esa.int/esa-mmg/mmghome.pl

To see all ESA-related articles in *Science in School*, see: www.scienceinschool.org/esa

w5 – For an interactive simulation of the photoelectric effect, as well as some associated activities, see the PhET website (http://phet.colorado.edu) or use the direct link: http://tinyurl.com/679wytg

To learn more about the photoelectric effect, see: http://physics.info/photoelectric

w6 – To browse *Science in School* articles about how high-energy X-rays (*synchrotron light*) are used in scientific research at the European Synchrotron Radiation Facility (ESRF) in Grenoble, France, see: www.scienceinschool.org/esrf

Like ESA, ESRF is a member of EIROforum[w9], the publisher of *Science in School*.

w7 – For an animation of the light path through XMM-Newton's telescopes, see: http://sci.esa.int/jump.cfm?oid=45618

w8 – To learn more about the coded-mask camera, see www.sron.nl/~jeanz/cai/coded_intr.html

More about ESA

The European Space Agency (ESA)[w4] 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.

The Directorate of Science and Robotic Exploration is devoted to ESA's space science programme and to the robotic exploration of the Solar System. In the quest to understand the Universe, the stars and planets and the origins of life itself, ESA space-science satellites peer into the depths of the cosmos and look at the furthest galaxies, study the Sun in unprecedented detail, and explore our planetary neighbours.

ESA is a member of EIROforum[w9], the publisher of *Science in School*.

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

Resources

The Science@ESA vodcasts explore our Universe through the eyes of ESA's fleet of science spacecraft. Episode 5 ('The untamed, violent Universe') offers a glimpse of the hot, energetic and often violent universe, and the ESA missions that detect it using X-ray and gamma-ray astronomy. See: http://sci.esa.int/vodcast

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

Claudia Mignone, Vitrociset Belgium for ESA – European Space Agency, is a science writer for ESA. She has a degree in astronomy from the University of Bologna, Italy, and a PhD in cosmology from the University of Heidelberg, Germany. Before joining ESA, she worked in the public outreach office of the European Southern Observatory (ESO).

Rebecca Barnes, HE Space Operations for ESA – European Space Agency, is the education officer for the ESA Science and Robotic Exploration Directorate. She has a degree in physics with astrophysics from the University of Leicester, UK, and previously worked in the education and space communications departments of the UK's National Space Centre.

To find out more about the education activities of the ESA Science and Robotic Exploration Directorate, contact Rebecca at SciEdu@esa.int

To learn how to use this code, see page 65.

Image courtesy of Euan McIntosh; image source: Flickr

Skimming stones

Publisher: EIROforum, www.eiroforum.org

Editor-in-chief: Dr Eleanor Hayes, European Molecular Biology Laboratory, Germany

Editor: Dr Marlene Rau, European Molecular Biology Laboratory, Germany

Copy editor: Dr Caroline Hadley

Composition: Nicola Graf, Email: nicolagraf@t-online.de

Printers: ColorDruckLeimen, Germany www.colordruck.com

Webmaster: Alexander Kubias Email: mail@alexander-kubias.net

ISSN:

Print version: 1818-0353

Online version: 1818-0361

Cover images:

Oil spill on the Mississippi Delta: image courtesy of NASA Goddard Space Flight Center

The dwarf planet Eris: image courtesy of ESO / L Calçada

At the end of each article in this issue, you may notice a square black and white pattern. With the aid of a smart phone, this QR code will lead you straight to the online version of the article. All you need to do is download a free QR code reader app (such as BeeTagg or i-Nigma) for your smart phone and scan the code with your phone's camera. To find a suitable one for your phone, see: http://tinyurl.com/byk4wg

Hint: the apps works better in good light conditions, and with a steady hand. You may also want to try holding your camera at different distances from the code.

You can then use all the live links to the references and resources, download the PDF, send the article to your friends, leave comments, and much more.

Safety note

For all of the activities published in *Science in School*, we have tried to check that all recognised hazards have been identified and that suitable precautions are suggested. Users should be aware, however, that errors and omissions can be made, and safety standards vary across Europe and even within individual countries.

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
- Care is taken with normal laboratory operations such as heating
- Good laboratory practice is observed when chemicals or living organisms are used
- 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.

