Winter 2012 Issue 25

SCIENCE in SCHOOL

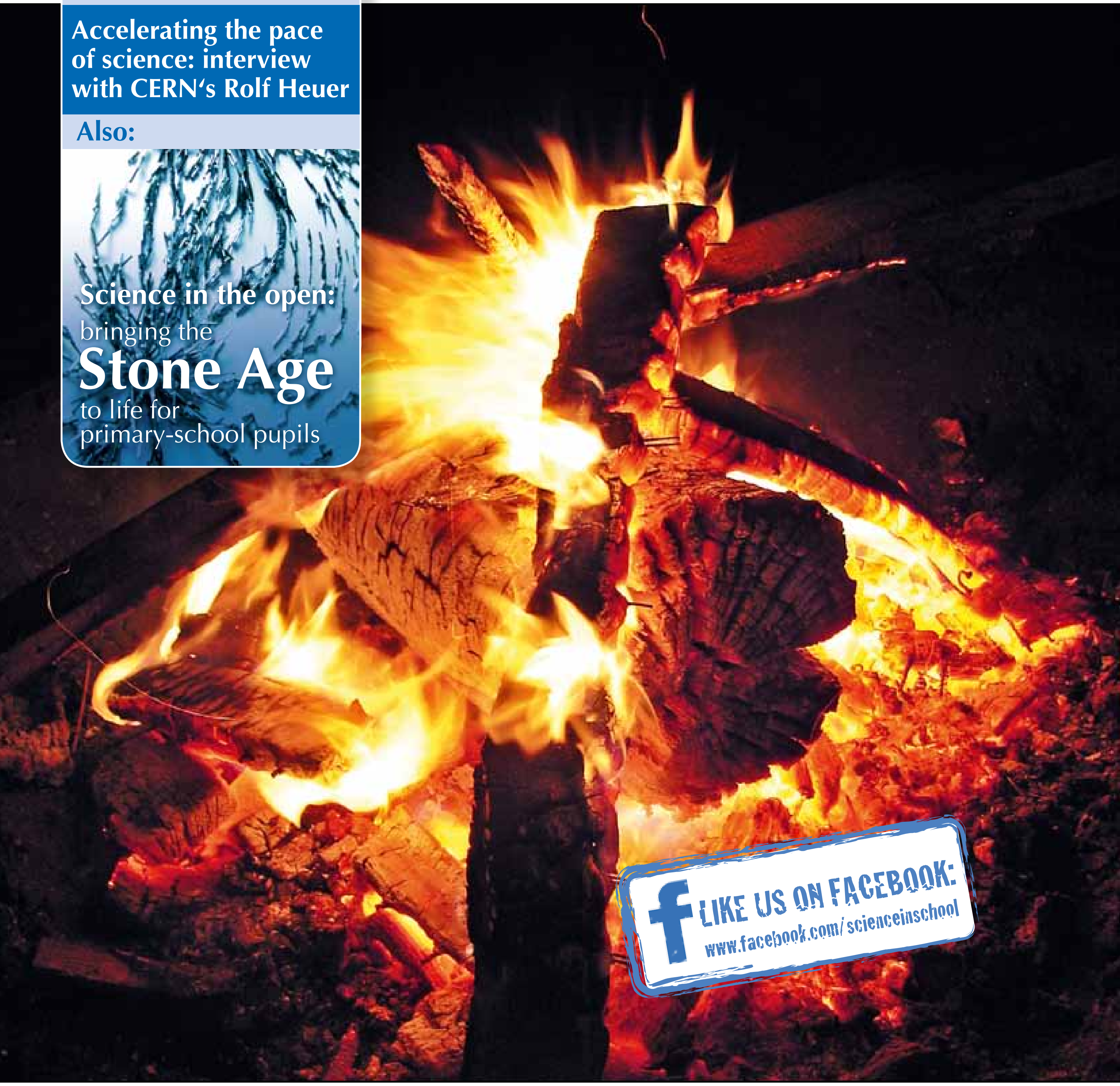
The European journal for science teachers

In this issue:

Accelerating the pace of science: interview with CERN's Rolf Heuer

Also:

Science in the open: bringing the **Stone Age** to life for primary-school pupils



Published and funded by EIROforum

Editorial

This print copy of *Science in School* has a mass of nearly a quarter of a kilogram. But do you know how a kilogram is defined? And did you know that the definition may be about to change, with the help of CERN (page 59)? Does this have anything to do with the Higgs, you might ask? It doesn't, in fact, but we're proud to have CERN's director general, Rolf Heuer, share his excitement about the Higgs boson (page 6).

The discovery of this new boson is certainly a historic moment in physics, perhaps comparable to Galileo Galilei's discovery of Jupiter's moons in the 17th century. Now you and your students can follow in his footsteps, re-discovering the motions of these celestial bodies (page 41). If you're a chemistry teacher, however, you may be more interested in how another cornerstone of science, the periodic table, is still under development, with scientists striving to create the next heaviest element (page 18).

And during your stroll through history, you could step all the way back into the Stone Age with your pupils, with an outdoor project for primary school (page 48). As far as we know, people in the Stone Age didn't have soap, but the Babylonians, 5000 years ago, did. Today, scientists are adapting this old invention by making magnetic surfactants (page 22), which could, for example, be used to clean up oil spills before they spread through the ocean, following the currents.

Ocean currents and waves are a complex and exciting topic, although they aren't always addressed outside geography lessons. With the help of some simple activities, however, your students can explore the physics of the ocean for themselves (page 28).

Out on the open seas, fishermen need to pay careful attention to currents as they search for fish. On a microscopic scale, scientists at EMBL are also concerned with fishing – the way that microtubules 'fish' the chromosomes apart during cell division. It turns out that the process is rather inaccurate, which is one cause of infertility (see page 13).

Bringing cutting-edge science such as this into the classroom can be a powerful motivating factor for your students – and of course it's part of the purpose of *Science in School*. To help you do this, we've got some ideas on how to introduce and analyse research papers with your students (page 36). Alternatively, you could use some of our simply written but informative science articles; for example, you could introduce your students to the science involved in orthodontics (page 54) or to the mystery of altruism (online only).

Science in School, of course, relies on the altruism of many of its readers, so why not get more involved? You could translate articles so that we can share them with other teachers in your country; review articles to ensure they are up to standard; review websites and other materials; or submit your own articles. And of course, you can spread the word about *Science in School*, for example by 'liking' our Facebook page.

We wish you a cosy wintertime and look forward to seeing you in 2013!

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*

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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.

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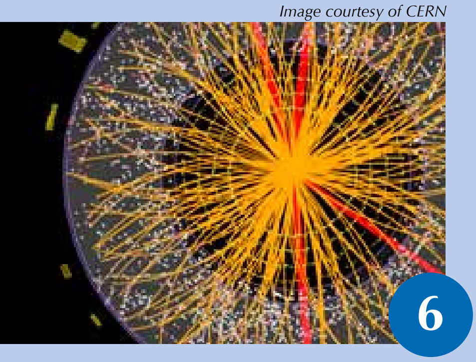
Contents

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

To read the whole issue, see: **www.scienceinschool.org/2012/issue25**

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

Image courtesy of CERN



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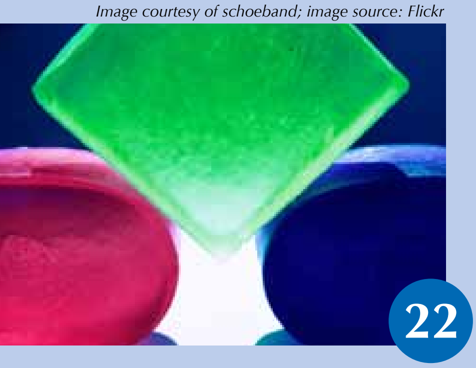

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48

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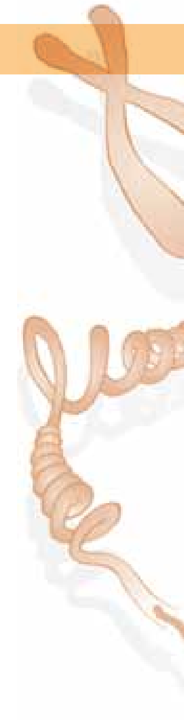


Cool and hot science for a bright future

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).

CERN: proudly presenting the new (Higgs?) boson

On 4 July 2012, the ATLAS and CMS experiments at CERN's Large Hadron Collider (LHC) announced the discovery of a new particle with a mass of about 126 GeV and characteristics similar to those expected for the long-sought Higgs boson. This discovery is a major step forward in our understanding of the origin of mass, and of the fundamental properties of matter, space and time.

The preliminary results come from data taken in 2011 and 2012, corresponding to about 10^{15} proton-proton collisions at 7 and 8 TeV energy. More data will be needed to study the different decay modes of the new particle, to find out if the theoretical predictions are correct, or if there are any – even tiny – differences between the predictions of the Higgs model and the observations.

Find out more about the search for the Higgs in this issue's feature article:

Hayes E (2012) Accelerating the pace of science: interview with CERN's Rolf Heuer. *Science in School* **25**: 6-12. www.scienceinschool.org/2012/issue25/heuer

To learn more about how the LHC works and the search for the Higgs boson, see:

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

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

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

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

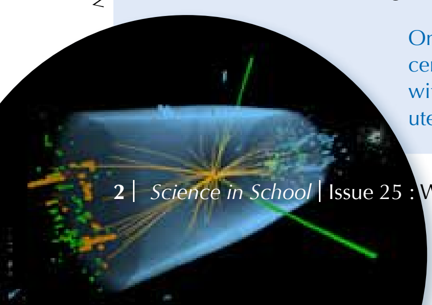


Image courtesy of CERN

One of the proton-proton collisions at a centre of mass energy of 8 TeV, recorded with the CMS detector, which contributed to the discovery of the new particle.

EFDA-JET: paving the tungsten-tile road to ITER

ITER, the world's biggest fusion experiment, is under construction in the south of France. During its construction, the Joint European Torus (JET) – currently Europe's largest fusion experiment – is a vital test bed for ITER design and operation.

In this capacity, JET has successfully completed its 2011-2012 experimental campaign by running 151 identical high-powered plasma pulses, totalling 900 seconds of stable operating time. This emulates a single pulse of ITER – by virtue of its superconducting magnets, ITER will be able to maintain a stable pulse 20 times longer than JET. On the basis of the recent experiments, scientists are confident that they will be able to maintain stable fusion conditions for the length of these longer pulses.

The experiment also tested the long-term behaviour of the wall materials – a range of JET's wall tiles will now be extracted by the remote-handling system (pictured) for analysis.

The ITER design team are very interested in the results, and have already requested an even more severe test for the materials when experiments recommence next year: deliberate melting of some tungsten wall tiles.

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

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

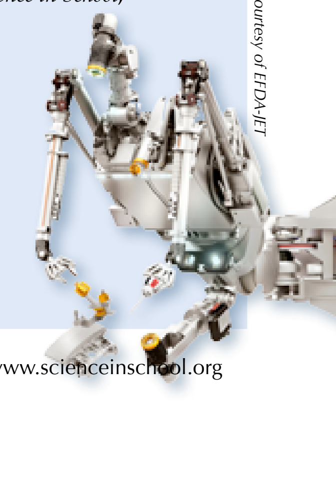


Image courtesy of EFDA-JET

The remote handling mascot is mounted on a 6 m articulated boom, which allows maintenance without humans entering the JET vessel. An operator in a remote control room controls the mascot's two gripper arms, which can operate around 1500 bespoke tools.

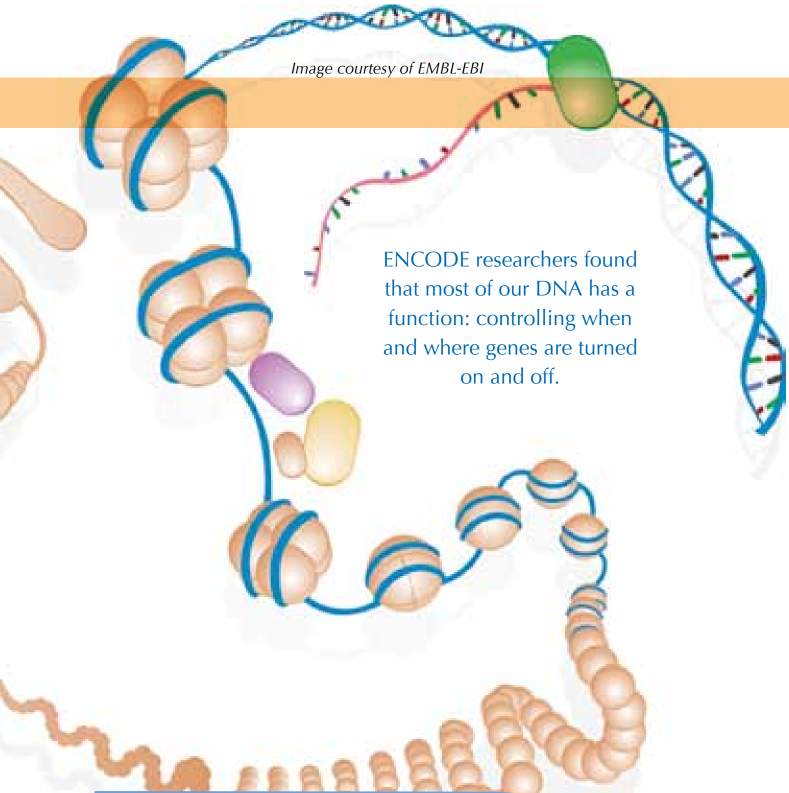


Image courtesy of EMBL-EBI

ENCODE researchers found that most of our DNA has a function: controlling when and where genes are turned on and off.

EMBL: ENCODEing the switchboard of the human genome

For the past five years, hundreds of scientists in the 'Encyclopaedia of DNA elements' (ENCODE) project have been systematically exploring what the human genome does, to identify all its functional elements. Their findings show that much of what has been called 'junk DNA' is actually a massive, 3D switchboard turning genes on and off. Together with colleagues from around the globe, scientists at EMBL's European Bioinformatics Institute have found that while only 2% of our DNA is genes, a much bigger part of the genome – at least 20% – is involved in controlling when and where those genes are active, and as much as 80% of the genome has a distinct biochemical activity. This opens up new avenues of biomedical research.

To give some sense of the scale of the project, ENCODE used around 300 years' worth of computer time studying 147 tissue types to determine what turns specific genes on and off, and how that 'switch' differs between cell types. All of the data is now publicly available and the findings are published in 30 connected, open-access papers in three science journals: *Nature*, *Genome Biology* and *Genome Research*.

For more details including the full publication list, see the press release on the EMBL website (www.embl.org) or use the direct link: http://tinyurl.com/ebiencode

What is the ENCODE project all about? Watch a video interview with leading scientists Ewan Birney, Tim Hubbard and Roderic Guigo: http://bit.ly/Ro9UDt

Learn how the insights from the ENCODE project were represented in the 'Dance of the DNA'. Visit the website of the Science Museum, London, UK (www.sciencemuseum.org.uk) or use the direct link: http://tinyurl.com/8cr7249

EMBL is Europe's leading laboratory for basic research in molecular biology, with its headquarters in Heidelberg, Germany. The European Bioinformatics Institute is part of EMBL and is based in Cambridge, UK. To learn more, see: www.embl.org

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

Image courtesy of ESA / AOES Medialab

ESA's Earth Explorer CryoSat mission is dedicated to precisely monitoring changes in the thickness of marine ice floating on the polar oceans, and variations in the thickness of the vast ice sheets that blanket Greenland and Antarctica.

ESA: The Arctic ice cap is thinning

The year 2012 saw the surface area of Arctic sea ice hit a record low since satellite measurements began in the 1970s. The consequence of losing part of the Arctic's ice coverage could be profound: the ice cap reflects sunlight back into space; sunlight that, unless reflected, would contribute to global warming.

The European Space Agency (ESA)'s satellites SMOS and CryoSat have found that not only is the area of sea-ice getting smaller but the ice is also getting thinner: 900 km^3 of summer sea ice have disappeared from the Arctic ocean over the past year, a rate of loss that is 50% higher than most scenarios outlined by polar scientists.

In addition to the total ice volume, it is important to evaluate the thickness of the young ice that forms in winter. Only those areas thick enough to survive the next summer's melting period can become the basis of the following winter's thick ice. It is this thick, multi-year ice that ultimately indicates how healthy the Arctic is.

ESA's measurements show that this newly formed ice is becoming significantly thinner each year, so that less and less of it survives the summer. In particular, SMOS detected extensive areas less than half a metre thick. Scientists therefore predict that of the total Arctic sea-ice cover for Winter 2012-13, a larger fraction than ever before (about 12 million km^2) will consist of thin ice. This suggests that less Arctic sea-ice than ever before will survive the melting phase in Summer 2013.

To model the effect of the changing ice cover with your students in class, see:

Shallcross D, Harrison T (2008) Climate change modelling in the classroom. *Science in School* **9**: 28-33. www.scienceinschool.org/2008/issue9/climate

See our article series on climate change in several languages: www.scienceinschool.org/climatechange

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

ESO:
Sweet discovery in space

Astronomers using ALMA, one of the world's largest ground-based astronomy projects, have spotted molecules of glycolaldehyde – a simple form of sugar – around a young binary star with similar mass to the Sun, called IRAS 16923-2422. Glycolaldehyde ($C_2H_4O_2$) has been seen in interstellar space before, but this is the first time it has been found so near to a Sun-like star. The molecule is one of the ingredients in the formation of RNA, which – like DNA, to which it is similar – is one of the building blocks of life. The discovery shows that these building blocks are in the right place, at the right time, to be included in planets forming around the star.

For more information, see the press release: www.eso.org/public/news/eso1234

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

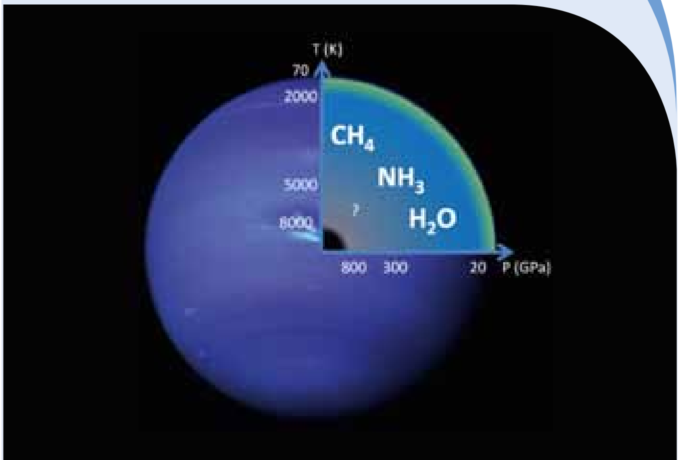
The European Southern Observatory (ESO) is by far the world's most productive ground-based astronomical observatory, with its headquarters in Garching near Munich, Germany, and its telescopes in Chile. ESO is the European partner in the ALMA project, which is a collaboration between Europe, North America and East Asia, in co-operation with the Republic of Chile. For more information, see: www.eso.org

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

The Rho Ophiuchi star-forming region seen in infrared light. IRAS 16293-2422 is the red object in the centre of the small square. Inset: an artist's impression of glycolaldehyde molecules, the form of sugar that has been found around IRAS 16293-2422.

Image courtesy of ALMA (ESO / NAOJ / NRAO) / L Calçada (ESO) & NASA / JPL-Caltech / WISE Team

ESRF:
Hot ice in Neptune



Neptune's main constituents are water (H_2O), ammonia (NH_3) and methane (CH_4) ices. The core may be composed of rocks and ice; the outside layer is formed mainly by helium, hydrogen and methane.

Image courtesy of Sandra Ninet; image of Neptune by NASA / JPL-Caltech; model adapted from Hubbard WB, Podolak M, Stevenson DJ (1995) The Interior of Neptune. In Cruikshank DP (ed) Neptune and Triton. pp. 109-138. Tucson, AZ, USA: University of Arizona Press. ISBN 978-0816515257

The main constituents of the planets Neptune and Uranus are water, ammonia and methane in solid phases called 'ices'. They are very different from ice on Earth, though: up to 5000 K hot and under extreme pressures of several million atmospheres. Under such conditions, scientists have predicted the existence of a new state of ammonia ice, called superionic ammonia. Superionicity is an exotic state of matter that behaves simultaneously as a crystal (fixed ion lattice) and as a liquid (diffusive ions).

Now scientists have confirmed the existence of superionic ammonia experimentally at the European Synchrotron Radiation Facility (ESRF): they submitted an ammonia sample to very high pressure while heating it, and followed its phase transformations using intense X-rays. Unexpectedly, however, they detected superionic ammonia at a lower temperature than predicted: 750 K instead of 1200 K. The exact boundaries of this superionic phase are crucial, because they determine whether it could exist in Neptune and Uranus. Therefore, the scientists will next test whether superionic ammonia is stable under even higher temperatures and pressures. Should this be the case, it could help explain the origin of the planets' magnetic fields, which are not yet well understood.