Credits

Science in School is a non-profit activity. Initially supported by the European Commission, it is now funded by EIROforum.

Disclaimer

Views and opinions expressed by authors and advertisers are not necessarily those of the editors or publisher.

We are grateful to all those who volunteer to translate articles for the *Science in School* website (see the guidelines on our website). We are, however, unable to check the individual translations and cannot accept responsibility for their accuracy.

EIROforum

Science in School **is published and funded by EIROforum, a collaboration between eight of Europe's largest inter-governmental scientific research organisations, which combines the resources, facilities and expertise of its member organisations to support European science in reaching its full potential. See: www.eiroforum.org**

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

Image courtesy of NASA (magnetosphere) and ESA / NASA – SOHO (the Sun)

Science teaching in space: the ESA teachers workshop

Meet an astronaut, cook a comet and plan a trip to Mars. **Shamim Hartevelt** introduces a recent teacher workshop at ESA.

This composite image shows a SOHO image of the Sun and an artist's impression of Earth's magnetosphere

Space can be a great topic for capturing the imagination of school children – or indeed adults. It certainly inspired the 40 secondary-school science teachers who were invited to the European Space Agency (ESA[w1])'s technology centre in Noordwijk, the Netherlands, for a four-day workshop in July 2011.

Hands-on activities, lectures, presentations and a meeting with an astronaut – ESA's second summer workshop for teachers was packed with action and ideas to use in the classroom and share with colleagues. The teachers learnt how to cook a comet, plan a trip to Mars, hunt for exoplanets and build bridges between art, science and language. They also looked at ESA's Earth observation activities and were introduced to Europe's fleet of Solar System and astronomy missions – all ready to be integrated into their science lessons.

Image courtesy of NASA

Anu Ojha cooking a comet

In some of the lively and engaging workshops, the participants learned about the many valuable resources provided by ESA[w2]. For example, the Eduspace website[w3], which provides secondary-school students and their teachers with learning and teaching tools about Earth observation. Or the archive of data from SOHO, the collaborative ESA-NASA project to study the Sun, from its deep core to the outer corona and the solar wind. During the workshop, the teachers learned how to use the archive tool to access over 14 years' worth of SOHO data[w4].

The highlight for many was a close encounter with ESA astronaut Léopold Eyharts, who talked about living and working in space and described how ESA's Columbus laboratory was delivered to the International Space Station (to learn more about Columbus, see Wegener, 2008).

Space may sound beyond the reach of most teachers, but the workshop was not. As one happy participant, Yves Carbonnier from France, put it, "The workshop was strongly directed toward real classrooms and real teachers: no expensive materials, no sophisticated apparatus, no high-level content useless for our daily work. I'm sure that my lessons will be influenced by this workshop."

After four days, the participants left Noordwijk with their bags bulging with ESA education materials and resources[w2] and their minds bursting with ideas and information to share with their colleagues back home.

European teachers will be invited to apply for the third workshop, taking place in Summer 2012. To be informed when the application is open, contact isseducationteam@esa.int, asking to be added to the mailing list. The workshop will also be advertised on the ESA website and in *Science in School*. Priority will be given to those who have not attended before and to teachers who are committed to sharing what they have learned with their colleagues.

Image courtesy of NASA

ESA astronaut Léopold Eyharts on board the International Space Station

Image courtesy of ESA / S Corvaja

The space shuttle Atlantis lifts off from the Kennedy Space Center in Florida, USA, on 7 February 2008. On board is ESA astronaut Léopold Eyharts

Reference

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

Web references

w1 – The European Space Agency (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

ESA is a member of EIROforum[w5], the publisher of *Science in School*.

w2 – To browse, order or download a wealth of space-related education materials developed by ESA, visit: www.esa.int/educationmaterials

w3 – The Eduspace website encourages teachers to use Earth observation data in their curriculum by providing ready-made projects. See: www.esa.int/eduspace

w4 – To investigate the SOHO data archive for yourself, visit http://soho.esac.esa.int/data/archive

w5 – To learn more about EIROforum, see www.eiroforum.org

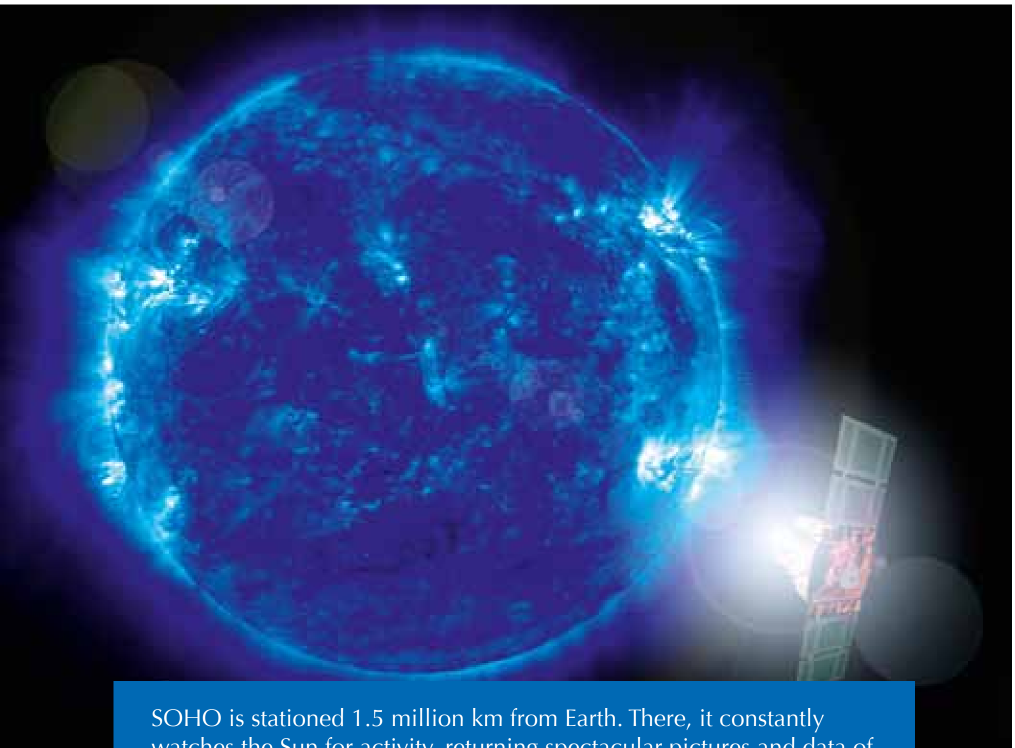
Resources

To learn more about ESA's space missions, see:

Mignone C, Barnes R (2011) More than meets the eye: unravelling the cosmos at the highest energies. *Science in School* **21**: 57-64. www.scienceinschool.org/2011/issue21/em

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

Image courtesy of ESA



SOHO is stationed 1.5 million km from Earth. There, it constantly watches the Sun for activity, returning spectacular pictures and data of the storms that rage across its surface. SOHO was launched in 1995 and was designed to work for three years. It is still working today

---

Shamim Hartevelt-Velani is a secondary-school teacher currently working under contract at ESA's European Space Research and Technology Centre (ESTEC), in the Human Spaceflight and Operations Directorate. She is the didactics specialist in the education unit.

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

Science: on stage and in action

In the year 2106, Earth is facing a crisis: it no longer rains. 22nd-century scientists Kara and Bering travel back to 2011 to carry out experiments on the nature of water. With help from the audience, can they save our planet?

Image courtesy of Wolfgang Gollub

Andrew Brown reviews the latest Science on Stage event in Spain: Ciencia en Acción.

Science on Stage is a network of local, national and international events for teachers, initially launched in 1999 by EIROforum, the publisher of *Science in School* (see Hayes, 2009). Currently, twelve years later, teachers in 27 European countries are participating in national events, vying to earn their places in the eighth international science teaching festival[w1], to be held in April 2013.

Ciencia en Acción

More than 1000 teachers and students took part in this year's Science on Stage event in Spain: Ciencia en Acción[w2], which took place on 7-9 October in the Parc Tecnologic Cientific I Agroalimentari de Lleida. Participants came not only from Spain but also from Portugal and Spanish-speaking South American countries; there was even a guest delegation from Italy.