To learn more, see the news item on the ESRF website (www.esrf.eu), use the direct link (http://tinyurl.com/superionic), or read the research paper:

Ninet S, Datchi F, Saitta AM (2012) Proton disorder and superionicity in hot dense ammonia ice. *Physical Review Letters* **108(16)**: 165702-1–165702-5. doi: 10.1103/PhysRevLett.108.165702

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

Image courtesy of European XFEL

Tuning the pole heights of an undulator in the magnetic measurement laboratory.

European XFEL: The brightest light source on Earth

The European XFEL will deliver up to 27 000 very intense X-ray light flashes per second with a brightness more than 100 septillion (100 x 10^{24}) times that of an ordinary 60 W light bulb, making the new research facility the brightest light source on Earth. Deliveries of the devices generating this incredible firework – the undulators – to the site in Hamburg have been taking place since October 2012. The magnetic structures of the undulators will force accelerated electrons onto a slalom course, inducing them to emit X-ray flashes of extraordinary quality.

The new facility will have three undulator systems, with the two larger ones each 212 m long. They consist of segments that have been produced in close collaboration with European XFEL. Before the segments are installed, the undulator group of European XFEL will extensively measure and tune their magnetic properties. The light they produce will eventually be used, for example, to examine biomolecules, to film ultrafast processes and to study matter under extreme conditions.

The European X-ray Free Electron Layer (XFEL) is a research facility currently under construction in the Hamburg area in Germany. Its extremely intense X-ray flashes will be used by researchers from all over the world. To learn more, see: www.xfel.eu

For a list of *Science in School* articles relating to European XFEL, see: www.scienceinschool.org/xfel

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

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

Image courtesy of schauhi / photoopia.com

Image courtesy of Dieter / pixelio.de

Image courtesy of John Carnemola / iStockphoto.com

ILL: Cold-blooded platypus and hot-blooded chicken

Using the facilities at the Institut Laue-Langevin (ILL), a team of biologists have shown that haemoglobin in different species has evolved to perform its function as an oxygen carrier very effectively at that species' body temperature. They found variations in the amino-acid composition of this iron-rich protein, which is found in all vertebrates, that affect the protein's softness and flexibility, and thus its ability to withstand warmer or cooler temperatures.

The team studied haemoglobin from a range of vertebrates. The duck-billed platypus, at 33 °C, has the lowest body temperature of all endotherms (vertebrates that maintain a constant body temperature, such as mammals or birds). Humans, at 36.6 °C, have an intermediate body temperature, whereas the chicken, at 41 °C, is as hot-blooded as birds tend to be. The scientists also studied the ectothermic saltwater crocodile – which has a body temperature that is regulated by the environment, varying between 25 and 34 °C.

The scientists found a direct correlation between the resilience of haemoglobin and the average body temperature of the species from which it was sampled. In other words, each species' haemoglobin appears to have evolved to unfold at exactly the right body temperature.

To learn more, see the press release on the ILL website (www.ill.eu), use the direct link (http://tinyurl.com/hbevolution), or read the research paper:

Stadler AM et al. (2012) Thermal fluctuations of haemoglobin from different species: adaptation to temperature via conformational dynamics. *Journal of the Royal Society* 9(76): 2845-2855. doi: 10.1098/rsif.2012.0364

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

Image courtesy of CERN

Rolf Heuer

Accelerating the pace of science: interview with CERN's Rolf Heuer

By Eleanor Hayes

CERN is not just the world's largest particle physics laboratory. As its director general, Rolf Heuer, explains, "CERN is a role model, demonstrating that science can bridge cultures and nations. Science is a universal language and this is what we speak at CERN."

CERN also unites people in other ways. "As a young summer student, you can find yourself having lunch next to a Nobel Prize winner. And everyone, from the canteen workers to the senior management – we all identify ourselves with CERN, sharing a desire to increase human knowledge. We all do our bit towards that goal, leaving political, cultural and educational differences outside the campus."

This undoubtedly makes CERN a very special place to work, but what makes it unique is its particle accelerator, the Large Hadron Collider (LHC). First used in 2008, the LHC is the world's largest particle accelerator, its 27 km tunnel forming a ring beneath the French-Swiss border. As Professor Heuer explains, "It's also one of the coldest places in the Universe, cooled to 1.9 K with superfluid helium. Even outer space is warmer, at 2.7 K.

"Simultaneously, it's one of the hottest places in our galaxy because when we collide protons in the LHC, we produce temperatures that are much, much higher than those at the centre of the Sun." Professor Heuer describes the collision of two protons

Part of the 27 km tunnel that houses the LHC. To allow for the necessary measurements on the new particle, the LHC will run until February 2013. Professor Heuer explains: "Imagine you see someone a long way away who looks like your best friend. To be certain that it is not actually his or her twin, you need to wait until you're close enough. That takes time."

Image courtesy of CERN

Image courtesy of Nicola Graf

Einstein's iconic equation tells us that to create the very heavy particles that existed a fraction of a second after the Big Bang, the LHC needs to collide particles at very high energies.

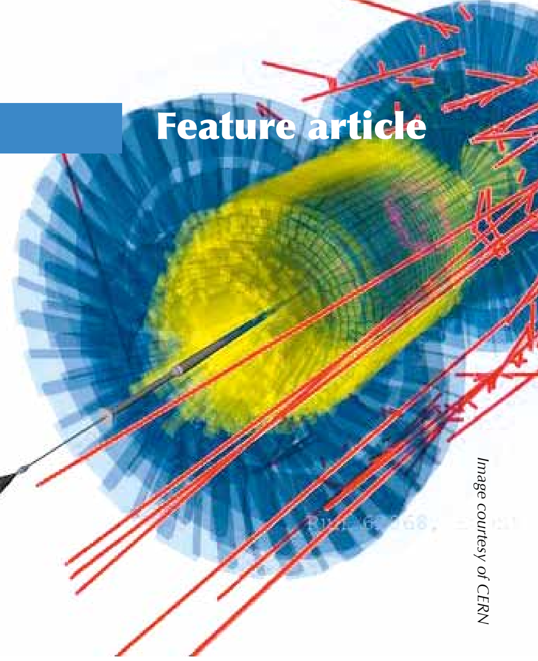


Image courtesy of CERN

at close to the speed of light as being like two mosquitoes colliding in mid-flight. "The key difference is that these protons are tiny, tiny, tiny particles, so their energy density – the energy of the protons divided by their volume – is huge, and it is this energy density that brings us close to the Big Bang."

As detailed in two previous *Science in School* articles (Landua & Rau, 2008; Landua, 2008), these enormously energetic collisions can create very heavy particles, the sort of particles that were formed in the extremely energetic conditions a fraction of a second after the Big Bang. These are particles so massive that they have not been created since then (remember that Einstein's law $E=mc^2$ tells us that to create a very heavy particle, we need a large amount of energy).

Image courtesy of CERN

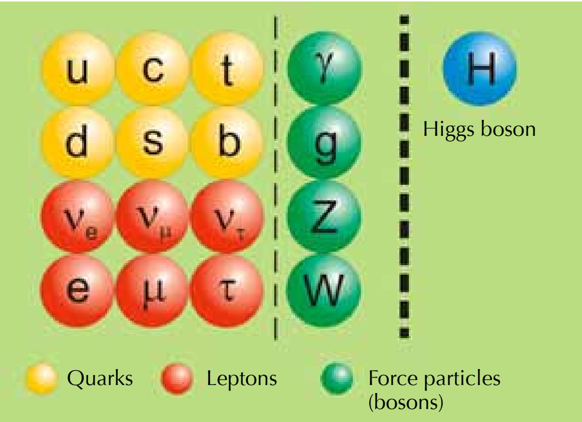
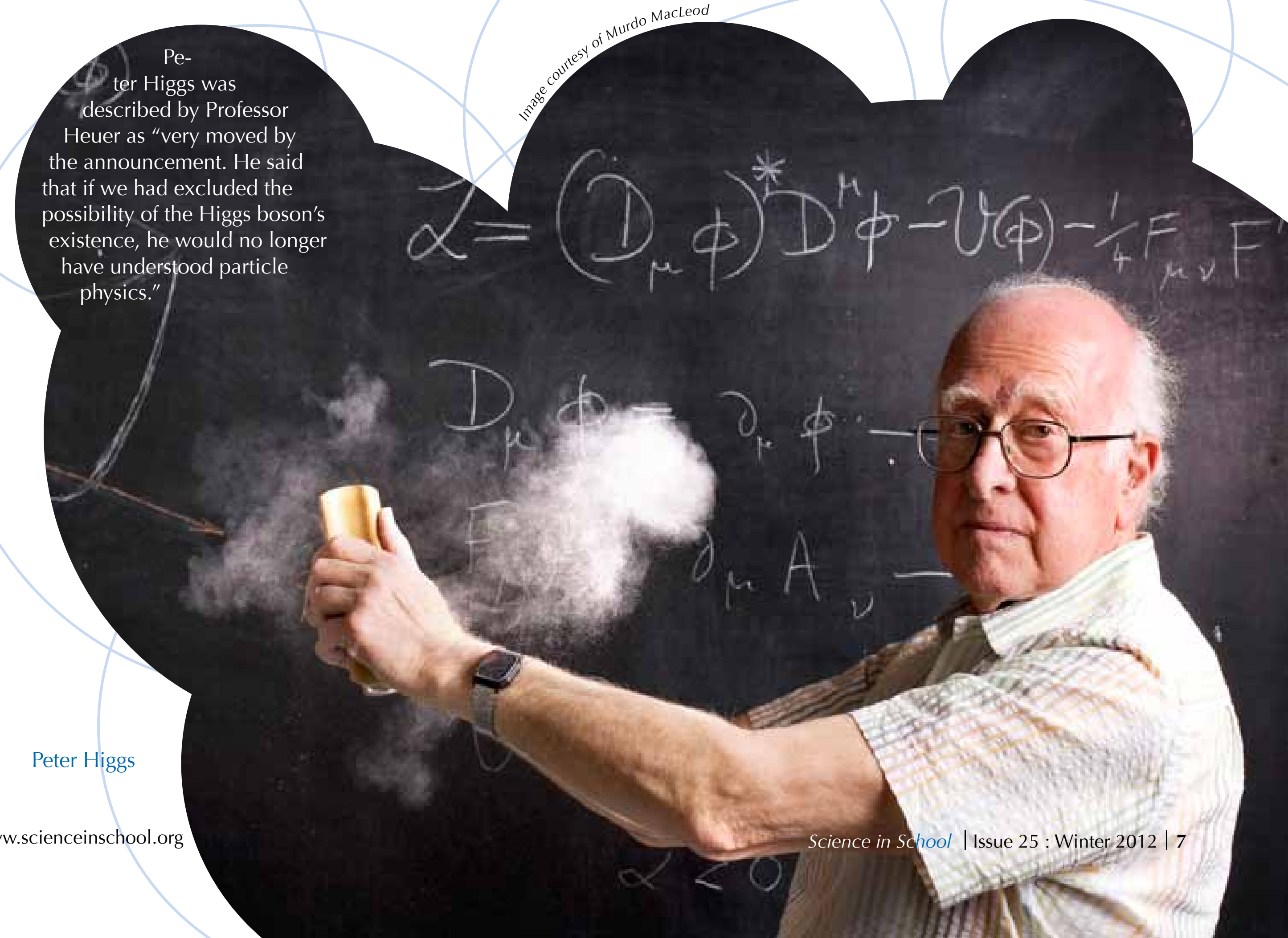


Figure 1: The standard model describes the fundamental particles from which we, and every visible thing in the Universe, are made, and the forces acting between them.

As Professor Heuer and I talk, extremely distant history has just been

Image courtesy of Murdo MacLeod



Peter Higgs was described by Professor Heuer as "very moved by the announcement. He said that if we had excluded the possibility of the Higgs boson's existence, he would no longer have understood particle physics."

Peter Higgs

Physics

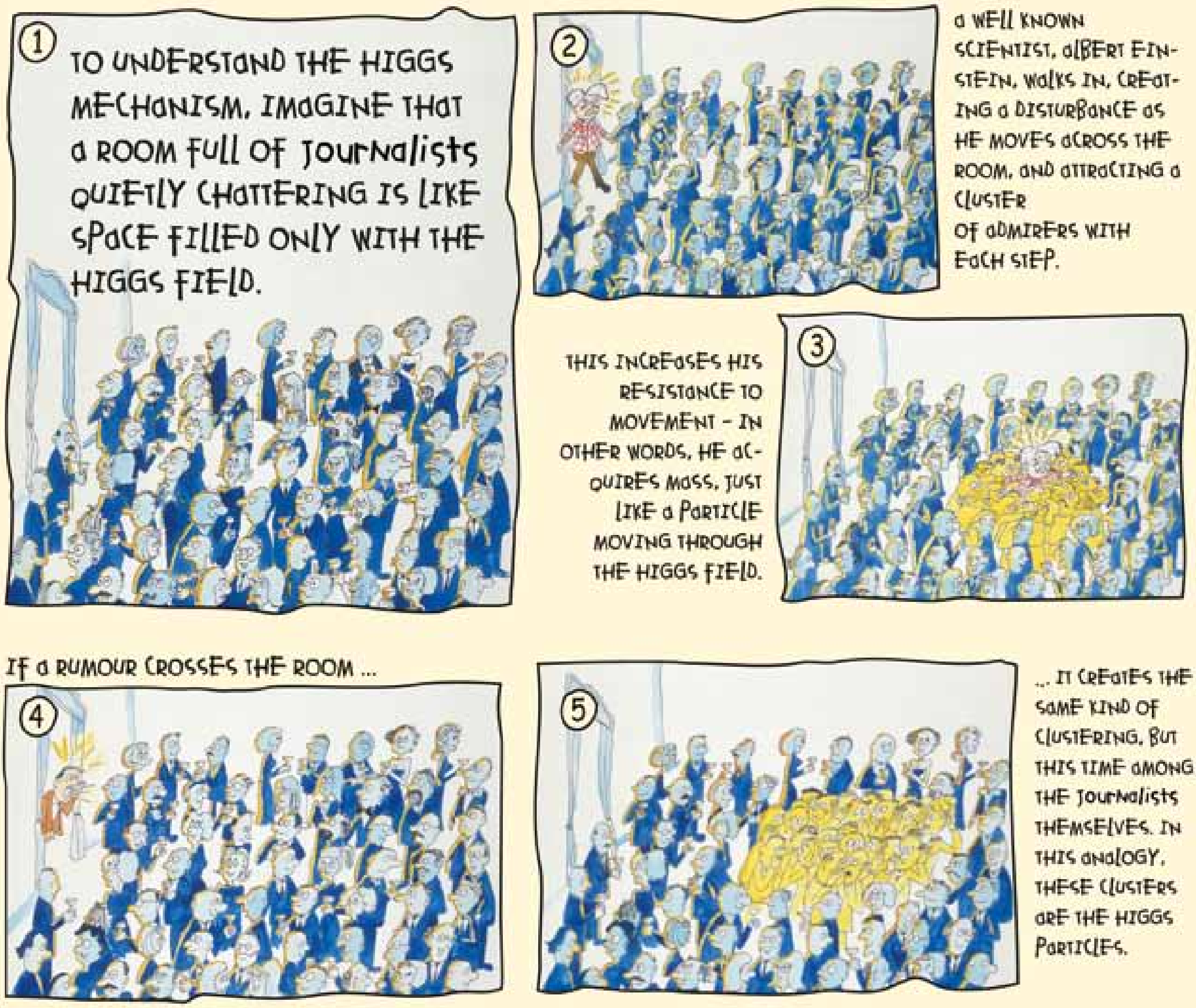


Image courtesy of CERN

Figure 2: The Higgs mechanism

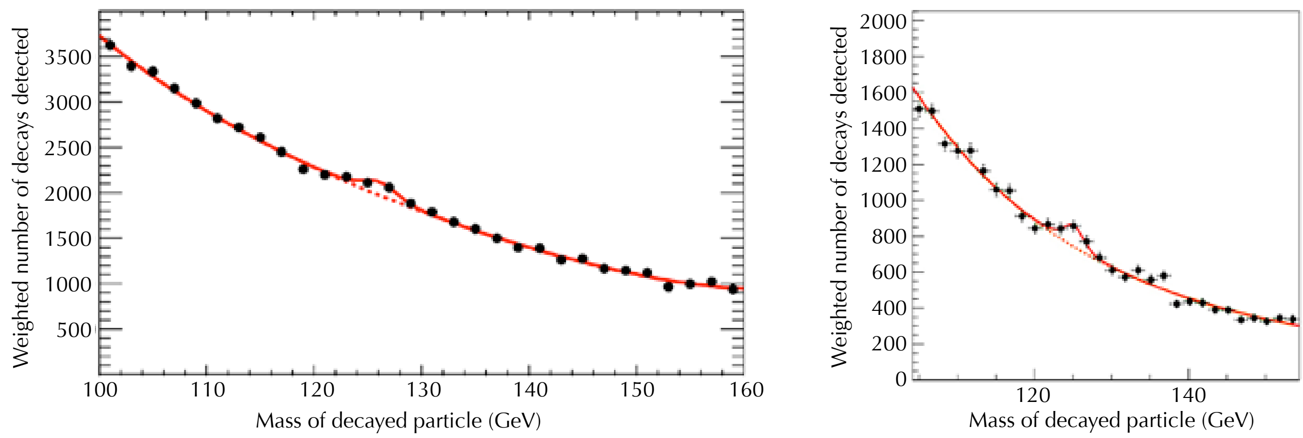
re-enacted: on 4 July 2012, CERN announced the detection by the LHC of a particle that is 'consistent with the Higgs boson', last created about 10^{-12} seconds after the Big Bang. This is momentous news. "We've been looking for this particle for 40 years. I'm not sure if I've digested the news yet, but I think this might be one of the biggest discoveries of recent decades," he tells me.

If the newly detected particle is indeed the Higgs boson, this discovery will validate the standard model of particle physics. The standard model (figure 1, page 7) describes the fundamental particles from which we and every visible thing in the Universe are made, and the forces acting between them. And as Professor Heuer explains, "The Higgs boson was the missing cornerstone of the standard model."

The discovery would also explain why particles – and thus matter – have mass. The search for the Higgs boson began in the 1960s, when a group of physicists, including Peter Higgs, postulated what is now known as the Higgs field. Immediately after the Big Bang, they believed, particles had no mass but rapidly acquired it by interacting with this field; the more the particles interacted with the Higgs field, the more massive they became.

"Imagine that the Higgs field is a party of journalists, equally distributed in the room," says Professor Heuer. "I can pass through the room mass-less – with the velocity of light – because they don't know me. If someone well known enters, the journalists cluster around that person: the person's velocity is limited and he or she acquires mass. The better known that person is, the more the journalists cluster around, and the more massive that person becomes. This is how a

Images courtesy of CERN



Results obtained from the ATLAS (left) and CMS (right) experiments, showing the (weighted) number of decays detected at each particle mass. The gap between the dotted and solid red lines shows the deviation from the expected results, representing the decay of the new particle.

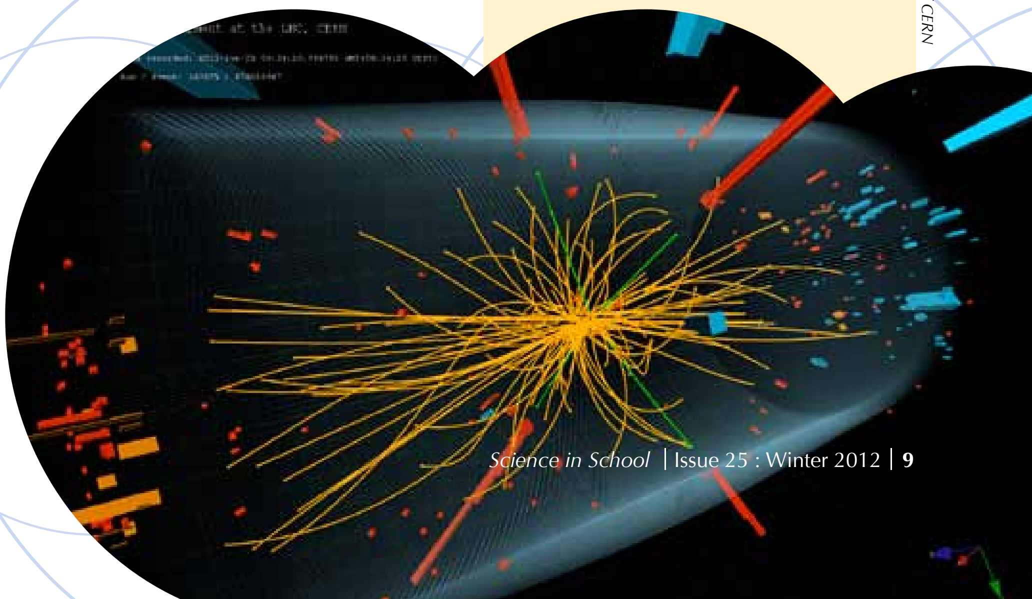
particle acquires mass from the Higgs field." See figure 2, page 8.

But where does the Higgs boson come in? By definition, bosons are particles with an internal angular momentum – known as *spin* – corresponding to an integer multiple of the Planck constant (e.g. 0, 1 or 2). Some bosons are force particles, through which matter particles interact with each other. For example, a photon is a boson that carries the electromagnetic force; a graviton is a boson that carries the gravitational force. The Higgs boson, however, is postulated to be different: it is the result of the Higgs field interacting with itself (figure 2, page 8). "Suppose I open the door to the journalists' party and whisper a rumour into the room. The journalists will be curious – 'what did he say?' That's the journalists interacting among themselves – or the self-interaction of the Higgs field: that is a Higgs boson."

The only problem with the Higgs boson was that nobody knew if it actually existed. Over the years, larger and larger particle accelerators have been built to look for it, capable of colliding particles with higher and higher energies. This enabled physicists to create more and more massive particles, but there was still no sign of the Higgs boson. Did it not exist after all, or did it just require a still more powerful accelerator to detect it? The new particle may well have answered that question.

So how did the CERN scientists actually detect this new particle? The signal they were looking for was the decay of the Higgs boson. However, the scientists needed to be able to distinguish the decay pattern of the Higgs boson from the decay signals of the many, many other particles created in the LHC. As Professor Heuer jokes, "It's like looking for one type of snowflake by taking photos of it against a background of a snowstorm. Very difficult."

One promising signal to look for was the decay of the Higgs boson into two photons, specifically two high-energy photons. When two photons are detected originating from the same spot, they may be the result of a Higgs boson decaying. On the other hand,



A computer-generated image of data from one of the many collisions that was used to search for the Higgs boson. "It's not looking for a needle in a haystack: this is looking for a needle in millions of haystacks, with the slight problem that the haystacks also consist of needles and we have to find one needle with a very slight difference from in among many, many other needles," Professor Heuer explains.

Image courtesy of CERN

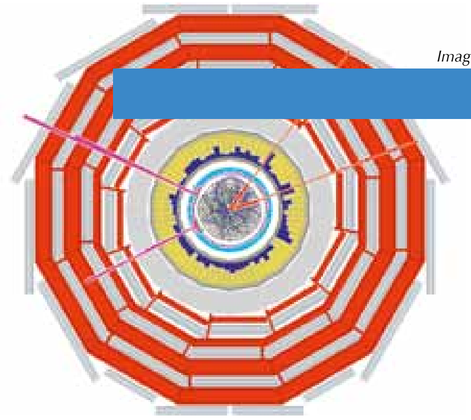


Image courtesy of CERN

they may be part of the background noise of other particle collisions and decays occurring in the LHC. So how do the scientists distinguish the two?

The answer is that they cannot, in any one case, tell whether the photons originate from a Higgs boson or from the decay of some other particle, but they can use statistical analysis to test whether the *number* of decays detected is what they would expect. For this, they construct a *null hypothesis* – in this case, that the Higgs particle does not exist – and predict what they would find if the null hypothesis were true. If more decays were detected than expected, this would indicate the existence of the Higgs boson.

This was precisely what two of the LHC experiments, ATLAS and CMS, found in July 2011: above the smooth curve of the expected results, there was a deviation representing more decays than expected. Importantly, both experiments found this deviation at the same point – representing the decay of particles with a mass of 126 GeV – and the deviation had the same magnitude – representing the same number of 'extra' decays in the accelerator. The question was, were these deviations statistically significant? For new discoveries in particle physics, the bar for statistical significance is set very high: at five sigma, which represents about a one in 3.5 million chance of detecting more decays than expected by chance alone, even if the null hypothesis were true[w1].

The initial data in July 2011 certainly looked promising, but offered nowhere near this level of certainty. Over the following year, however, the two LHC experiments gathered more and more data, all pointing in the same direction: there were more two-photon events with a mass of 126 GeV than would be expected if there were no Higgs boson. Finally, on 4 July 2012, the five-sigma threshold was crossed and the CERN scientists were confident enough to announce to the world that they had indeed detected 'a particle consistent with the Higgs boson'.

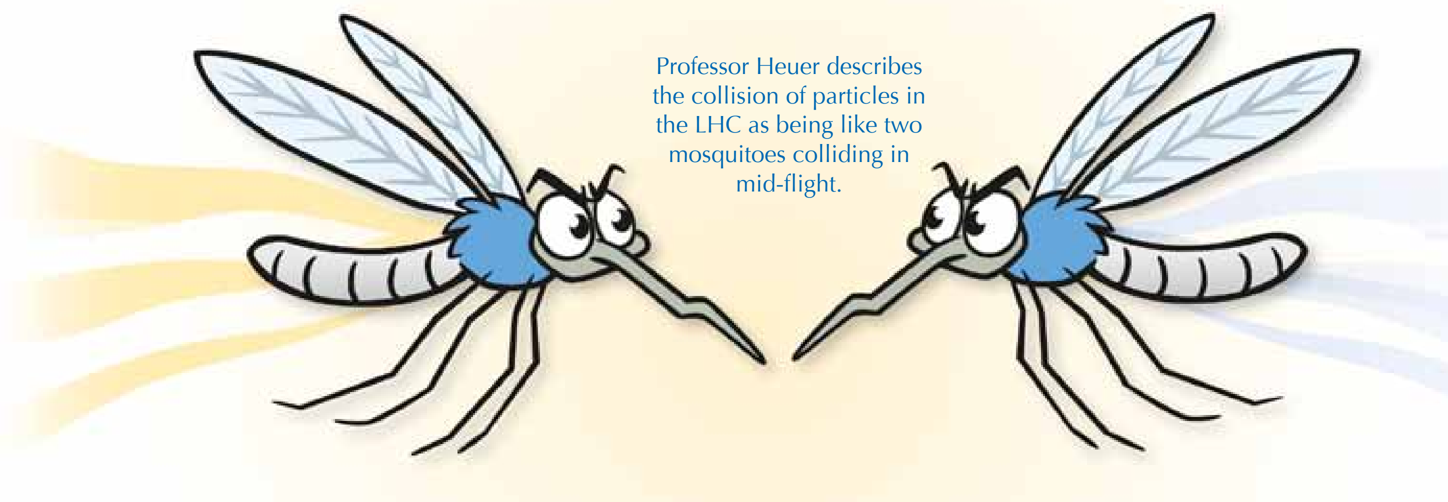
For most of us, despite previous tentative statements from CERN, this announcement came quite unexpectedly. For Professor Heuer, in contrast, the excitement had been building up over months, but the step-by-step revelation of the discovery did not reduce its impact one bit. "The discovery is the most exciting moment of my career, because we are writing a little bit of history."

So how much do we actually know about this new particle? "We know it's a new particle and we know it's a boson. It's the heaviest boson ever found, and it looks like the Higgs boson. However, scientists can be very cautious. As a layman, I would say 'we've found the Higgs boson'. As a scientist, I have to ask 'what have we found?'"

The next step, therefore, is to measure the properties of this particle, including its spin. All previously known bosons are particles with spin 1, for example photons. They are associated with vector fields: the electromagnetic field, for instance, is a vector field that has both a direction and a strength. As a result, the photon is moved in a particular direction: it has spin. The Higgs boson, however, is postulated to be different – it is associated with a scalar field, the Higgs field, and that means it has spin 0.

"If you swim in a river, the force that the water exerts on you will depend on which direction you swim in. That would be a vector field. If, in contrast, you are in a swimming pool, the force that the water exerts on you will be the same whichever direction you swim in. That's a scalar field."

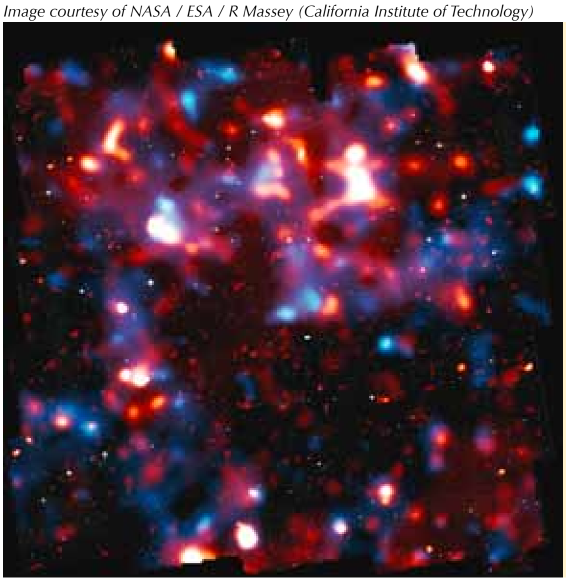
It's also important to measure the new particle's mass more accurately. "Instead of being *the* Higgs boson, it could be *a* Higgs boson. The standard model predicts only one, but supersymmetry – an extension of the standard model (as explained in Landua & Rau, 2008) – predicts at least five. And the lowest-mass Higgs boson predicted by supersymmetry is very similar in mass to that predicted by the standard model. That makes it difficult to distinguish the two; we need



Professor Heuer describes the collision of particles in the LHC as being like two mosquitoes colliding in mid-flight.

Image courtesy of ARTPUPPY / iStockphoto

Image courtesy of NASA / ESA / R Massey (California Institute of Technology)



This map compares the distribution of 'normal' matter, traced via hot gas, seen by the space telescope XMM-Newton (in red) and stars and galaxies observed with the Hubble Space Telescope (in grey), to the distribution of the invisible dark matter (in blue), which has been inferred from the gravitational lensing effect. The map demonstrates how 'normal' matter across the Universe follows the structure of an underlying 'scaffolding' of dark matter.

more measurements." To this end, the LHC will collect data from as many collision events as possible before February 2013, when it will be closed until the end of 2014 to refit it for still higher energy collisions, enabling it to create and detect even heavier particles.

So if the measurements over the next few months show the new particle to be the (or a) Higgs boson, then the standard model would be validated, proving the existence of the Higgs field, and thus confirming the mechanism by which particles acquire mass. But what if the newly discovered boson turns out *not* to be a Higgs boson? "If it's slightly different to what we expected, it could introduce physics beyond the standard model."

Whatever the outcome of the measurements on the new particle, once the LHC is reopened, it will turn its focus beyond the standard model, which describes only the visible Universe – thought to be no more than 4-5% of the total energy balance of the Universe. As Professor Heuer points out, "The standard model leaves many questions open. For example, it doesn't tell us what happened to the antimatter that existed at the beginning of the Universe, nor does it tell us in how many space or time dimensions we are living. And it casts not the faintest light on what dark matter or dark energy is."

Of the dark 95% of the Universe that is not addressed by the standard model, 25% is thought to be dark matter. "When we compare that to the 5% that comprises the visible Universe, it's obvious that dark matter must have played a dominant role in shaping the early Universe. Astronomers can tell us how it has shaped the Universe, but only particle accelerators are likely to be able to produce dark matter in the laboratory and help us understand exactly what it is. Is dark matter composed of a single kind of particle or is it rich and varied like the normal world?" One potential answer involves supersymmetry, and after refurbishment, the LHC will be powerful enough to create and detect some of the very massive particles that supersymmetry would predict.

The other three quarters of the dark Universe is dark energy, thought to drive the Universe apart. Professor Heuer believes that the LHC and its investigation of the Higgs boson could be important here too. "The Higgs field is scalar, as is dark energy. They are not the same, but studying the Higgs field might tell us a lot about dark energy."

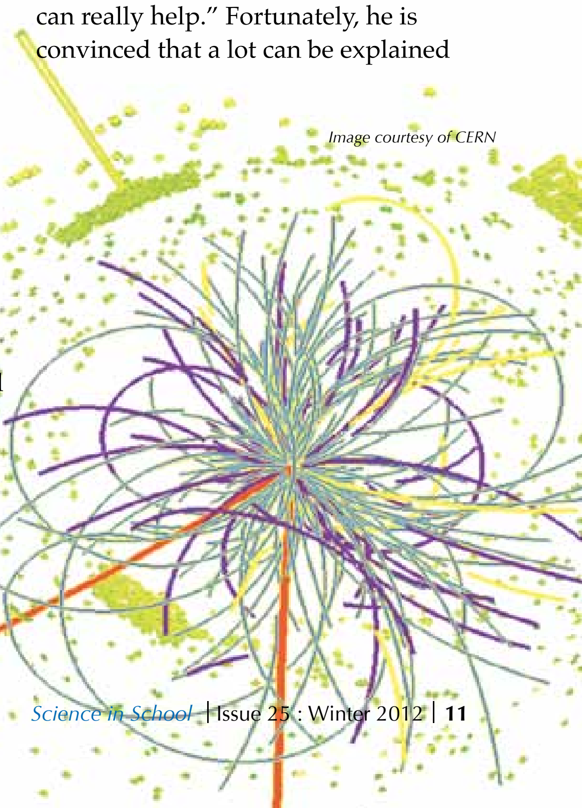
In short, "So far, we know very little about dark matter and we know essentially nothing about dark energy, but I think that, with the LHC, we are about to enter the dark Universe."

Throughout our interview, it's been obvious just how much Professor Heuer relishes bringing physics alive for non-specialists. He's clearly very good at it, too: "I gave a public lecture in the Royal Society in London in which I presented the LHC, the science around it and the fascination of the dark Universe. A day later, I received an email from a 14-year-old boy who wrote that he was doing very well in maths and physics and that he wanted to start work at CERN in 2018."

The difficulty, as Professor Heuer acknowledges, is not rousing young people's enthusiasm for science, but maintaining it. To this end, he emphasises the importance of "explaining new developments and important topics in science, for example using *Science in School*". Professor Heuer is clearly a fan.

As we close our interview, I ask if Professor Heuer has any further advice for our readers. "Enthusing students within the current school curricula can be very difficult – if you start with 19^{th}-century mechanics, you will lose 99% of them immediately. Introducing modern science, however, can really help." Fortunately, he is convinced that a lot can be explained

Image courtesy of CERN



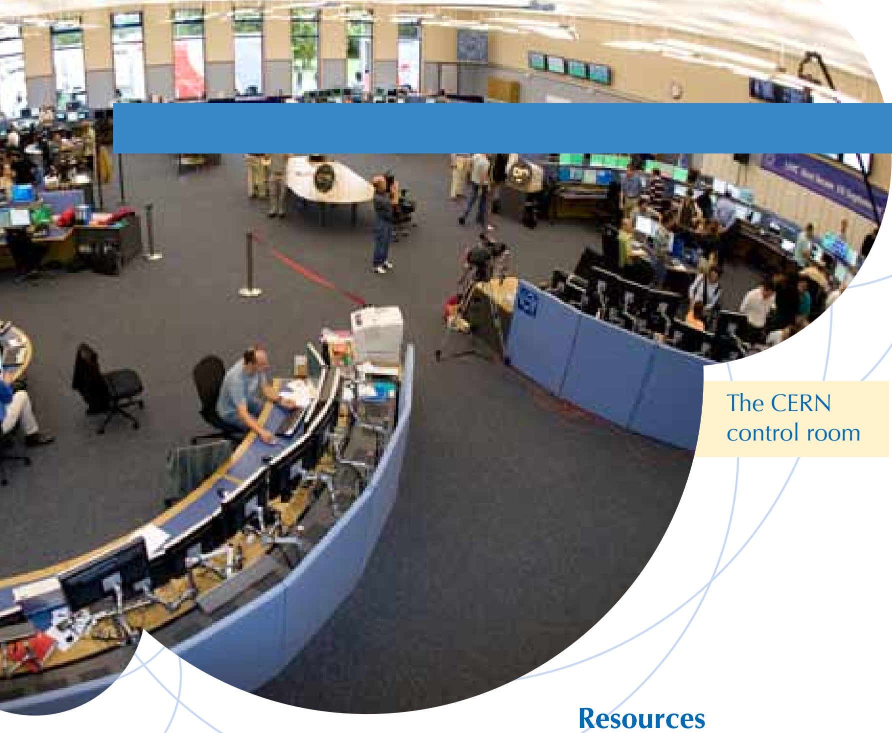


Image courtesy of CERN

The CERN control room

without mathematics. "For example, I explained the Higgs mechanism by talking about journalists. Of course, to fully understand it and explain it, your students would need to use mathematics, but they can always look that up. What they need to understand is the logic."

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Web reference

w1 – To find out more about the statistical analysis, see '5 sigma – what's that?' in the Scientific American blog. See: http://blogs.scientificamerican.com (search for '5 sigma') or use the direct link: http://tinyurl.com/5sigmap

Resources

To learn more about the LHC shutdown, planned for 2013-14, see:

Brewster S (2012) Scientists already planning for LHC long shutdown. *Symmetry* **September 2012**. www.symmetrymagazine.org or via the direct link: http://tinyurl.com/9oo3erw

To learn more about the research leading to the discovery of the new particle, see:

Baggott J (2012) Higgs: The invention and discovery of the 'God Particle'. Oxford, UK: Oxford University Press. ISBN: 9780199603497

For an explanation of the LHC in layperson's terms, see:

Ginter P, Franzobel, Heuer RD (2011) LHC: Large Hadron Collider. Paris, France: UNESCO. ISBN: 9783901753282

Watch Rolf Heuer's lecture 'The search for a deeper understanding of our Universe at the Large Hadron Collider: the world's largest particle accelerator', given at the Euroscience Open Forum in Dublin, on 14 July 2012, just 10 days after the announcement that a boson compatible with the Higgs boson had been discovered at CERN. See: www.livestream.com/esof2012 or use the direct link: http://tinyurl.com/95xmwf2

To learn more about the next generation of particle accelerators that will study the Higgs boson in more detail, see:

Chalmers M (2012) After the Higgs: the new particle landscape. *Nature* **488**: 572-575. doi:10.1038/488572a

Download the article free of charge on the *Science in School* website (www.scienceinschool.org/2012/issue25/heuer#resources), or subscribe to *Nature* today: www.nature.com/subscribe

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

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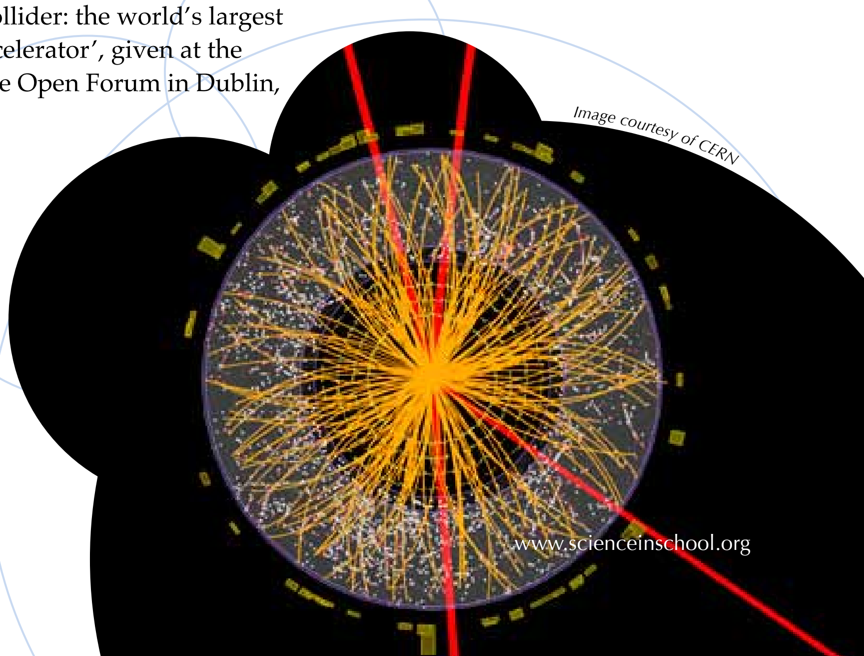
Image courtesy of CERN

Sloppy fishing: when meiosis goes wrong

Why does meiosis so often go wrong? And what are the consequences?

Image courtesy of QUOI Media; image source: Flickr

Fishing with magnets

By Sonia Furtado Neves, EMBL

At a village fair, past the bumper cars and candy-floss, a child's forehead creases in concentration. He's doing his best to snag a wooden fish out of a plastic pond, using the magnet on the end of his fishing rod. Freeze the scene, rewind all the way through the child's development, past the point when the sperm fertilised the egg, to when the egg cell itself was formed, and you'll find a similar fishing game in action. The difference, as scientists at the European Molecular Biology Laboratory (EMBL; see box on page 15) have found, is that magnet-wielding children are probably more successful fishermen than the egg cell's machinery (Kitajima et al., 2011).

As an egg cell, or oocyte, matures inside a woman's ovary, it undergoes a type of cell division called meiosis, in which the pairs of chromosomes inside it are lined up and fished apart, and half of them are expelled. The chromosomes are brought together from all over the cell (Mori et al., 2011) and fished apart by protein rods called microtubules. Like the child's rod pulling a toy fish by its magnet, a

- Biology
- Cytology
- Genetics
- Reproduction
- Ages 15+

This article is about new scientific inputs concerning the understanding of cell division mechanisms, namely the attachment of microtubules to chromosomes during mitosis and meiosis.

The level of detail in this article makes it particularly useful for upper-secondary biology classes (ages 15+), for topics such as cytology (mitosis and meiosis), genetics (the causes and implications of chromosomal abnormalities) and reproduction (gametogenesis and infertility).