It was not only teachers and their students who were fascinated by the range of science on offer: on one day alone, more than 12 000 people flocked to Ciencia en Acción, and the event was widely reported on television and radio and in newspapers. The many visitors were able to try out hands-on activities from 130 school science projects.

Some visitors test-drove an electric car that was designed and built by students and teachers from the secondary school IES Caparrella in Lleida. The car is perfect for some disabled people, as it requires only one foot to operate the pedals. In the 'Elements Market' – a huge periodic table – participants were challenged to classify materials according to their elemental composition.

But Ciencia en Acción does more than just organise the science festival: it also runs teacher-training courses, produces educational materials – available on the Ciencia en Acción website and on YouTube – and

Visitors enjoying a ride in an electric car made by teachers and students from school IES Caparrella in Lleida

Image courtesy of Wolfgang Gollub

Image courtesy of Wolfgang Gollub

Image courtesy of Ciencia en Acción

The Elements Market

co-ordinates a network of teachers that offer their expertise to schools, university fairs and other scientific events. To find out more, visit the website[w2].

Attending the international festival

At each national Science on Stage event, a delegation of teachers is selected to represent their country at the Science on Stage international teaching festival on 25-28 April 2013, in Słubice-Frankfurt (Oder) on the Polish-German border. During the festival, 350 teachers from 27 countries will share their most innovative teaching ideas in workshops, on-stage performances and the teaching fair.

Participation is free for the delegates. For other science teachers, there will be a limited number of places for which a registration fee will be charged. See the Science on Stage Europe website[w1] for details.

Reference

Hayes E (2009) Science on Stage: heading for a country near you. *Science in School* **13**: 2-3. www.scienceinschool.org/2009/issue13/sons

Web references

w1 – To find out more about Science on Stage Europe and to contact your national organisers, see: www.science-on-stage.eu

w2 – To learn more about Ciencia en Acción and view photos and videos of all past events, see: www.cienciaenaccion.org

Resources

After each of the previous international Science on Stage festivals (and the Physics on Stage festivals that preceded them), the Irish delegates produced a book describing how to carry out their favourite experiments in the festival. These books can be downloaded free of charge from the Science on Stage Ireland website: www.scienceonstage.ie/resources.html

They have also produced 50 videos of their favourite science teaching ideas and demonstrations from the previous international teaching festivals. See: www.scienceonstage.ie

The organisers of Science on Stage Germany have produced a publication describing some of their favourite projects from the 2011 Science on Stage international teaching festival. It can be downloaded here: http://www.science-on-stage.de/?p=296&l=en

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

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

A science teacher on air

Marco Martucci tells **Eleanor Hayes** what science teaching and radio journalism have in common.