The article can also be used to initiate wider discussions about both the benefits of modelling biological phenomena (models can help us to understand processes) and the risks. For example, in the majority of text-books describing mitosis and meiosis, chromosomes are represented as large structures. This can lead students to believe that chromosomes are easily observable in any type of cells. As is clear from the article, however, this is not the case.

Finally, the article illustrates how the efforts made in one research group might benefit other research areas, as well as highlighting the synergistic relationship between science and technology.

Betina da Silva Lopes, Portugal

REVIEW

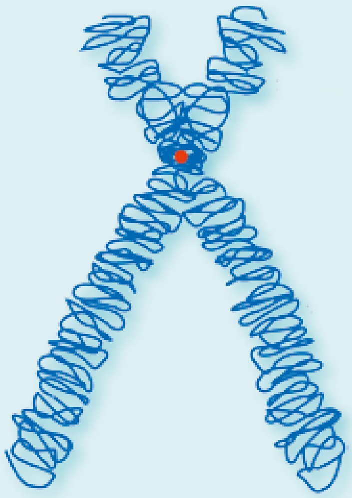

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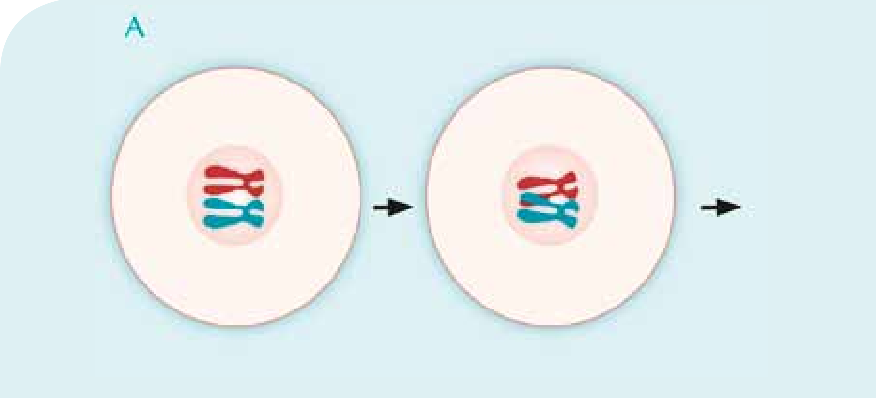
Diagram of a chromosome. The centromere (red dot) is the site of assembly of the kinetochore.



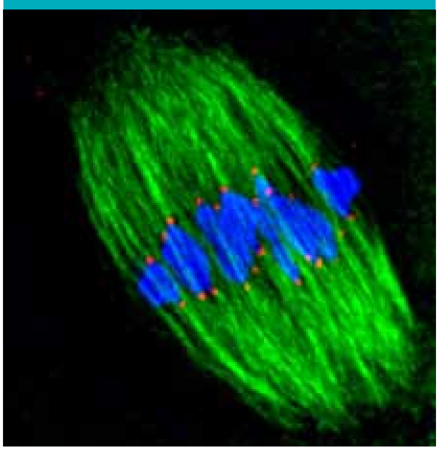
The main events of meiosis during cell maturation. A: During the first five months of development of a female human embryo, all its potential future egg cells are formed. In each of these cells, after DNA duplication, homologous chromosomes exchange genetic material during crossing over. Meiosis is then halted until ovulation, and most of the potential egg cells die off again. B: Between puberty and menopause, during each monthly cycle, a few potential egg cells progress further during the stages of meiosis, but only one at a time eventually

microtubule catches a chromosome by its kinetochore – a cluster of protein and genetic material at the centre of the chromosome's X shape.

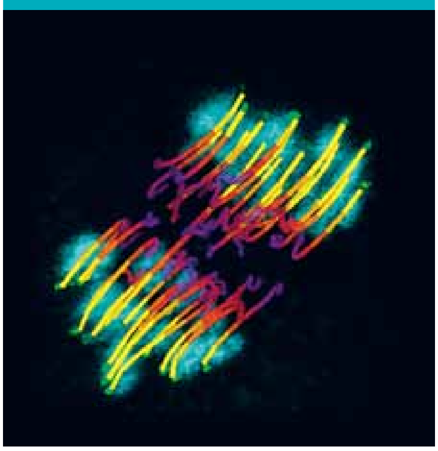
By examining mouse egg cells under the microscope, EMBL scientist Tomoya (Tomo) Kitajima was the first to track the movements of all of an egg cell's kinetochores during the whole of cell division – all 10 hours of it. "We were able, for the first time, to keep track of all the kinetochores throughout cell division – so there's not a single time point where it's ambiguous where that part of the chromosome is – and that's really a breakthrough in the field, achieving this in these very large and light-sensitive cells," says Jan Ellenberg, who heads the research group.

Tomo used software that had been previously developed in Jan's lab, which allowed him to programme a laser scanning microscope to find the chromosomes in the egg cell's vast inner space, and then film them during cell division. "The oocyte is a big cell, but the chromosomes sit in only a small part of that cell, and that's what we were interested in. So basically we just made our microscopes smart enough that they can recognise where the chromosomes are and then zoom

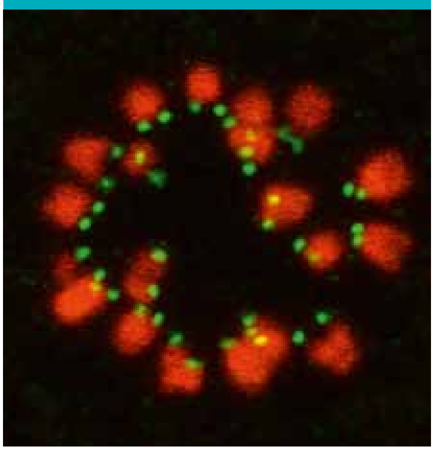
Chromosomes (blue) lined up in preparation for separation. Kinetochores (red) attach chromosomes to the cell's microtubules (green).



Mapping movement: the coloured lines chart the movement (purple to yellow) of kinetochores (green dots) as microtubules hook onto them to separate the chromosomes (cyan).

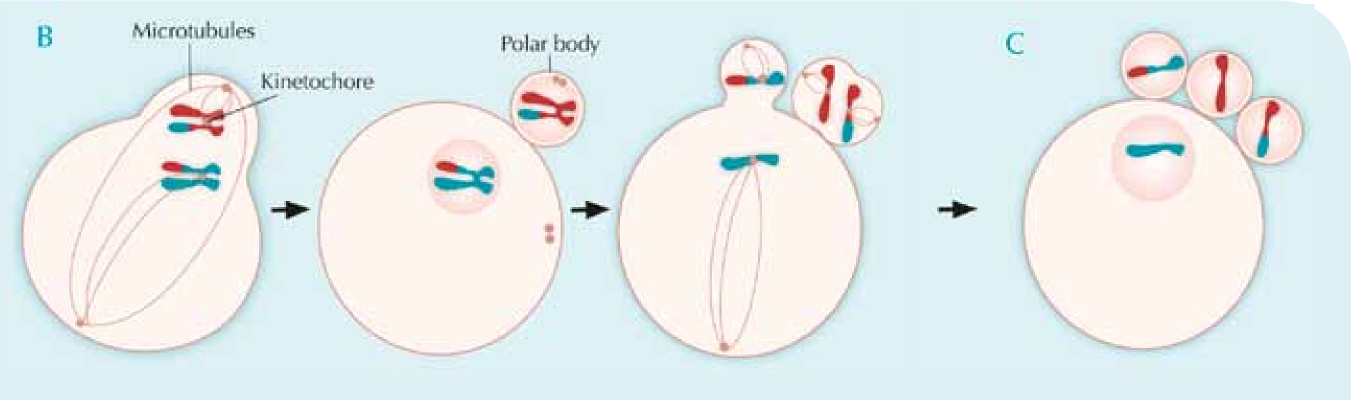


Cheating microtubules: before they start attaching themselves to kinetochores (green), microtubules nudge chromosomes (red) into a ring around the centre of the spindle.



Images courtesy of Tomoya Kitajima, EMBL

Image courtesy of Nicola Graf



completes the process. Homologous chromosomes line up at the primary egg cell's equator and are then fished apart by microtubules. The primary egg cell divides into a secondary egg cell and a polar body.

Now paired chromatids line up at the equators of both the polar body and the egg cell, and at the time of ovulation, microtubules attach to them. Meiosis is arrested here until fertilisation.

C: If fertilisation happens, the paired chromatids are pulled apart, moving to opposite poles of the cells. The polar body divides in two, the secondary egg cell divides into a third polar body and a mature egg cell, and meiosis is complete. Each of the four resulting daughter cells has a different genetic makeup.

The genetic material of the polar bodies is discarded, while that of the mature egg cell is joined by the genetic material of the fertilising sperm, to start the development of a new embryo.

in, in space and time, just on that region," Jan explains. By focusing the microscope only on the part of the cell where the chromosomes are, Tomo was able to obtain high-resolution images at short intervals of only one and a half minutes, which gave him a very clear picture of the process. And, because the microscope was only firing light at that small region of the oocyte, it did less damage to the cell, which enabled the scientists to keep up the imaging for the 10 hours of cell division (for more on smart microscopy, see box on page 17).

Back at the fishing pond, tempers can flare and voices rise in shrill accusation: "That's cheating! You can't push the fish with your rod!" Thanks to Jan and Tomo's work, the accused child could argue, in his defence, that his cells were already 'cheating' like this before he was even born. When the EMBL scientists analysed the videos, they found that, before microtubules attach to kinetochores, they nudge chromosomes into a favourable position, like a child repositioning a fish with the end of his rod. The microtubules nudge the chromosome arms, arranging the chromosomes in a ring from which they can then fish them out more easily.

"But even with this pre-positioning, it still doesn't work very well," says Jan. "We saw that 90 % of kinetochore connections were initially wrongly established, and the microtubules had to release the chromosome and try again – on average, this had to be done three times per chromosome."

Scientists in the USA have now shown that the same 'cheating' also happens in the other type of cell division, which our cells undergo when we grow or when tissues such as skin regenerate (Magidson et al., 2011). In this second type of cell division, called mitosis, a cell divides into two daughter cells, each with the same amount of genetic material as the 'mother cell', instead of half the genetic material as in meiosis. But Jan and Tomo's findings highlight that the fishing of chromosomes involves much more error in the egg cell's meiosis than in mitosis. The greater degree of error in meiosis

More about EMBL

EIROforum

The European Molecular Biology Laboratory (EMBL)[w1] 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.

EMBL is a member of EIROforum[w2], the publisher of *Science in School*.

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could, the scientists believe, be due to a fundamental difference in how microtubules fish chromosomes apart in the two types of cell division.

During mitosis, the microtubule rods start forming at two opposite points in the cell and come together in a lemon-shaped structure – the spindle – that then pulls each chromosome in a pair to one side, or pole. But in meiosis, as Jan's group discovered a few years ago (Schuh & Ellenberg, 2007), the spindle's microtubules converge from as many as 80 different points at first, and only later arrange themselves into a two-poled structure. "So when microtubules are first attaching to chromosomes, it's hard to know if they're going to end up pulling them in opposite directions or not," Jan explains. This, along with the fact that the egg cell is a much larger expanse across which microtubules have to find and drag chromosomes – a human egg cell is more than four times larger than a skin cell – could explain why chromosome fishing is so much more error-prone in egg-cell division.

These findings also provide scientists with a more concrete place to look when studying female infertility and conditions like Down syndrome, which largely stem from egg cells with an abnormal number of chromosomes. By showing that such errors most likely occur because microtubules fail to make the right connections to separate chromosomes properly, Tomo and Jan have provided a focus for future studies. In fact, Tomo is now going on to study why this trial-and-error process is even more error-prone in older egg cells. If he and others can pinpoint where the error-correction mechanisms fail in older cells, it could one day be a starting point for medical procedures to help microtubules improve their fishing technique. Perhaps the secret to countering age-related infertility is to make microtubules as successful at fishing as children are with their toy magnets.

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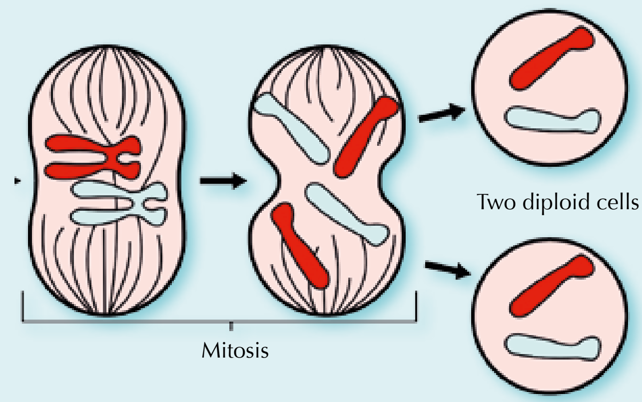

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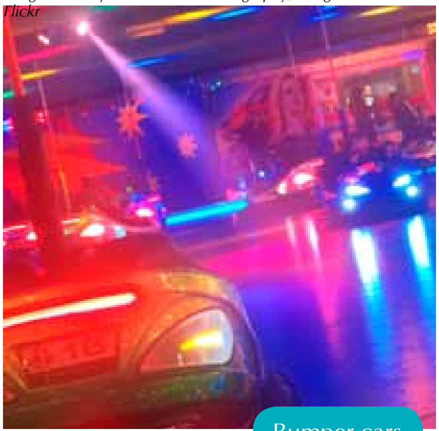
Mitosis: after the cell has replicated its DNA, the chromosomes line up at the cell's equator. Microtubules attach to the kinetochores of sister chromatids and fish them apart. After mitosis, the cell divides. The two resulting daughter cells are genetically identical to the parent cell.

Image courtesy of D Petzold Photography; image source: Flickr



Bumper cars

A freely available and simply written explanation of this research is available in the EMBL annual report:

EMBL (2012) Neat nets. In *EMBL Annual Report 2011/2012* pp 86-88. Heidelberg, Germany: European Molecular Biology Laboratory. www.embl.de/aboutus/communication_outreach/publications

Schuh M, Ellenberg J (2007) Self-organization of MTOCs replaces centrosome function during acentrosomal spindle assembly in live mouse oocytes. *Cell* **130(3)**: 484-98. doi: 10.1016/j.cell.2007.06.025

A freely available and simply written explanation of this research is available in the EMBL annual report:

EMBL (2008) Push me, pull you. In *EMBL Annual Report 2007/2008* pp 46-50. Heidelberg, Germany: European Molecular Biology Laboratory. www.embl.de/aboutus/communication_outreach/publications

BACKGROUND

Making microscopes smarter

The software that Tomo used to find and film chromosomes throughout cell division was a prelude of things to come. Since then, in collaboration with another team at EMBL led by Rainer Pepperkok, Jan's group has developed a more complex programme, capable of even greater feats of automation. Called Micropilot, the new software analyses low-resolution images taken by a microscope and finds not just chromosomes but whatever structure the scientist has taught it to look for.

Once Micropilot has identified the cell or structure that the scientists are interested in, it automatically instructs the microscope to start an experiment. This can be as simple as recording high-resolution time-lapse videos or as complex as using lasers to interfere with fluorescently tagged proteins and recording the results. The software is a boon to systems biology studies, as it generates more data at a faster pace. Thanks to its high throughput, Micropilot can easily and quickly generate enough data to obtain statistically reliable results, allowing scientists to probe the role of hundreds of different proteins in a particular biological process.

Web references

w1 – For more information about EMBL, see the EMBL website: www.embl.org

w2 – EIROforum is a collaboration between eight of Europe's largest inter-governmental scientific research organisations, which combine their resources, facilities and expertise to support European science in reaching its full potential. As part of its education and outreach activities, EIROforum publishes *Science in School*. To learn more, see: www.eiroforum.org

Resources

Watch a video of microtubules nudging the chromosomes into position. See: http://youtu.be/LH9wI7_B-4g

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

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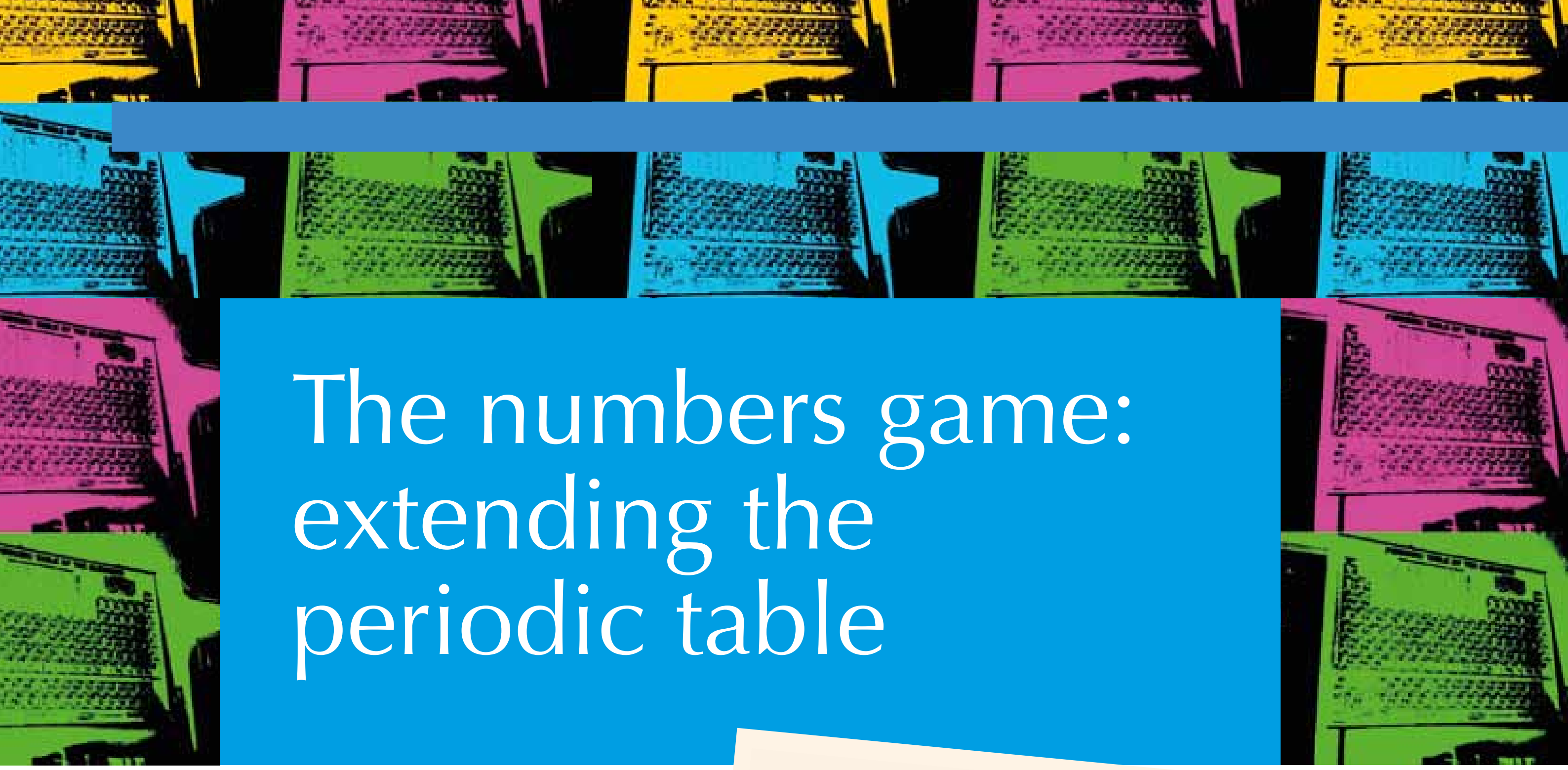
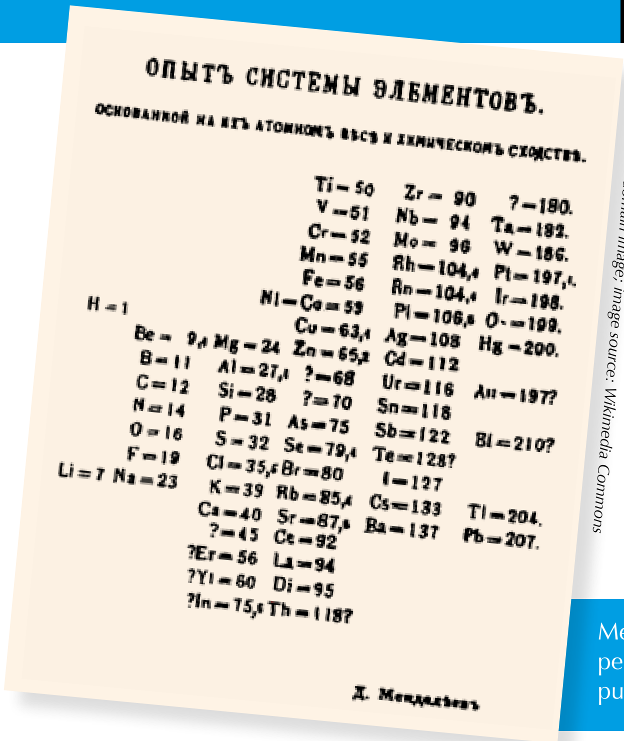


The numbers game: extending the periodic table

Image courtesy of Jim Mikulak; image source: Wikimedia Commons



ОПЫТЪ СИСТЕМЫ ЭЛЕМЕНТОВЪ.