Image courtesy of Marco Martucci

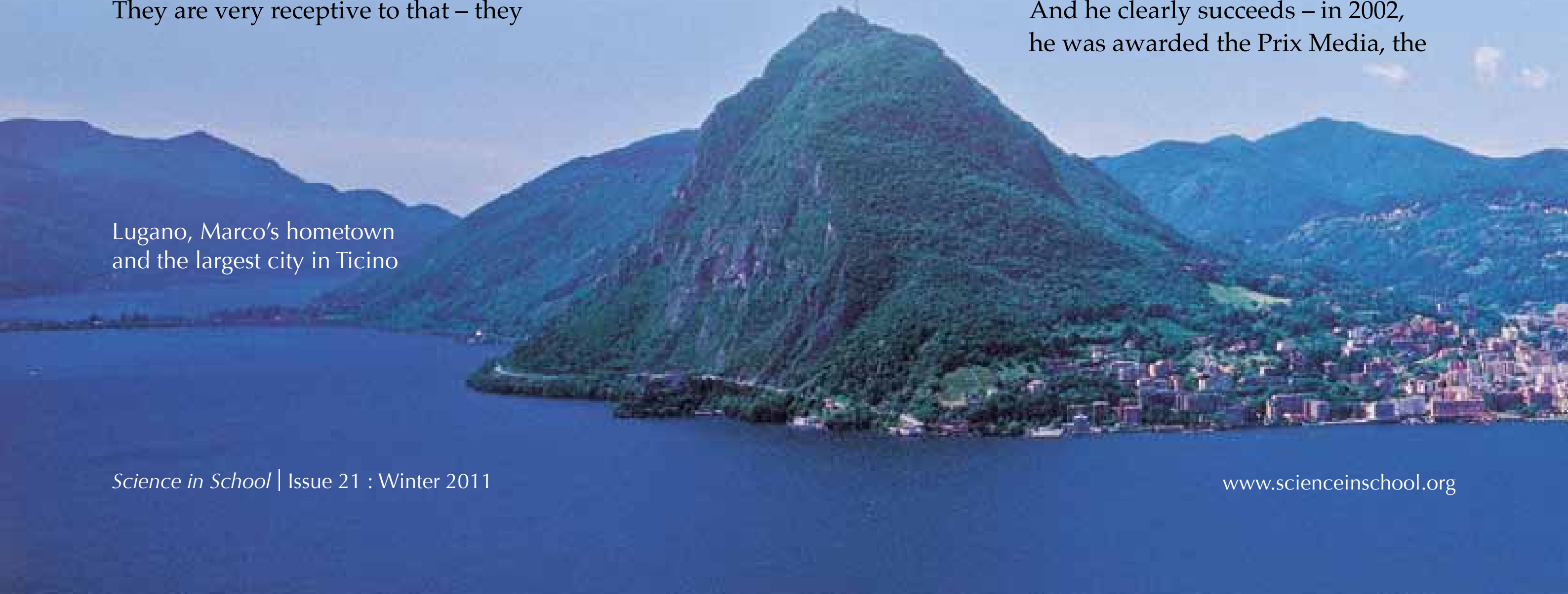
Marco Martucci

When explaining a particularly interesting topic in class, have you ever wished you could tell the world about it? Explain what makes the structure of the cell so fascinating, why we need Newtonian physics to visit Mars, or the chemistry involved in an oil spill? Marco Martucci does just this, combining his teaching job with presenting a weekly radio show on science. How did that happen?

After his chemistry degree in Zurich, Switzerland, Marco began working as a chemist in industry, but it was not the right job for him. "I like to communicate, I like to explain, and it was not possible there. It was interesting but it was a closed world." He thought teaching sounded more satisfying – and he was absolutely right. After re-training as a teacher, Marco began teaching general science to children aged 11-15. "I enjoy teaching that age group more than older students: they can do several topics and are not limited in lessons to biology, or chemistry, or physics. They are very receptive to that – they are curious, they want to know, and I enjoy that too."

Marco began writing the occasional article for newspapers in Ticino – the only Swiss canton in which Italian is the sole official language. He wrote about chemistry, of course, but also about two of his other passions – nature and cutting-edge science in general. His newspaper articles were popular, and soon he was approached to transfer his talents to another medium: radio. Marco was offered his own radio show: each week, he had seven minutes to educate, enchant and engage his audience with scientific topics of the day.

Over the past 15 years of doing his programme, 'La scienza, la natura, le cose' (Science, nature, things)[w1], Marco has covered chemistry, nature, astronomy, aeronautics, nuclear energy, stem cells, climate change, genetically modified organisms, the oil spill in the Gulf of Mexico, and many more topics. "I think it's important that the general public are well informed about science, because there is a lot of misleading information available. It's incredible what people don't know! So I try to correct this – not only at school but also via my radio show." And he clearly succeeds – in 2002, he was awarded the Prix Media, the



Lugano, Marco's hometown and the largest city in Ticino

Swiss Academy of Sciences' national award for science journalism.

Clearly, despite his wide interests and impressive scientific knowledge, Marco cannot be the expert on all topics. Fortunately, he has a very wide network of contacts – in research institutes, at universities and in industry. "This is very important for a journalist, but of course it's also very useful for my work as a teacher – having direct contact with these people. It's a big benefit for my teaching, and one of the reasons why my head teacher allows me to take the time to do the radio show. After all, music teachers often play in orchestras – similarly, there is a synergy between my two jobs. As a teacher, one of the risks is not being up to date in your field – especially in science. But my work for the radio keeps me up to date, enabling me to introduce cutting-edge research to my school students. They are very receptive to it, because they hear about the topic on television and the next week in school, we can talk about it."

"As a teacher, one of the risks is not being up to date in your field."

The school curriculum itself is not always very up to date, so introducing cutting-edge science in lessons can be a problem. Marco, however, feels that this is something that can be done, given the right materials and some imagination. "For example, *Science in School* is a very, very good journal," he says.

I'm hardly likely to disagree. Marco has obviously long been a fan of the materials produced by EIROforum[w2], the publisher of *Science in School*, and by its members. "In 2002, EIROforum produced a very good teaching kit – *Couldn't be without it*[w3] – showing the links between modern science and everyday things like CDs or lasers, our energy supply or medical treatment. The European Space Agency also produces excellent teaching materials – we used some of their International Space Station materials[w4] in the classroom last week, and I got the students riding a skateboard!"

And indeed, we are talking during the lunch break of a conference at the European Molecular Biology Laboratory[w5] – a conference all about sex. Marco is collecting material for his radio show but also for future lessons. And the conference should offer ample opportunity – as its topics include the evolution of sex, the biology of intersex, as well as 'male' and 'female' brains.

With this wealth of materials to choose from, I ask, how does Marco select the topics for his radio show?

"I get ideas from the scientific topics that are in the news, but sometimes I decide to explain a topic that isn't particularly current – because I feel people need to understand more about the cell, for example. But I'm always on the lookout for new topics. As a teacher and a journalist, my antenna is always switched on, 24 hours a day. Fortunately, my wife is very patient about it!"

"As a teacher and a journalist, my antenna is always switched on, 24 hours a day."

And who does Marco address his radio programme to?

"When you're on the radio, you never know who is listening. It could be a scientist, a very simple person or even a child. So I try to tell a story that is understandable without being patronising, but above all, it has to be scientifically accurate. So if I'm going to talk about something that's outside my field – remember I'm a chemist – I consult people before I write the show. If possible, I speak to the scientist, or at least with the press officer [at the scientist's institution]. I want to make sure that what I say is correct – if I can't check, I don't say it."

"When you're on the radio, you never know who is listening to you."

If only all journalists were that meticulous. Perhaps more science teachers should take to the airwaves?

Image courtesy of Lugano Tourism

Image courtesy of Marco Martucci

Marco's school, the Scuola Media Barbengo, in Lugano, Switzerland

Web references

w1 – To listen to podcasts of Marco Martucci's radio programme, 'La scienza, la natura, le cose' (Science, nature, things), visit: www.rsi.ch/podcast

Previously, the programme was known as 'Dentro le cose' (Inside things) and 'Natura sott'occhio' (Nature watch).

w2 – EIROforum, the publisher of *Science in School*, is a collaboration between eight of Europe's largest inter-governmental scientific research organisations. To learn more, see: www.eiroforum.org

w3 – Produced in 2002 by EIROforum, the publisher of *Science in School*, the 'Couldn't be without it' teacher kit can be downloaded free of charge. See: http://scitech.web.cern.ch/scitech

The supporting materials for the malaria activity in the teacher kit can be downloaded from the *Science in School* website: www.scienceinschool.org/2011/issue21/martucci#resources

w4 – The European Space Agency (ESA)'s DVDS (Missions 1-4) about the International Space Station (ISS) and ISS education kit – together with a wealth of other education material – can be downloaded or ordered from the ESA website (click on 'Online material'): www.esa.int/educationmaterials

ESA is Europe's gateway to space, with its headquarters in Paris, France. It is a member of EIROforum, the publisher of *Science in School*. For more information, see: www.esa.int

w5 – The European Molecular Biology Laboratory is Europe's flagship laboratory for the life sciences, and a member of EIROforum – the publisher of *Science in School*. To learn more, see: www.embl.org

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

Image courtesy of Lugano Tourism

The Astronaut's Cookbook: Tales, Recipes, and More

By Charles T Bourland and Gregory L Vogt

Reviewed by Dean Madden, National Centre for Biotechnology Education, UK

The question that astronauts are most frequently asked is 'How do you go to the toilet in space?' This rather puts the cart before the horse because the next most popular questions concern the other end of the alimentary canal: 'How do you eat in space?', 'What does the food taste like up there?', and 'How do you cook it'? *The Astronaut's Cookbook: Tales, Recipes, and More* is an engaging book that provides answers to all of these questions, but, more importantly, also gives instructions for making authentic space cuisine in your own kitchen – including 'Skylab butter cookies', 'space shuttle black beans' and 'Leroy Chial's Chinese cold peanut noodles'.