ОСНОВАННОЙ НА ИХЪ АТОМНОМЪ ВѢСѢ И ХИМИЧЕСКОМЪ СХОДСТВѢ.

Ti=50 Zr=90 ?=180.
V=51 Nb=94 Ta=182.
Cr=52 Mo=96 W=186.
Mn=55 Rh=104,4 Pt=197,4.
Fe=56 Ru=104,4 Ir=198.
H=1 Ni=Co=59 Pl=106,6 Os=199.
Cu=63,4 Ag=108 Hg=200.
Be=9,4 Mg=24 Zn=65,2 Cd=112
B=11 Al=27,4 ?=68 Ur=116 Au=197?
C=12 Si=28 ?=70 Sn=118
N=14 P=31 As=75 Sb=122 Bi=210?
O=16 S=32 Se=79,4 Te=128?
F=19 Cl=35,5 Br=80 I=127
Li=7 Na=23 K=39 Rb=85,4 Cs=133 Tl=204.
Ca=40 Sr=87,6 Ba=137 Pb=207.
?=45 Ce=92
?Er=56 La=94
?Yt=60 Di=95
?In=75,6 Th=118?

Д. Менделѣевъ

Public domain image; image source: Wikimedia Commons

Mendeleevs's periodic table, published in 1869

Until a few centuries ago, people believed that the world was made only of earth, air, water and fire. Since then, scientists have discovered 118 elements and the search is on for element 119.

By Oli Usher

In space-age labs across Europe, researchers are working together to discover new elements. If they succeed, they will join the club of scientists who have rewritten the periodic table.

The Ancient Greeks might not have been right about there being just four elements – earth, air, fire and water – but they were onto something: elements are the ingredients of everything that surrounds us, bound to each other in compounds and mixed together in different proportions. But while compounds exist in kaleidoscopic variety, elements are pretty simple, and there are so far only 118 elements known to science[w1]. Discovering a new one is a big deal.

Atoms, the building blocks of matter, are all made of the same simple components: tiny particles called protons and neutrons, and even tinier electrons orbiting them. The number of protons in an atom – its atomic number – defines what element it is. An atom of oxygen, for example, has eight protons, eight neutrons (usually) and eight electrons, whereas the heaviest elements can have more than a hundred of each.

* * *

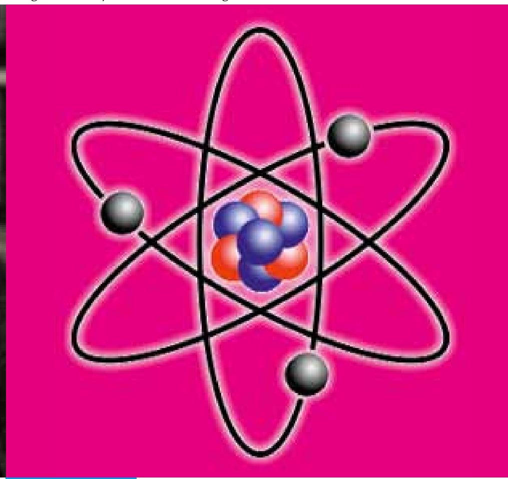
The Russian chemist Dmitri Mendeleev knew none of this when, in 1869, he arranged the elements into a table based on their atomic weight. He quickly saw patterns emerge: in particular, columns grouped together elements with startlingly similar properties. For example, potassium, rubidium and caesium, three metals that react violently with water, are stacked one above the other.

At first, Mendeleev's table had a problem: it was full of gaps. Between zinc and arsenic, for instance, there seemed to be two elements missing.

Public domain image; image source: Wikimedia Commons

Dmitri Mendeleev

Image courtesy of Halfdan; image source: Wikimedia Commons



Lithium

Image courtesy of Jim Mikulak; image source: Wikimedia Commons

Chemistry

But he boldly predicted that these holes would be filled with newly discovered elements, and used his table to forecast what their properties would be. And he was right: the gap was soon filled by gallium and germanium.

With a few refinements and modifications, the table that Mendeleev created became what we use to this day: the periodic table[w1], something so basic that we never stop to think that it had to be invented.

In the following decades, chemists raced to fill the remaining gaps. Along the way, they also discovered why the periodic table works: the rows and columns mirror the way electrons are arranged in their orbits in different elements, and the electrons in turn dictate many of the elements' properties.

In 1945, the last gap in the table was filled. Had science at last discovered all the elements? Curiously, the answer is both yes and no. All the elements that exist naturally on Earth were known. But – and it's a big but – there was nothing to say that new elements could not be created artificially, tagged onto the end of the periodic table beyond element number 92, uranium.

So with the development of atomic research in the 1940s, just as the last holes in the table were being filled, a trickle of new lab-created elements started to join the end of the periodic table, bringing us up to the 118 elements known today. Nobody knows how many are yet to be discovered.

What is known, though, is that creating new elements is getting harder. Today, you need the most advanced labs in the world if you are to stand a chance: the easy ones have all been found.

* * *

Known by the tongue-twisting name ununennium, the predicted element that an international team is focusing on today is likely to be the hardest yet.

REVIEW

- **Chemistry**
- **Physics**
- **History of science**
- **Ages 14+**

After a brief summary of the creation and evolution of the periodic table, this article introduces current research to discover new elements. It could be used in chemistry and physics lessons, particularly when studying nuclear chemistry, atomic physics or the history of science. The article could also be used to discuss the scientific method, the velocity of scientific progress, the difficulties that researchers encounter and the usefulness of basic research.

History of science is a topic rarely seen in secondary school and it can be very useful to make science more appealing to students, especially to those more interested in the humanities. This article could be used to demonstrate the links between the sciences and humanities.

Potential comprehension questions include:

1. According to Ancient Greeks, how many elements were there?
2. What is the atomic number?
3. How many elements does the periodic table currently comprise?
4. Describe the method used by the team to try to discover new elements. What are the problems associated with this method?

Mireia Güell Serra, Spain

Image courtesy of G Otto / GSI

Creating ununennium: team members Professor Christoph Düllmann and Dr Alexander Yakushev in front of the experimental setup. With the aid of a particle accelerator, titanium ions are accelerated to close to the speed of light, after which they pass along the silver tube on the left and smash into a target made of berkelium (in the yellow-striped box in the centre). Using three magnets (red boxes on the right), the resulting ununennium ions are separated from all other particles, after which they enter the detector, where their decay can be registered.

To make element 119, scientists plan to fire an intense beam of titanium atoms into berkelium.

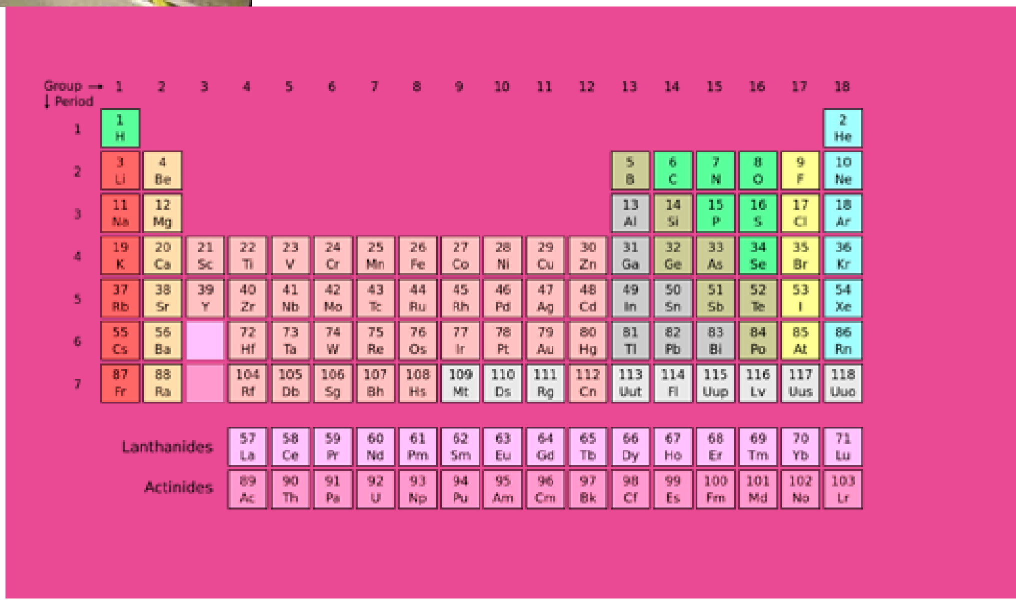


Image courtesy of NikNaks; image source: Wikimedia Commons

The team, co-ordinated by the GSI Helmholtz Centre for Heavy Ion Research (*GSI Helmholtzzentrum für Schwerionenforschung*), in Germany, and involving about 20 research centres from around the world, plans to create element 119. Their method sounds deceptively simple: fire a beam of titanium atoms (atomic number 22) into some berkelium (97). Add the two together and – eureka! – you get 119.

Of course it's not so easy.

First of all, highly radioactive berkelium doesn't exist in nature either: it first has to be created in a nuclear reactor. Moreover, it's ludicrously hard to actually smash the elements together.

"It is extremely difficult to create intense titanium beams. To accomplish this, we have secrets that we will not share with others," explains Professor Jon Petter Omtvedt, one of the team members. "We shall bombard the plate with a beam of five trillion [5 x 10^{12}] titanium atoms per second. [...] The probability of a direct hit [between the atoms] is extremely low. When the atoms collide with each other on rare occasions, they are usually merely shattered or partly destroyed in the collision. However, less than once a month, we will get a complete atom."

That's like winning the lottery jackpot by buying enough tickets to guarantee a win. It's slow and inefficient, but it's a numbers game, and you'll get there eventually.

But there's another problem. All the heavy elements are radioactive: their atoms break down into lighter ones over time, releasing radiation. And the heaviest elements discovered have all been incredibly unstable. Ununoctium (element 118) decomposes within milliseconds of being created; ununennium may be even shorter-lived.

It's not that they're dangerous – the amounts are so tiny that the dose of radiation is safe. But it makes it difficult to study the element you've just created: you can't drop it in a test-tube or heat it in a Bunsen burner flame, because you only ever have a single atom at a time and for just a fraction of a second.

The team's solution is to create the ununennium with the aid of a particle accelerator, then fire it into a detector and look for the tell-tale signs of ununennium nuclei disintegrating – radiation and the atoms that it breaks up into – rather than the ununennium itself.

It's a clever solution, but it leaves one of the team's ambitions out of reach: they would love to be able to study how atoms of these exotic elements react with each other. But that's probably never going to be possible, at least not using any kind of

Image courtesy of stock photos for free.com

Image courtesy of Alchemist-hp; image source: Wikimedia Commons

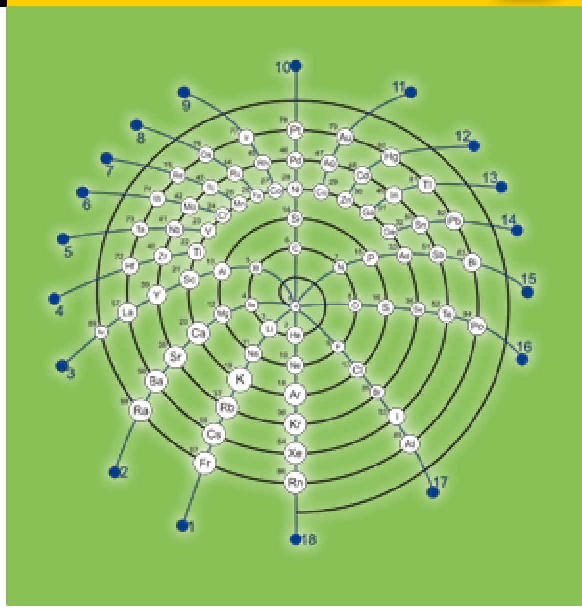


Image courtesy of Shape; image source: Wikimedia Commons

technology we can imagine today.

But if your job is to create new elements for a living, beating lottery jackpot odds along the way, 'impossible' might sound like a challenge....

Acknowledgement

The editors of *Science in School* would like to thank Professor Christoph Düllmann from the GSI Helmholtz Centre for Heavy Ion Research for his help with this article.

Web reference

w1 – The International Union of Pure and Applied Chemistry (IUPAC) is the official body that decides whether an element has been discovered. The IUPAC periodic table includes all elements from 1 to 112, as well as elements 114 and 116. Elements 113, 115, 117 and 118 are not officially recognised by IUPAC, although claims have been made in the scientific literature about the discovery of these elements. The IUPAC periodic table can be downloaded from the IUPAC website (www.iupac.org) or via the direct link: http://tinyurl.com/iupactable

Resources

Two press releases from the University of Oslo, Norway, provide more information on the hunt for ununennium:

Racing to be the first to create the world's heaviest element: www.apollon.uio.no/english/articles/2011/element1.html

The world's most difficult chemical experiment: the struggle to discover the secret of super-heavy elements: www.apollon.uio.no/english/articles/2011/element2.html

The University of Nottingham, UK, has created a website with videos relating to each of the elements in the periodic table. For a review of the website, see:

Walsh M (2012) Review of the Periodic Table of Videos website. *Science in School* **24**. www.scienceinschool.org/2012/issue24/videos

The website of the UK's Royal Society of Chemistry offers an interactive version of the periodic table, with all 118 known elements. Visit: www.rsc.org/periodic-table

If you found this article interesting, you might like to browse all the chemistry-related articles in *Science in School*. See www.scienceinschool.org/chemistry

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Oli Usher is a science writer. He has a postgraduate degree in the history and philosophy of science, has been a journalist and science communicator, and currently works as a public information officer for the NASA / ESA Hubble Space Telescope. He is a co-author of the book *An Element of Controversy: The History of Chlorine in Science, Technology, Medicine and War.*

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

Magnetic science: developing a new surfactant

With the use of detergents and other surfactants on the rise, the resulting pollution is worrying. One answer: surfactants that can be collected and re-used simply by switching a magnetic field on and off.

By Julian Eastoe, Paul Brown, Isabelle Grillo and Tim Harrison

It has been estimated that each person in the EU uses about 10 kg of detergents annually. This includes not only the bars of soap, shampoos, toothpastes, washing powders and household cleaning agents we are familiar with, but also detergent-type compounds found in fuels, pharmaceuticals and even foods and beer. In industry, huge quantities of detergents are used, for example in commercial laundries, in preparing cloth and leather for dyeing, in car washes and for cleaning and sanitising hospitals. Once they have performed their cleaning task, the residues are simply washed away into the sewers and eventually released into the environment. Imagine that instead these residues could be recovered. This article describes some of the latest research into recyclable detergents, and how they can be studied using advanced research methods.

Image courtesy of Roadsidepictures; image source: Flickr

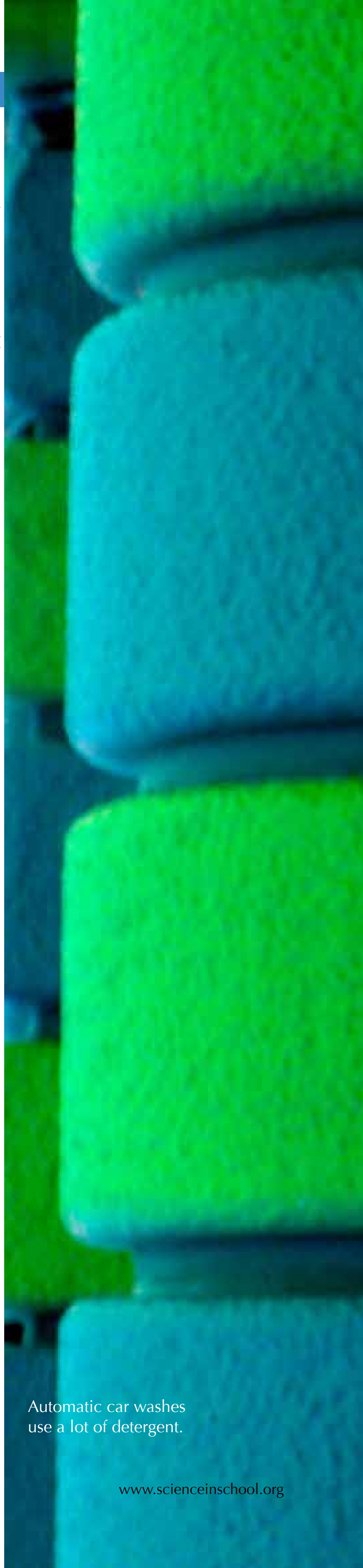

Image courtesy of swisscan; image source: Flickr

Automatic car washes use a lot of detergent.

Detergent residues are washed into the sewers and ultimately released into the environment, where they can be harmful.

Image courtesy of autowitch; image source: Flickr

Toothpaste contains detergents.

Image courtesy of Gustavo (lu7frb); image source: Flickr

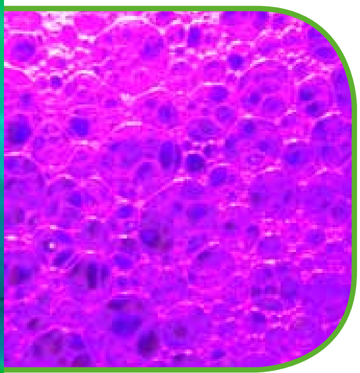

Image courtesy of The Matrix; image source: Flickr

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Image courtesy of GeorgHH; image source: Wikimedia Commons

Soaps, detergents and surfactants

Surfactants are compounds that lower the surface tension of a liquid, making them suitable for a number of applications – such as emulsifiers, foaming agents, wetting agents and dispersants, for example. Surfactants or mixtures of surfactants that are used in cleaning are known as detergents. The simplest and oldest of all detergents is soap, used in Babylon almost 5000 years ago; in fact, soap manufacture is one of the oldest chemical industries.

Sodium dodecanoate (figure 1) demonstrates the general structure for all surfactants: one part of the molecule is hydrophilic, meaning it will be soluble in water as it has a charged 'head', and the rest of the molecule is an oily hydrophobic 'tail'. The ability of a detergent to dissolve in water is due to a balance of intermolecular forces. The head is a negatively charged carboxylate ion able to form hydrogen bonds with water, whereas the hydrophobic tail cannot hydrogen bond because it is a long alkane chain, with no electronegative elements present. This explains why surfactants aggregate in clusters, known as micelles (figure 2, page 24), which are essential for the action of detergent cleaners.

Image courtesy of the University of Bristol

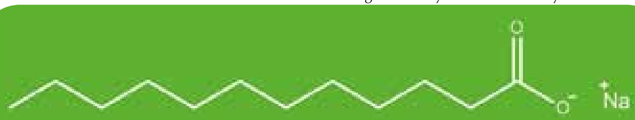


Figure 1: Sodium dodecanoate, $C_{11}H_{23}COO^{-}Na^{+}$, showing the long hydrophobic hydrocarbon tail and the hydrophilic carboxylate head structure

Image courtesy of schoeband; image source: Flickr

The earliest detergent: soap

The two ends of the detergent also behave differently with non-polar stains such as grease. The hydrophobic tails interact with the grease, while the hydrophilic heads attract water molecules through hydrogen bonding. After a little agitation, the grease leaves the material to which it was attached, forming detergent droplets containing grease; the droplet surfaces consist of the water-soluble hydrophilic heads. The grease is therefore removed from the material

Chemistry

Physics

Image courtesy of Mariana Ruiz Villarreal; image source: Wikimedia Commons

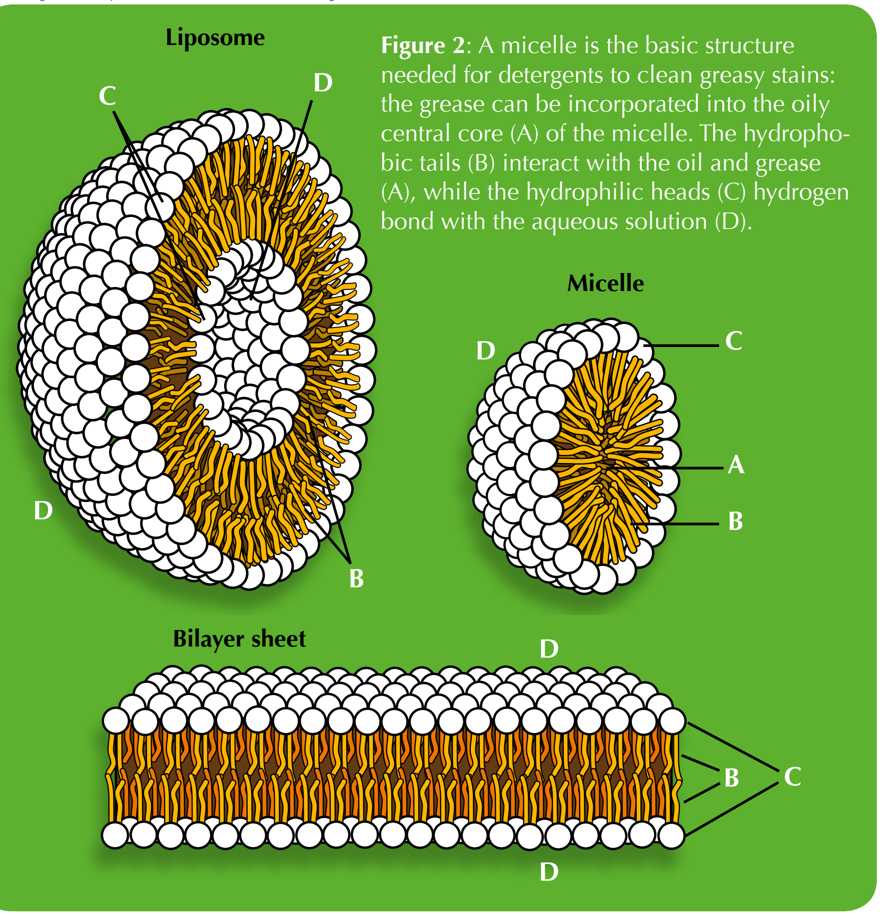


Figure 2: A micelle is the basic structure needed for detergents to clean greasy stains: the grease can be incorporated into the oily central core (A) of the micelle. The hydrophobic tails (B) interact with the oil and grease (A), while the hydrophilic heads (C) hydrogen bond with the aqueous solution (D).

and held in the water by these micelles (figure 2).

Developing magnetic surfactants

A research group at the University of Bristol, UK – including two of the current authors – is currently working on a new type of surfactant: magnetic surfactants, which respond to a magnetic field as a result of iron atoms in their head groups (figures 3 and 4). These surfactants could have both environmental and medical applications (see below).

How were the magnetic surfactants developed? And how do you prove that you really have produced a magnetic surfactant?

To begin with, the Bristol researchers took a known surfactant and replaced its bromine group with an iron-containing group (figure 3). They then demonstrated that the compound still functioned as a surfactant: it was capable of lowering the surface tension of liquids, and could cause them to foam. Next, the group demonstrated that the iron in the head group had conferred the desired magnetic activity.

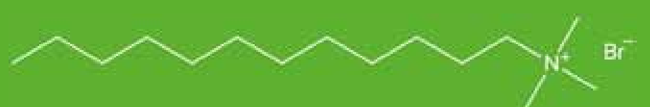
To really understand what was happening, however, the researchers needed to look more closely at their compound. For example, although its ability to lower surface tension strongly indicated that it was forming micelles, it was not conclusive proof. To test this, the researchers used a super-sensitive specialist technique called small-angle neutron scattering (SANS).

Surfactants can be imaged using small-angle neutron scattering

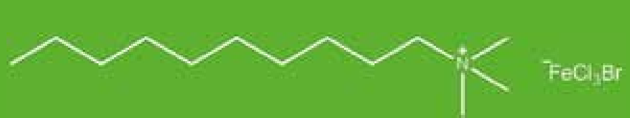
SANS is an excellent technique for investigating structures about 0.1-100 nm in size; perfect, then, for searching and characterising surfactant micelles and emulsion droplets, which are typically 2-10 nm in diameter. SANS is also widely used to investigate soft matter (e.g. polymers, colloids and

Images courtesy of the University of Bristol

Figure 3: Developing a magnetic surfactant from a conventional surfactant.



A) The structure of dodecyltrimethylammonium bromide, a non-magnetic surfactant that the Bristol group took as one of the starting materials



B) The structure of dodecyltrimethylammonium trichlorobromoferrate, one of the magnetic surfactants that the Bristol group is working on

Image courtesy of the University of Bristol

Figure 4: The effects of a magnet on solutions of normal (left, with added dye to show the two layers) and magnetic (right) surfactants. The presence of iron in the magnetic surfactant explains the attraction seen on the right.

The magnetic field lines caused in iron pellets by a magnet. Magnetic surfactants are magnetic because they contain iron atoms.

Image courtesy of oskay; image source: Flickr

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NEUTRONS FOR SCIENCE

SANS experiments require intense beams of neutrons, which can only be produced at large facilities. In Europe these are done at laboratories jointly funded and run through inter-governmental collaborations, such as ISIS[w2], in the UK, and the Institut Laue-Langevin (ILL)[w3], in France.

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.

ILL is a member of EIROforum[w4], the publisher of *Science in School*.

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liquid crystals), biological molecules (e.g. DNA and proteins in solution) and hard condensed matter (e.g. clusters in alloys, and flux line lattices in supra-conductors).

In a SANS experiment, an intense neutron beam is directed onto the sample of interest (figure 5); this beam can be viewed as a stream of free particles travelling in the same direction and with the same speed. The free neutrons in the beam interact with the bound nuclei of the atoms in the sample, scattering the beam. These scattered neutrons are recorded by a position-sensitive detector. The resulting data – the intensity of the neutrons scattered by different areas of the sample – is used in mathematical models to determine the shape, size and charge of the scattering objects in the sample. For a more detailed explanation of SANS analysis, download the supporting materials from the *Science in School* website[w1].

For their SANS analysis, the Bristol group teamed up with scientists at the Institut Laue-Langevin (ILL; see box above) in Grenoble, France. Although other surfactant properties such as surface tension reduction had already been observed with the new com-

Image courtesy of ILL

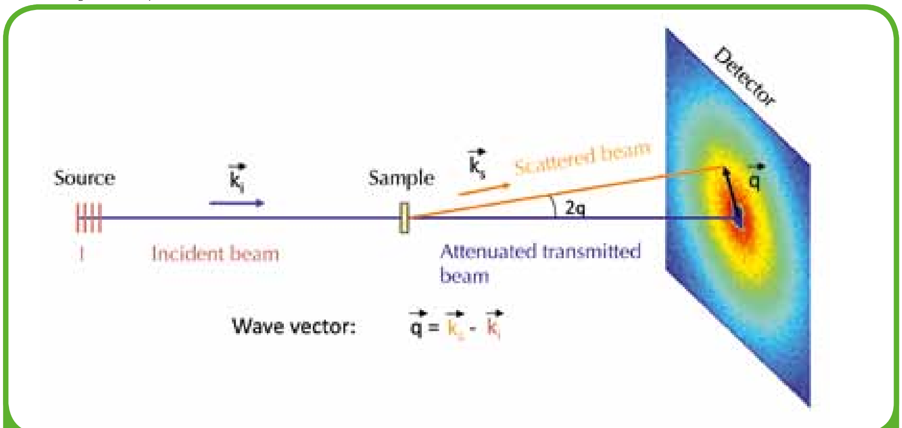


Figure 5: Schematic representation of a small-angle neutron scattering experiment. The incident k_i and scattered k_s wave vectors are shown, along with the resultant scattering vector q, which is in the plane of the detector.

pound, the SANS results provided the first conclusive proof that it really was forming micelles.

Furthermore, the scientists were able to show that the micelles formed by the new surfactant were small, spherical and uncharged. This was important, because the behaviour of a surfactant, and thus its applications, are affected by characteristics of the micelles and emulsion droplets that it forms with different liquids. With this information, the scientists are now better able to predict – and in future investigate – the behaviour of their surfactant under different conditions.

Using SANS, the team was also able to test whether in solution, the iron particles dissociated from the surfactant, effectively resulting in a mixture of non-magnetic surfactants and dissolved magnetic particles, or whether the two elements remain bound, forming genuinely magnetic micelles. The results suggested that the iron compounds were firmly integrated in the micelles. This opened up the possibility of creating magnetic

The Deepwater horizon oil spill in the Gulf of Mexico, as seen from space in 2010. The spill was the largest in the history of the petroleum industry. Detergents were used to try to disperse the oil.

Image courtesy of NASA

emulsions with potential medical applications (see below).

Magnetic surfactants have environmental and medical applications

Magnetic surfactants may sound like a strange idea, but they have some very practical applications. For example, many surfactants are not biodegradable. If magnetic surfactants were used instead, they could be retrieved from waste-water using a magnetic field and recycled, resulting in lower levels of detergents entering the environment.

Moreover, currently when there is an oil spill at sea, surfactants are used to break oil slicks into emulsion droplets so small that they diffuse away into the ocean, where the oil remains a pollution hazard. If magnetic surfactants were used instead, the resulting emulsions could be collected, removing both the oil and the surfactants from the water.

Magnetic surfactants may even have medical applications. Targeted drug delivery aims to get medication only to the specific cells where it is required, preventing the waste of valuable pharmaceutical compounds and minimising side effects. Figure 6 shows how emulsion droplets (dyed blue) formed from the magnetic surfactants can be manipulated with a small magnet efficiently enough to overcome typical blood flow in the body. These emulsions could encase medication in the same way as emulsions currently used in drug delivery, but the magnetic emulsions could be directed to the right spot in the body with a magnet.

Figure 6: The effect of a magnetic field on a magnetic emulsion: the magnet drags the droplet uphill, against gravity. Once the magnet is removed (picture 5) gravity causes the droplet to flow back down the tube.

Image previously published in Brown et al. (2012a). Reproduced by permission of The Royal Society of Chemistry

Future prospects

Magnetic surfactants are not the only new type of surfactants that are currently being developed in Bristol. The research team are also investigating surfactants that can be turned on and off by changes to light, pH, temperature, pressure and carbon dioxide concentration. The current challenge is to learn how to scale up the synthesis of these surfactants to make these smart surfactants cheaply and effectively.

Julian Eastoe is a professor of chemistry, specialising in surfactant chemistry at the University of Bristol, UK. Paul Brown is a PhD student, investigating novel surfactants at the University of Bristol, UK. Isabelle Grillo is an instrument scientist at the Institut Laue-Langevin in Grenoble, France.

Julian Eastoe and Paul Brown came up with the idea of magnetic surfactants and carried out the laboratory experiments (with the help of Professor Annette Schmidt from the University of Cologne, Germany). Isabelle Grillo was heavily involved with the neutron scattering and data analysis.

Tim Harrison also works at the University of Bristol, as the school teacher fellow at the School of Chemistry. This is a position for a secondary-school teacher that was created to bridge the gap between secondary schools and universities, and to use the resources of the School of Chemistry to promote chemistry regionally, nationally and internationally. Tim is a frequent author for *Science in School*.

Reference

Brown P et al. (2012a) Magnetic emulsions with responsive surfactants. *Soft Matter* **8**: 7545-7546. doi: 10.1039/C2SM26077H

Web references

w1 – To learn more about SANS analysis, download the supporting material from the *Science in School* website: www.scienceinschool.org/2012/issue25/soap#resources

w2 – ISIS is a world-leading centre for research in the physical and life sciences that uses a suite of neutron and muon instruments to understand the properties of materials at the scale of atoms. An international community of more than 2000 scientists uses the facility to research subjects from clean energy and the environment, pharmaceuticals and health care, through to nanotechnology, materials engineering and IT. See: www.isis.stfc.ac.uk

w3 – More information about ILL: www.ill.eu

w4 – EIROforum is a collaboration between eight of Europe's largest inter-governmental scientific research organisations, which combine their resources, facilities and expertise to support European science in reaching its full potential. As part of its education and outreach activities, EIROforum publishes *Science in School*. To learn more, see: www.eiroforum.org

Resources

For more details of the research, see:

Brown P et al. (2012b) Magnetic control over liquid surface properties with responsive surfactants. *Angewandte Chemie* **51**: 2414-2416. doi: 10.1002/anie.201108010

For teaching activities on surface tension and surfactants for primary school, see:

Kaiser A, Rau M (2010) LeSa21: primary-school science activities. *Science in School* **16**: 45-49. www.scienceinschool.org/2010/issue16/lesa

If you found this article useful, why not browse the other chemistry-related articles in *Science in School*? www.scienceinschool.org/chemistry

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

Movers and shakers: physics in the oceans

Contrary to the popular saying, deep waters are often far from still – which is just as well for marine life. Activities using simple water tanks are a good way to find out about the physics at work beneath the waves.

By Susan Watt

When we think about climate change, one of the biggest concerns is that major ocean currents such as the Gulf Stream are being sent off course, jeopardising the weather systems that depend on them. But what causes such currents to be established in the first place?

Part of the answer is gravity. Gravity acts on water masses of different density and this, together with wind and Earth's rotation, produces forces and currents within the oceans. Such processes not only have a potential impact on our climate, but are also a huge influence on the environment inhabited by marine organisms.

As a result, any student of oceanography will need a good understanding of these processes. But a group of university oceanographers in Maine, USA, noticed a few years ago that their marine science students seemed unaware of the physics involved in their subject, focusing instead mainly on the biology. As a result, they decided to put together a teaching resource to convince students that oceans are an unusually exciting place to study physics. This article is based on that resource (Karp-Boss et al., 2009), which focuses on key concepts in physics that are also fundamental in oceanography, and provides a compelling environmental context for ideas within physics.

Of course, students learn best when they are actively engaged, so central to the resource is a series of activities designed to engage students and challenge their assumptions. Two activities that the oceanographers have

REVIEW

- **Physics**
- **Biology**
- **Ages 12+**

Physics is often seen as unrelated to everyday life, which makes many students uninterested in the subject. This article uses oceanography to provide a context for physical concepts, thus helping to raise students' interest. It could be used in biology or physics lessons, particularly when studying marine topics.

The two activities described can either be used by teachers as demonstrations or carried out by students. They can be used before explaining the physics concepts that appear in them (to make students think about them) or after their explanation. Additional exercises about physical oceanography that would be useful for teaching physics to students aged 12-18 are listed at the end of the article.

Finally, the text could help students understand that seemingly diverse scientific subjects can be interlinked. For example, to understand how the environment affects marine life, we need concepts from physics (and also chemistry and geology).

Mireia Güell Serra, Spain

Image courtesy of somebody_; image source: Flickr

Image courtesy of Nicola Graf

The Gulf Stream is one of the strongest ocean currents in the world. It originates at the tip of Florida in the US, then follows the eastern coastlines of the USA and Newfoundland, Canada, before crossing the Atlantic Ocean towards the British Isles.

The Gulf Stream is driven by winds and differences in water density. Surface water in the north Atlantic is cooled by winds from the Arctic, whereupon it becomes denser and sinks to the ocean floor. This cold water then moves towards the Equator where it is slowly warmed. To replace the cold water moving towards the Equator, warm water moves from the Gulf of Mexico north into the Atlantic.

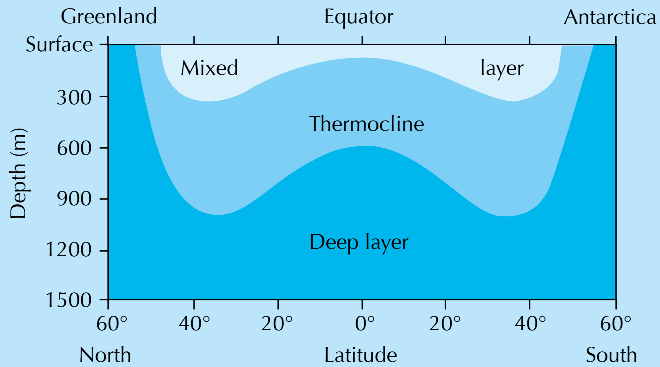


Figure 1: In open ocean regions, there are at least three distinct water layers: an upper mixed layer of warm water; the thermocline, in which the temperature decreases rapidly with increasing depth; and a deep zone of cold, dense water in which density increases slowly with depth. The three layers are illustrated in this cross-sectional diagram of the Atlantic Ocean. Note that the thickness of the layers varies with latitude. At high latitudes, only the deep-water layer exists.

Image from the DataStreme Ocean project. ©American Meteorological Society. Used with permission.

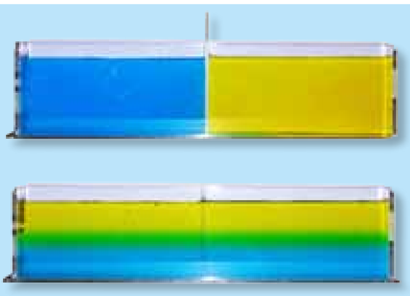
used successfully in their classes are described here: one focusing on density, the other on waves. Both could be used with secondary-school students of all ages (11-19).

The first activity shows how stratification occurs as a result of density differences due to temperature or salinity. The second activity looks at internal waves; resonance and natural frequency are also demonstrated. For both activities, the apparatus is set up prior to class, and the students carry out the activities for up to 30 minutes per activity (using worksheets). The last part of the lesson is used for summarising findings and discussion.

Density and stratification

Density is a fundamental property of matter. It is the mass per unit volume of a material – that is, how much mass is packed into a given volume.

Image courtesy of Lee Karp-Boss



Density layers. The top image shows the tap water and salt solution before the divider is removed. Afterwards (lower image), the salt solution forms a stable layer at the bottom of the tank with the tap water above it.

In oceanography, density is used to characterise water masses and to study ocean circulation. Many ocean processes are caused by differences in densities: large-scale ocean circulation and carbon transport by particles sinking from surface to deep waters are just two examples.

Whereas the density of water ranges from 998 kg/m^3 for fresh water at room temperature to nearly 1250 kg/m^3 in salt lakes, ocean waters have a much smaller density range (about 1020–1030 kg/m^3). Most of the variability in seawater density is due to salinity and temperature. As salt concentration increases, due to evaporation or ice formation, density increases. Higher temperatures reduce density, whereas cooling increases it.

Ocean seawater density increases with depth, but not in a uniform way: instead, water of different densities forms a series of layers (figure 1).

This stratification acts as a barrier for the exchange of nutrients and dissolved gases between the top, sunlit layer where phytoplankton thrive, and the deep, nutrient-rich waters.

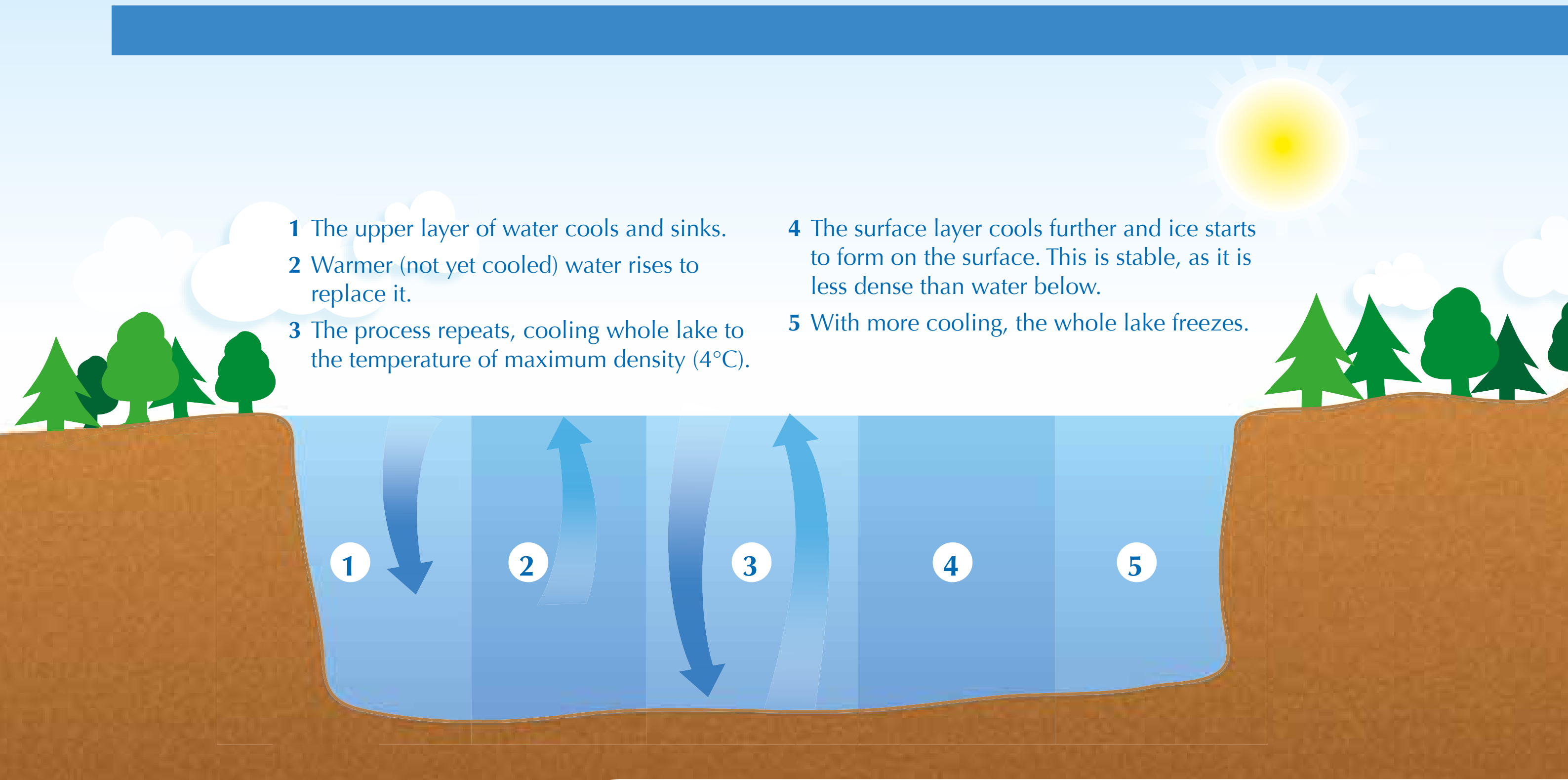


Image courtesy of Nicola Graf

Density is fundamental to how lakes freeze. As winter approaches in high latitudes, lake waters are cooled from the top. When the upper waters become cooler and denser than the waters below, they sink. The warmer, less dense water underneath then rises to replace the sinking water. If low air temperatures persist, these processes will eventually cool the entire lake to 4 °C – the temperature of maximum density for fresh water. With yet further surface cooling, the density of the upper waters will decrease, and the lake becomes stably stratified with colder but less dense water at the top. As surface waters cool to 0 °C, they begin to freeze. If cooling continues, the frozen layer deepens.