Spaceflight seems so commonplace these days that it is easy to forget that when people first ventured beyond Earth's atmosphere, it was not even known whether they would be able to eat and swallow under conditions of microgravity. Since then, space-food technologists have had to overcome numerous problems, many of them unexpected. *The Astronaut's Cookbook* juxtaposes fascinating tales about these technological challenges with recipes. For example, the first astronauts to walk on the Moon suffered from potassium deficiency, which sometimes led to heart arrhythmias. The solution was to add potassium to the orange-flavoured drink that they sucked through a tube inside the helmet of their spacesuit. This worked well until Apollo 16 astronaut Charlie Duke accidentally spilt the drink inside his helmet. The result could have been catastrophic had the highly conductive solution come into contact with electrical cables. Since then, only pure water has been allowed inside spacesuits.

One of the authors of *The Astronaut's Cookbook*, Charles Bourland, spent 30 years developing food for the US National Aeronautics and Space Administration (NASA) and solving problems like this one. Co-author Gregory Vogt was once a NASA education specialist, a science teacher and an author of numerous educational publications. Given the US background of both authors, it is unsurprising that the book's principal focus is on American astronauts' food; consequently there are numerous references to processed food products that are available only in America (such as 'Cugino's Veggie Weggie DIPZ Mix'). A little ingenuity, however, will allow European readers to find reasonable equivalents of the products mentioned.

This book should appeal to teachers and secondary-school students of all ages. Science and food technology teachers should be able to use it to develop stimulating educational activities that introduce aspects of product development, evaluation and processing methods.

Details

Publisher: Springer, New York
Publication year: 2009
ISBN: 9781441906236

Resources

If you found this review interesting, why not browse all the resource reviews in *Science in School*? See: www.scienceinschool.org/reviews

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

Who Cloned my Cat? Fun Adventures in Biotechnology

By Reinhard Renneberg

Reviewed by Michalis Hadjimarcou

Who Cloned my Cat? Fun Adventures in Biotechnology is a collection of two-page articles that briefly describe discoveries from the field of biotechnology. Each product or technique is accompanied by a short, interesting and sometimes humorous story, as well as cartoon illustrations – together, these ensure that the reader's level of interest remains high. The book covers a vast selection of topics from scientific disciplines that are supported by biotechnology, including molecular genetics, microbiology, biochemistry and environmental biology.

Who Cloned my Cat? provides basic biotechnology information – some of which will be common knowledge among scientists (particularly biologists) – with a twist. Content that goes beyond these basics will be new to most readers and may provide a few surprises. Some articles require a good knowledge of biology to be understood whereas others are simple enough for anyone to benefit from them.

Author Reinhard Renneberg goes beyond the simple presentation of facts. He describes the advantages and disadvantages of biotechnology and discusses current hot topics surrounding biotechnology products – such as those relating to the availability of personal genetic information.

Who Cloned my Cat? would be suitable for biology and, to a lesser degree, chemistry teachers and for the advanced-level (16- to 18-year-old) secondary-school students of both subjects. The book would be useful for teaching topics on the syllabus or for supplementing a lesson to make it more interesting. The accompanying stories will also help students understand the history behind discoveries that have changed the way we live.

Even for those without an academic background, *Who Cloned my Cat?* would make a good read, particularly as it includes useful tips on how to improve everyday life. Most importantly, whoever reads this book will acquire the knowledge they need to clone his or her cat – that is, with the help of a biotechnology company and a generous bank!

Details

Publisher: Pan Stanford Publishing
Publication year: 2010
ISBN: 9789814267656

The book is also available in German:

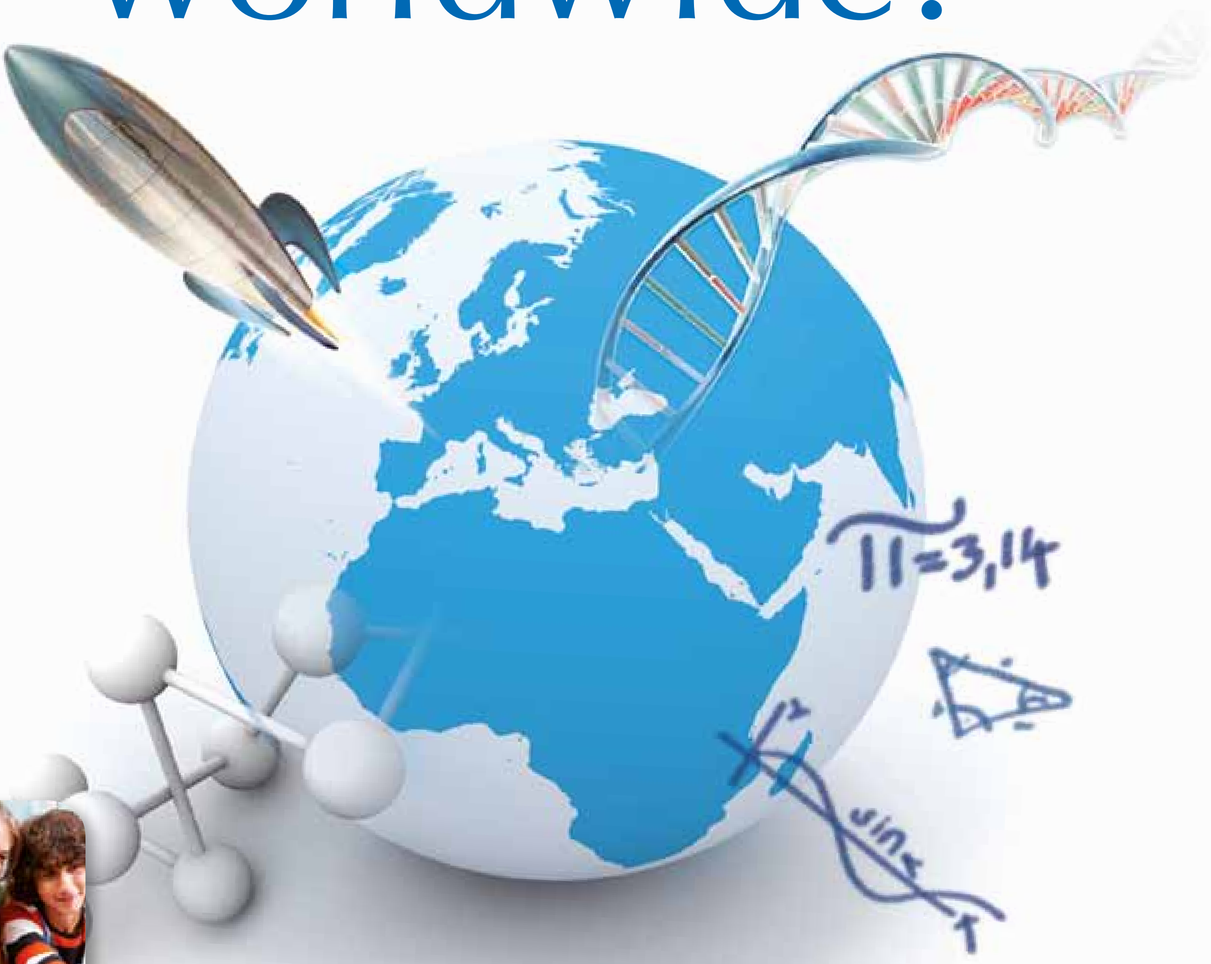
Title: *Katzenklon, Katzenklon: Und Andere Biotechnologie-Geschichten*
Publisher: Spektrum Akademischer Verlag
Publication year: 2007
ISBN: 9783827419415

Resources

If you found this review interesting, why not browse all the resource reviews in *Science in School*? See: www.scienceinschool.org/reviews

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

How many schools and teachers do you reach – worldwide?



Advertising in *Science in School*

- Choose between advertising in the quarterly print journal or on our website.
- Website: reach over 30 000 science educators worldwide – every month.
- In print: target over 5000 European science educators every quarter, including over 3500 named subscribers.
- Distribute your flyers, brochures, CD-ROMs or other materials to the recipients of the print copies.

For more details, see www.scienceinschool.org/advertising

Published by EIROforum:

Subscribe (free in Europe): www.scienceinschool.org

ISSN: 1818-0353