Mixing stratified layers requires work: think how hard you need to shake a bottle of salad dressing to mix the oil and vinegar. So, without enough energetic mixing due to wind or breaking waves, phytoplankton at the ocean's surface will lack nutrients.

Types of waves

Although density is not the first thing that comes to mind when we think of the sea, waves are a different matter. Waves are ubiquitous in the ocean, in lakes, and of course on beaches – and they are feared in their destructive form as tsunamis.

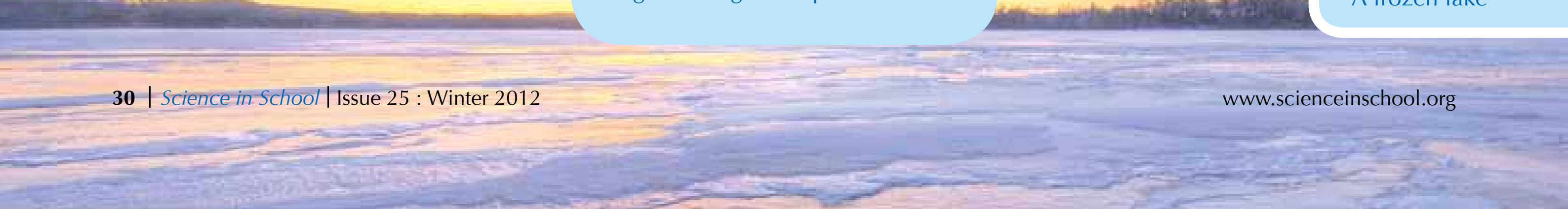
Most of these waves are what physicists call surface waves. But there are also internal waves, which occur at the interface between density layers of water. In the ocean, breaking internal waves mix up the water layers and lift the nutrients they contain.

The geometry of a water basin (such as a lake or a bay) determines which waves are excited when force is applied and then released (e.g. due to a passing storm). These waves are the 'natural modes' of the basin – in a similar way to sound waves in a musical instrument, where a particular frequency is produced by a given length of string or air column. This phenomenon is called resonance.

In oceanography, there is an additional phenomenon known as seiche (pronounced 'saysh', from an old French word meaning 'to sway'). This is when a standing wave is established in a semi-enclosed body of water, which moves from side to side as a mass – rather like tides. For example, the Adriatic seiche, which has a period of 21.5 hours, is associated with serious floods in Venice, Italy. Other naturally occurring examples of seiches have been observed in Lake Geneva and in the Baltic Sea.

Image courtesy of Moroder; image source: Wikimedia Commons

Acqua alta ('high water' in Italian) is the name given to the high water levels that occur periodically in the Venetian lagoon. The phenomenon occurs in part due to the Adriatic seiche. Shown here is Venice's famous Piazza San Marco, partially submerged during an acqua alta in 2004.



A frozen lake

Image courtesy of Raymond Larose; image source: Flickr

Activity 1: Investigating water density and stratification

Materials

- Rectangular tank with a divider
- Bottle containing salt solution (approximately 75 g salt dissolved in 1 l water)
- Two beakers containing tap water, at room temperature
- Food colouring (two different colours)
- Ice

Procedure

1. Calculate the densities of the tap water and the salt solution. To do this, students measure the weight of a known volume of water, making sure to subtract the mass of the container from the total mass of the container plus liquid. The density can then be calculated, since density (ρ) is mass (m) divided by volume (v) (or $\rho = m/v$).
2. Place the tap water in one compartment of the tank and salt solution in the other.
3. Add a few drops of food colouring to the water in each compartment, so that each has a different colour.
4. What do you predict will happen when you remove the divider between the compartments? Explain your reasoning.
5. Remove the tank divider. What happens? Are your observations consistent with the densities you measured?
6. Empty the tank and the beakers. Now fill one beaker with hot tap water and one beaker with ice-cold water.
7. Add a few drops of food colouring to each of the beakers (a different colour in each beaker).
8. Place the hot water in one tank compartment and the ice-cold water in the other. What do you predict will happen when you remove the divider? Explain your reasoning.
9. Remove the tank divider. What happens? Is it as you predicted?
10. After observing the new equilibrium in the tank, place your fingertips on top of the fluid surface and slowly move your hand towards the bottom of the tank. Can you feel a temperature change?
11. How might the effects of climate change, such as warming and melting of sea ice, affect the vertical structure of ocean water? Discuss possible scenarios.

Physics

Image courtesy of Hamed Saber; image source: Flickr

Activity 2: Investigating internal waves

Materials

- Rectangular tank with a divider
- Stopwatch
- Food colouring or other appropriate dye
- Two containers: one with fresh water and the other with dyed salt water (approximately 75g salt dissolved in 1 l tap water)
- Wave paddle (a wide piece of plastic about 2 cm high, with a width similar to that of the tank)
- Optional: a piece of plastic the same width as the tank but about one-third of its length

Procedure

1. Place the tap water in one compartment of the tank and the coloured salt solution in the other.
2. Remove the divider between the compartments, and watch what happens. Make a note of any waves you see, and describe their movements.
3. Identify the internal wave – this travels back and forth along the interface between the two differently coloured fluids. Measure the speed of this wave by timing how long it takes for the wave to travel the length of the tank. (Make sure you use an average value by timing several traverses.) Find the speed of the wave using the formula:

   Length of tank (m) / time taken (s) = wave speed (m/s)
4. Try producing surface and internal waves using the wave paddle. For surface waves, lower the paddle into the water and raise it again, repeating the cycle at a fast frequency (at least once a second). For internal waves, do this more slowly (about once every 10 seconds).
5. Discuss your results.
6. Optional: if you have time, you can repeat the experiments using the piece of plastic inserted at an angle to the bottom of the tank, to give the effect of a shallow sea bed. Place the plastic in position as shown below.

Discussion

The energy of internal waves is generally lower than that of surface waves. This is because the gravitational restoring force is smaller for internal waves, due to the relatively slight difference in density between water layers (compared to that between water and air for surface waves). This lower energy means that, for a tank (or water basin) of a given size, the natural frequency of the internal waves will also be lower than for surface waves.

In additional to surface waves, stratified fluids support internal waves; in two-layer fluids, these waves ride on top of the interface between the two fluids. Their periods are significantly longer than those of surface waves and their amplitudes can be significantly higher. When we perturb the two-layer system, many waves are initially excited, but only those that fit (resonate) with the geometry of the basin remain. Inserting the piece of plastic at one end of the tank, simulating an increasingly shallow seabed, can cause internal waves to break, similar to surface waves breaking on a beach, but occurring below the surface.

Image courtesy of Lee Karp-Boss

An internal wave at the interface between the denser (blue) salt water and less dense (clear) water. A wave paddle is shown on the right of the tank, and a piece of plastic to simulate shallow topography on the left.

Image courtesy of stock photos for free.com

Image courtesy of lycaon; image source: Wikimedia Commons

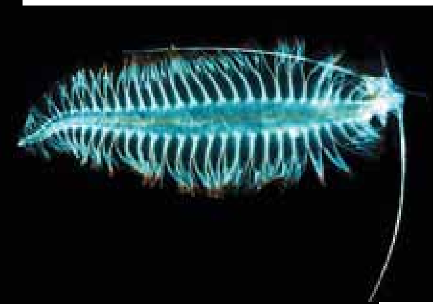


Image courtesy of Uwe kils; image source: Wikimedia Commons

Image courtesy of Biopics; image source: Wikimedia Commons

Image courtesy of Biopics; image source: Wikimedia Commons

Planetonic organisms are incapable of swimming against a current.

Acknowledgement

This article is based on the resource developed through the organisation COSEE (Center for Ocean Sciences Education Excellence) by oceanographers Lee Karp-Boss, Emmanuel Boss, Herman Weller, James Loftin and Jennifer Albright (Karp-Boss et al., 2009).

Reference

Karp-Boss L, et al. (2009) Teaching physical concepts in oceanography: an inquiry based approach. *Oceanography* **22(3)**: supplement. doi: 10.5670/oceanog.2009.supplement.01

Resources

The tanks can be obtained from sciencekit.com, where a set of six tanks costs 130 USD. You could also try building your own, using a small fish tank and constructing a divider with a good seal.

For more information and activities on ocean layering and mixing, see the article *Mix it up, mix it down: Intriguing implications of ocean layering*, available online at: www.tos.org/oceanography/archive/22-1_franks.pdf

The website of COSEE Ocean Systems offers images of density profiles and thermohaline circulation, videos on ocean convection, a collection of hands-on activities, and links to related concepts. See: http://cosee.umaine.edu/climb

In particular, there are videos demonstrating activity 1: water density and stratification (http://cosee.umaine.edu/files/coseeos/video_tsoi04.htm or use the shorter link: http://tinyurl.com/crjzwoq) and activity 2: internal waves (http://cosee.umaine.edu/files/coseeos/video_tsoi11.htm or use the shorter link: http://tinyurl.com/cf4so47#).

NASA offers a website with information and resources on ocean currents. See: http://oceanmotion.org/index.htm

Additional educational resources in oceanography are available on website of COSEE (Centers for Ocean Sciences Education Excellence). See: www.cosee.net/resources/educators

These two books are accessible introductions to oceanography:

Denny MW (1993) *Air and Water: The Biology and Physics of Life's Media*. Princeton, NJ, USA: Princeton University Press

Denny M (2007) *How the Ocean Works: An Introduction to Oceanography*. Princeton, NJ, USA: Princeton University Press

If you found this article useful, why not browse the other teaching activities in *Science in School*? www.scienceinschool.org/teaching

Susan Watt is a freelance science writer and editor with a special interest in science education. She studied natural sciences at the University of Cambridge, UK, followed by master's degrees in philosophy of science and psychology. She has worked as a curator at the Science Museum (London) and produced international exhibitions for the British Council, and is currently a school governor and event organiser for the British Science Association.

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

Physics

Image courtesy of Isolino; image source: Flickr

HOW CAN TEACHERS RECOGNISE CONTENT THAT HAS THE POTENTIAL TO TRAVEL ACROSS NATIONAL, CULTURAL AND LINGUISTIC BOUNDARIES?

European Schoolnet, a network of 30 European Ministries of Education based in Brussels, has been active in the field of Open Educational Resources (OER) for over a decade. It has particularly focused on promoting the exchange of quality OERs at the pan-European level via the Learning Resource Exchange for schools (LRE): **http://lreforschools.eun.org**

- The LRE, as a pan-European exchange, enables educators and learners to find over 240,000 resources from more than 50 content providers.
- The LRE relies on a rigorously tested set of criteria developed by the eQNet project to help assess which resources have the potential to 'travel well' across national, cultural and linguistic boundaries.
- Teachers and content producers can now use the criteria in their own work to create and discover OERs with real potential for re-use across Europe.

Travel Well

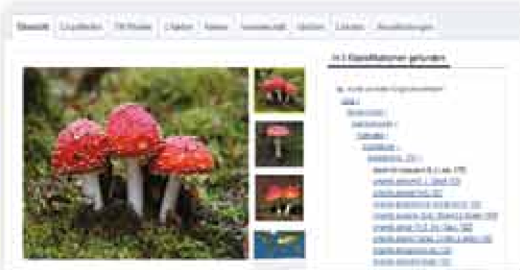
TRAVEL WELL CRITERIA WITH EXAMPLES

1. TRANS-NATIONAL TOPICS (must be present)

The resource addresses curriculum topics that could be considered trans-national. It can also be a resource well suited for use in multi-disciplinary or cross-curricular contexts.

Example: Encyclopedia of Life

Source: Encyclopedia of Life



2. KNOWLEDGE OF A SPECIFIC LANGUAGE IS NOT NEEDED (must be present)

The resource can be used without having to translate accompanying texts and/or the resource may be available in at least 3 European languages.

Example: Caves at Lascaux

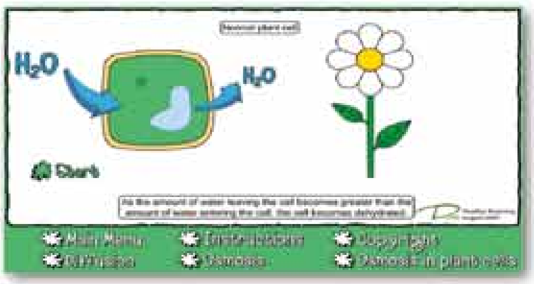
Source: French Ministry of Culture and Communication

3. STORED AS A FILE TYPE THAT IS USABLE WITH GENERALLY AVAILABLE SOFTWARE

The resource can be used in any environment (online and off-line) and runs on multiple platforms (also hand-held, IWB).

Example: Diffusion and Osmosis

Source: Bio-DiTRL

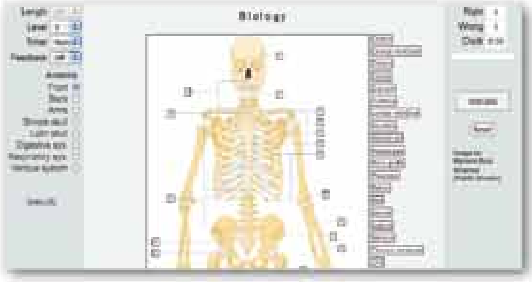


4. METHODOLOGICAL SUPPORT FOR TEACHERS IS NOT NEEDED

Subject teachers can easily recognize how this resource meets their curriculum requirements or how this resource could be used in a teaching scenario without further instructions.

Example: Human Anatomy

Source: ThatQuiz.org

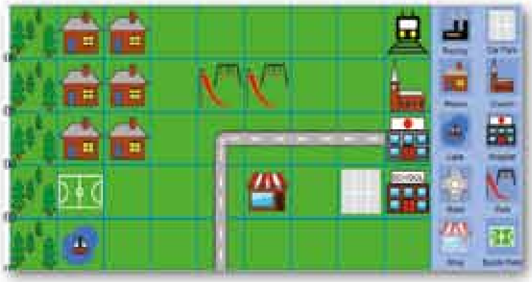


5. INTUITIVE AND EASY TO USE

The resource is intuitive to use in the sense that it has a user-friendly interface and is easy to navigate for both teachers and students without having to read or translate complex operating instructions.

Example: Map Maker

Source: TeacherLED

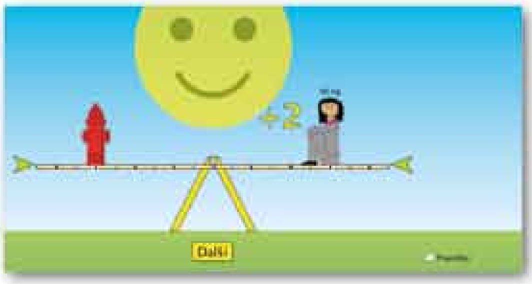


6. INTERACTIVITY WITH OR WITHOUT FEEDBACK IN A DIGITAL ENVIRONMENT

This kind of resource invites or requires a significant degree of user input or engagement, other than just reading something on a page in an online or offline environment.

Example: Balancing Act

Source: PhET



7. CLEAR LICENSE STATUS (must be present)

The user can easily find information about the license/rights (sometimes called Terms of Use, Copyright or Permissions) for this resource, clearly outlining what educators can do with this animation and what they may not do because it will infringe copyright.

Example: CellsAlive! Permission Page

Source: CellsAlive!

SEE A SHOWCASE OF TRAVEL WELL RESOURCES:
http://lreforschools.eun.org/web/guest/travelwell-all

European Schoolnet

Learning Resource Exchange for schools http://lreforschools.eun.org

For more information:
European Schoolnet: **www.europeanschoolnet.org** Email: **lre-contact@eun.org**

Lifelong Learning The Quality Network for a European Learning Resource Exchange (eQNet) and the work presented in this print ad is supported by the European Commission's Lifelong Learning Programme.

Image courtesy of chris2766 / iStockphoto.com

Exploring scientific research articles in the classroom

Learn how to use research articles in your science lessons.

By Miriam Ossevoort, Marcel Koeneman and Martin Goedhart

Scientists use research articles to communicate their research findings and scientific claims. These articles are not just factual reports of experimental work; the authors also try to convince the reader that their argument is correct. It is now easier than ever to read the original research behind science stories in the media, as more and more articles are being made freely available through open-access publishing.

Open-access logo, designed by the Public Library of Science. Open-access publishing makes it easier for you and your students to access scientific research articles.

Image courtesy of JakobVoss; image source: Wikimedia Commons

Reading research articles is an opportunity for secondary-school students to learn about:

- The language of scientific communication (structure, vocabulary and conventions such as writing in the third person)
- The way scientists use their evidence to form an argument and justify their claims
- How science works (designing research to test hypotheses; fair testing; presenting results; drawing conclusions; raising new questions; building on existing knowledge)

Research articles are generally written in the third person

Reading research articles is not an easy task for students, but they can find it inspiring. Here we describe a classroom activity that we have been using to teach students aged 15-16 years and older about the textual structure (part 1) and the argumentative structure (part 2) of a research article. This classroom activity takes about three hours. It could be less if, after part 1, the students read the article as homework.

Most research articles are written in English, the language of science. If

REVIEW

- All science subjects
- Ages 15+

Using the suggested activity for discussing or exploring a few well-chosen research papers with students, teachers can not only deepen their students' knowledge of the scientific research in question, but also help them to relate more closely to the professional activities of a scientist.

In addition to the questions posed in the article, the teacher could also ask the students to discuss peer review. For example, what is peer review? Why is it done? By how many reviewers? Why is it important (or desirable) that the review process is blind? What is double-blind peer review? The students could also consider the acknowledgements section and discuss how science is financed.

Some interesting follow-up strategies would be to ask students to design their own research project and to write a small research paper. If this were done in two different classes, the students could then review the research papers of the other class, who have investigated the same or a similar topic.

Which science lessons and which age groups to target with the activity would depend on the research paper chosen by the teacher. However, the strategy would be most useful for upper-secondary-level students (ages 15-18). The fact that most research papers are in English should not be seen as an obstacle, but as an opportunity to implement interdisciplinary projects with language teachers.

Betina da Silva Lopes, Portugal

you teach in a school where English is not the language of instruction, you might find it helpful to involve the English teacher in the activity.

Getting started

To begin with, you need to choose a good research article to use. The following criteria are key:

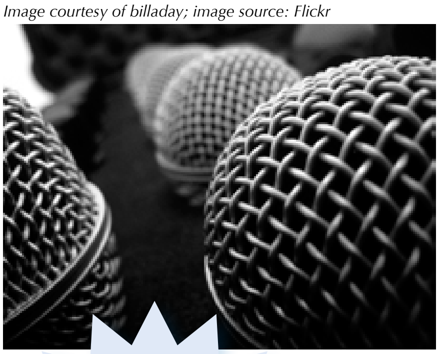
1. Limited length (three pages maximum)
2. Appealing, age-appropriate content
3. Structure including the following sections: abstract, introduction, materials and methods, results, discussion and / or conclusion
4. Easy-to-understand experimental procedure
5. Simple relationship between the data and conclusion
6. Obvious practical or social significance.

When selecting the topic, you might like to focus on something covered in the school curriculum. Once you have chosen a topic, you may want to start by searching for research articles published in open-access journals. For example, the Directory of Open Access Journals[w1] (DOAJ), a directory of scientific and scholarly journals published in many languages, is one potential starting point. We would also recommend Biomed Central[w2], a publisher of 220 open-access, online, peer-reviewed journals in biology and medicine. The Public Library of Science[w3] (PLOS) publishes seven open-access, peer-reviewed journals in biology and medicine. When using these collections, you could search for articles on a specific topic or browse the recent research, featured discussions and / or most viewed sections.

Another source of inspiration could be topics covered in media such as newspapers, popular science magazines like *New Scientist* or *Science News*, or their corresponding websites. These websites generally allow you to enter search terms and filter by topic, date and other criteria; some of the articles include suggestions for further reading, such as the original research articles. You will then need to judge whether the research article itself meets the selection criteria listed above.

Research articles on (animal) behaviour or testing medicines often have easy-to-understand experimental pro-

Image courtesy of billaday; image source: Flickr

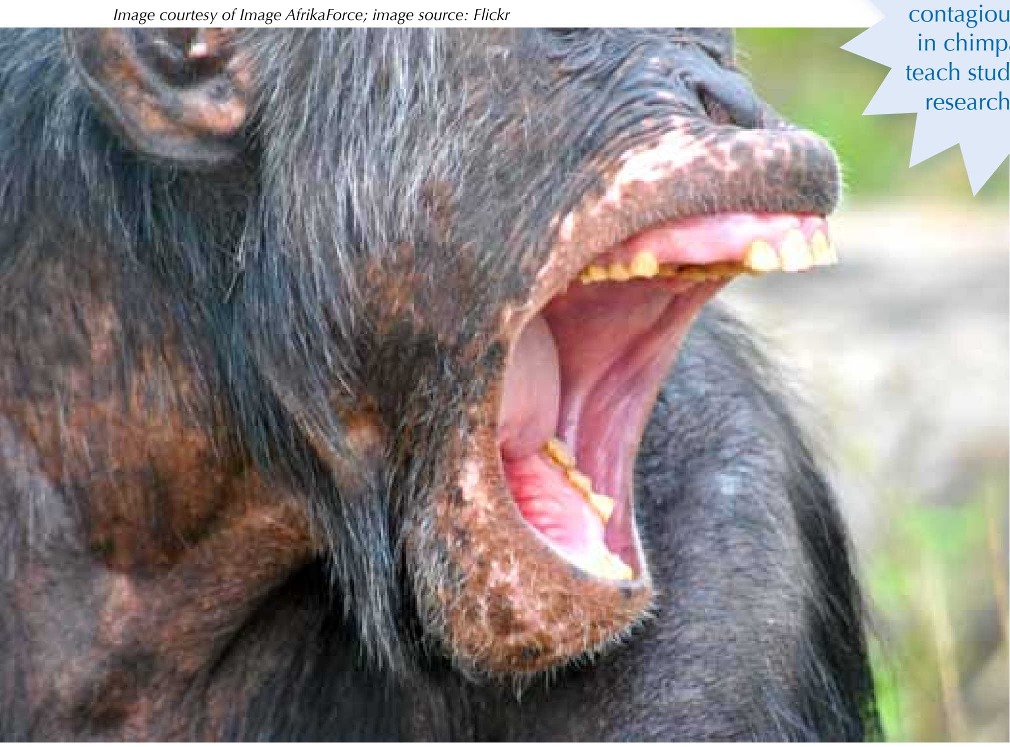


Topics covered in the media are a good place to search for research papers

Image courtesy of Valerie Everett; image source: Flickr

General science

Image courtesy of Image AfrikaForce; image source: Flickr



> We chose an article about contagious yawning in chimpanzees to teach students about research articles.

cedures. One good example is *Computer animations stimulate contagious yawning in chimpanzees* (Campbell et al., 2009), which was covered in several newspapers. We chose this article for its length, its appealing content (looking at pictures of yawning chimpanzees makes you yawn yourself), the straightforward experimental procedure and clear scientific claim. More details of how we used the article can be downloaded from the *Science in School* website[w4].

1) The textual structure of the article

Let's begin by looking at the text and the structure of a research article. It starts with a *title*, which summarises the study and / or its outcome. This is followed by a list of the *authors* and their *affiliations* (i.e. who they work for). Usually, the first author is the main researcher and the last author is the head of the department. Then, the *dates of submission and publication* are given; this shows how long the peer review and revision process has taken. Next, we find the *abstract*, which summarises the content of the article. The main body of the article starts after the abstract.

In the main body of the article, the first section is the *introduction*. Here the authors explain the context of the study, i.e. what other researchers have discovered, why this study is important (the gap in knowledge) and what they are going to do. The second section presents the *material and methods* in enough detail for other scientists to repeat the experiments. In the third section, the *results* of the study are summarised in text and presented as graphs, diagrams and tables. The fourth section is a *discussion* of the results. Most importantly, it states the main *conclusion* (claim), how the evidence supports this conclusion and the implications for further research or for society. After this, you may also find the *acknowledgements* where the authors thank those who contributed to the research and identify who funded the study. The *references* section lists all the source materials cited in the article.

To study the textual structure of a research article in class, give each student a copy of the article, and ask him or her to answer some basic questions. By skimming the article to find the answers, your students will quickly become familiar with the structure of the research article and its content. Questions might include:

- Who is the first author of this article? The first author is normally the person who had the idea behind the research or did most of the work.
- Who are the other authors?
- Where was the research done?
- Which sections does the article contain and what is in each section?
- When was this paper published?
- Who funded the research?

2) The argumentative structure of a research article

Remember, scientists write research articles to try and convince their peers to accept their scientific claims. This line of reasoning is called the *argumentative structure* and consists of: the *motive* (why the study was done), the *objective* (what was investigated), the *main conclusion* (the outcome of the study), *supports* (statements, including

> In a research article, the person who had the idea or did most of the work is normally the first author

Image courtesy of Jlay; image source: Flickr data from their own research), *references* (to previous research and refuted counter-arguments) and one or more *implications* (which might be a new theory, a new research question, or the impact on society or the research community). Each of these elements is usually found in a specific section of the research article (figure 1).

The next step in the teaching activity is to look at the argumentative structure in more detail. Students could read the whole article in detail, working individually or in small groups to answer guided questions. Next, the answers could be discussed to enhance the students' understanding.

First, let your students read the introduction, then ask them to answer the following questions:

- Why was this study done (*motive*)?
- What was investigated (*objective*)?

Next is the materials and methods section. In our experience, students often find this section hard to understand due to its highly technical vocabulary. Therefore, we suggest that you simply explain how the study was performed.

Then, the students can read the results and discussion sections and answer the questions below either as homework or in class. Ask them to:

- Identify the *main conclusion* (outcome of the study), *supports* for this main conclusion (data from this study or previous research) and the *implication* (e.g. need for further study or impact on society).

If your students find it difficult to identify these elements, let them discuss their answers in groups before sharing them with the class. A good visual way of doing this is to create a poster with a structure similar to figure 1. The students can then review their posters in a classroom discussion.

At the end of this classroom activity, you may want to write out the complete argumentative structure of the research article on the board. Finally, encourage your students to discuss

Image courtesy of Miriam Ossevoort

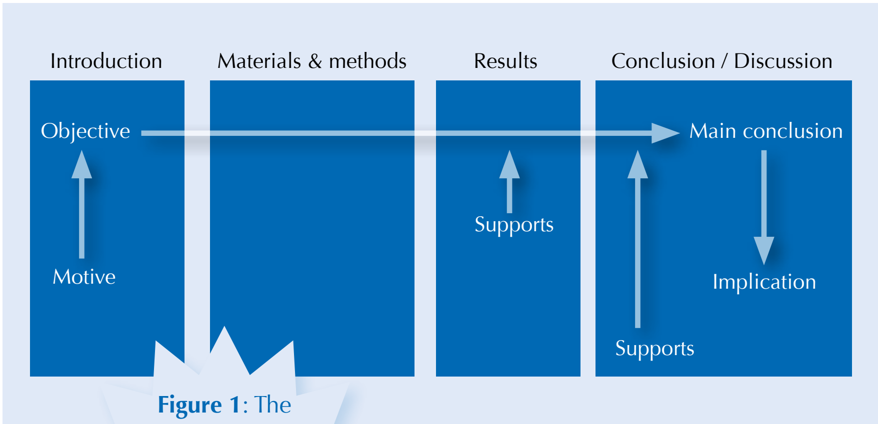


Figure 1: The argumentative structure of a research article and the location of the different elements in the text.

whether they agree with the authors' scientific claim (main conclusion) and to review the article as a whole by playing the role of a reviewer. You could use a role play about peer review[w5], developed by Sense about Science.

There are plenty of media stories about contagious yawning, so this topic would also be ideal for working with news articles. For more details of using news articles in science lessons, see Veneu-Lumb and Costa (2010).

As a follow-up activity, you could ask your students to conduct their own version of the experiment described in the research paper. For example if you used the article we chose, your students could play a yawning video from Youtube (search for 'contagious yawning') to another class of students (who did not know what was being tested) and watch how often they yawn. As a control, they could watch a non-yawning video of similar length.

References

Campbell MW et al. (2009) Computer animations stimulate contagious yawning in chimpanzees. *Proceedings of Royal Society B*. **276**: 4255–4259. doi: 10.1098/rspb.2009.1087

The article is freely available via the journal website (http://rspb.royalsocietypublishing.org)

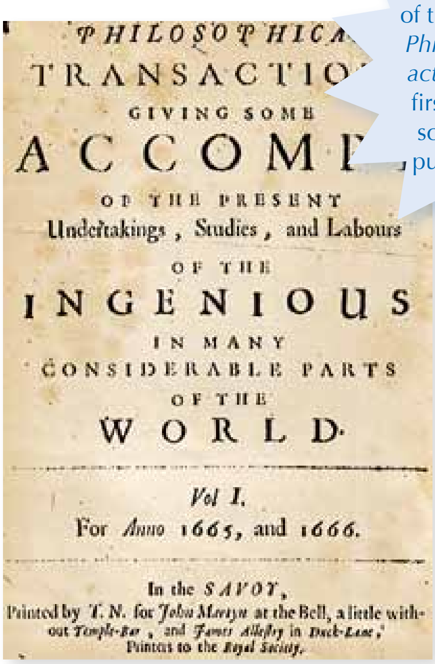
Veneu-Lumb F, Costa M (2010) Using news in the science classroom. *Science in School*. **15**: 30-33. www.scienceinschool.org/2010/issue15/news

Web references

w1 – The Directory of Open Access Journals (DOAJ) is a directory of scientific and scholarly journals published in many languages. See: www.doaj.org

w2 – Biomed Central is the publisher of 220 open-access, online, peer-reviewed journals in biology and medicine. See: www.biomedcentral.com

w3 – The Public Library of Science (PLOS) publishes seven open-access, peer-reviewed journals in biology and medicine. See: www.plos.org


PHILOSOPHICAL TRANSACTIONS: GIVING SOME ACCOMPT OF THE PRESENT Undertakings, Studies, and Labours OF THE INGENIOUS IN MANY CONSIDERABLE PARTS OF THE WORLD.

Vol I.
For Anno 1665, and 1666.

In the SAVOY,
Printed by T. N. for John Martyn at the Bell, a little without Temple-Bar, and James Allestry in Duck-Lane, Printers to the Royal Society.

Public domain image; image source: Wikimedia Commons

The front cover of the first volume of *Philosophical Transactions*, the world's first peer-reviewed scientific journal, published in 1665


April 25, 1953 NATURE

MOLECULAR STRUCTURE OF NUCLEIC ACIDS

A Structure for Deoxyribose Nucleic Acid

Image courtesy of Nature

A page from Watson and Crick's famous 1953 *Nature* paper, in which they reveal the structure of DNA

w4 – Download an in-depth analysis of the structure of Campbell et al. (2009) from the *Science in School* website. www.scienceinschool.org/2012/issue25/research#resources

w5 – In a classroom role play, students re-enact the peer-review process, assessing the quality of a mock study on the effect of chocolate on blood pressure. The role-play materials and some supporting information can be downloaded from the Sense about Science website: www.senseaboutscience.net/?page_id=52

Resources

Many *Science in School* articles link to research papers published in the prestigious scientific journal, *Nature*. These papers can be downloaded free of charge from the *Science in School* website. Explore our archive for articles that link to *Nature* papers. www.scienceinschool.org

In 2011, the Royal Society, the oldest scientific academy in continuous existence, made its entire historical journal archive freely available online. See http://royalsociety.org or use the direct link http://tinyurl.com/royalsocarchive

To learn more about authorship of papers, see:

Dance A (2012) Authorship: who's on first. *Nature* **489**: 591-593. doi:10.1038/nj7417-591a

The article is freely available via the *Nature* website (www.nature.com) or via the direct link: http://tinyurl.com/8h4c4lj

Venkatraman V (2010) Conventions of scientific authorship. *Science Career Magazine*: 16 April 2010. doi: 10.1126/science.caredit.a1000039

The article is freely available via the *Science Career Magazine* website (http://sciencecareers.sciencemag.org/career_magazine) or via the direct link: http://tinyurl.com/2uu6hrg

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

Miriam Ossevoort is an assistant professor in science education and communication at the University of Groningen, the Netherlands, and conducts educational research on reading science.

Marcel Koeneman is a teacher in biology and chemistry at an international secondary school in the Netherlands. He is also working towards a PhD on using research articles in the classroom.

Martin Goedhart is a full professor in mathematics and science education at the University of Groningen, the Netherlands.

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

Image courtesy of NASA

Galileo and the moons of Jupiter: exploring the night sky of 1610

Jupiter and the Galilean moons were photographed in 1979 by spacecraft Voyager 1 and assembled into this collage. They are in their relative positions but not to scale.

Physics

- Physics
- Mathematics
- ICT
- Simple harmonic motion
- Uniform circular motion
- Arcsine function
- History of astronomy
- Ages 17+

REVIEW

This article suggests a new enquiry-based way of teaching simple harmonic motion: students use their knowledge of mathematics, physics and information and communication technology to characterise the motion of Jupiter's moons. They collect data from a software programme, process it and then plot graphs, particularly of sine and arcsine functions, to calculate the moons' orbital periods.

The interdisciplinary nature of the article serves to make science more enjoyable. In addition, the activity develops soft skills such as the presentation of results and communication. By joining an international project, the students would have the opportunity to share their results not only with other members of their class but with students from different countries.

Corina Toma, Computer Science High School "Tiberiu Popoviciu" Cluj Napoca, Romania

Carla Isabel Ribeiro explains how mathematics can be used to study Jupiter's moons – and how students can do the same.

On a January night in 1610, Galileo Galilei looked at Jupiter through his telescope and saw what he thought were three stars near the planet. He continued his observations for about two months, and over this time realised that there were actually four 'stars', which changed their position around Jupiter. Galileo concluded that the 'stars' were in fact planets orbiting Jupiter – the Medicean planets, as he named them at the time, but which are now known as the Galilean moons in honour of their discoverer (figure 1, page 42).

"… I should disclose and publish to the world the occasion of discovering and observing four PLANETS, never seen from the very beginning of the world up to our own times…."

Galileo Galilei in *Sidereus Nuncius* (*Starry Messenger*; 1610)

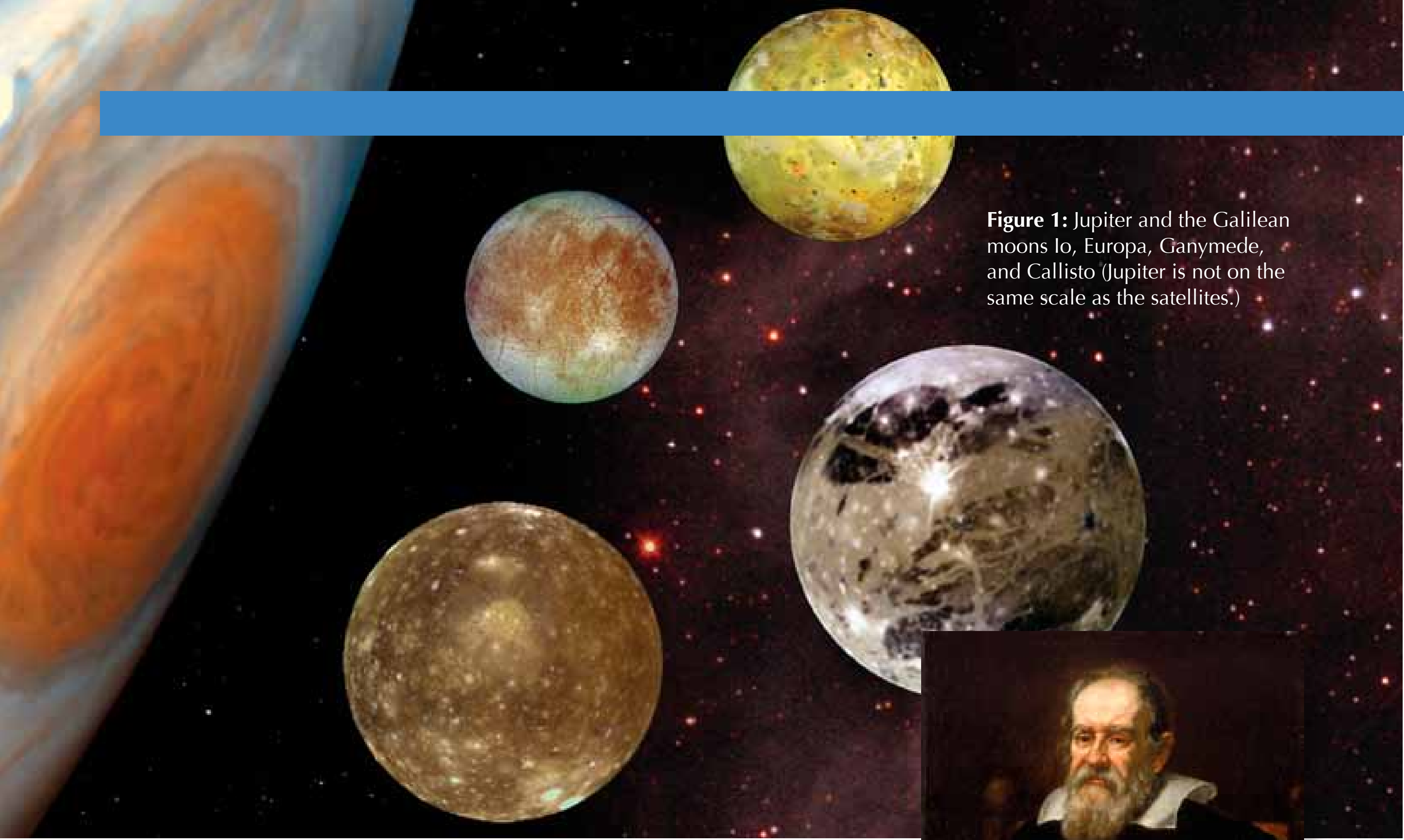


Figure 1: Jupiter and the Galilean moons Io, Europa, Ganymede, and Callisto (Jupiter is not on the same scale as the satellites.)

Image courtesy of NASA Planetary Photojournal

Portrait of Galileo Galilei (Justus Sutermans, 1636)

Public domain image; image source: Wikimedia Commons

This discovery of Galileo's forms the basis of a project that I devised for my 12th-grade physics students (17–18 years old) when teaching the topic of simple harmonic motion. The project builds on a similar activity I developed earlier, about the motion of the Galilean moon Io (Ribeiro, 2012). The current project is enquiry-based, and aims to engage students with a rich variety of scientific processes – from exploring historical contexts to obtaining and analysing experimental results and communicating their conclusions to others.

The aim of the project is for your students to prove that Galileo was right when he claimed that the 'stars' near Jupiter were in fact the planet's satellites. To do this, students collect data about the movement of the moons using a computer simulation, and then show that this movement has the characteristics of simple harmonic motion, with Jupiter as the centre. At the end of the project, students produce a report (a document or presentation) to describe their findings and the whole process – and, ideally, share this with students from other countries so they can learn to communicate scientific work internationally.

The duration of the project will vary depending on how the teacher decides to approach it. I spent four months working on the project with my students, but if you do not have time to run the whole project with your students, you could select individual activities from it.

Image courtesy of Nicola Graf

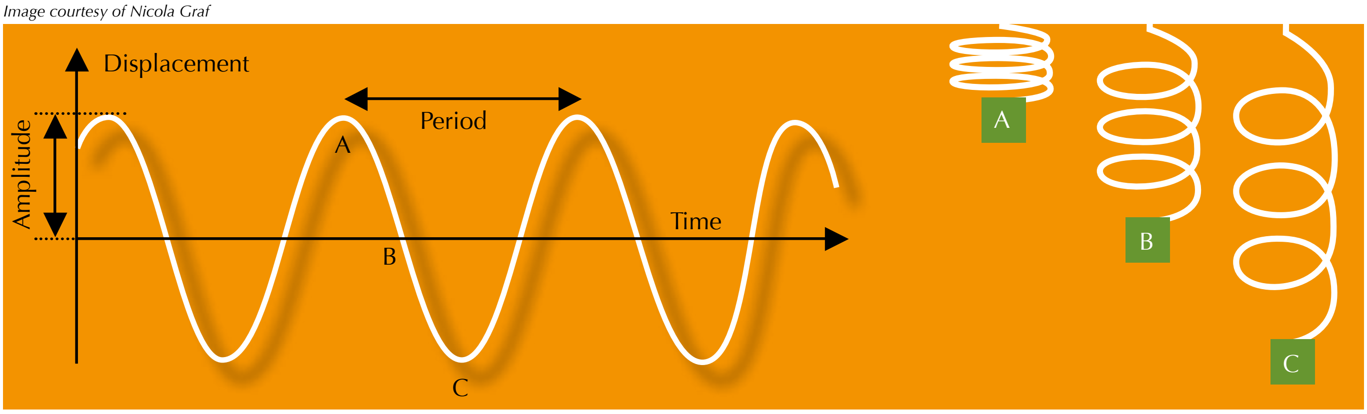


Figure 2: Plotting the motion of an object attached to a spring against time produces a sine wave.

Public domain image; image source: Wikimedia Commons

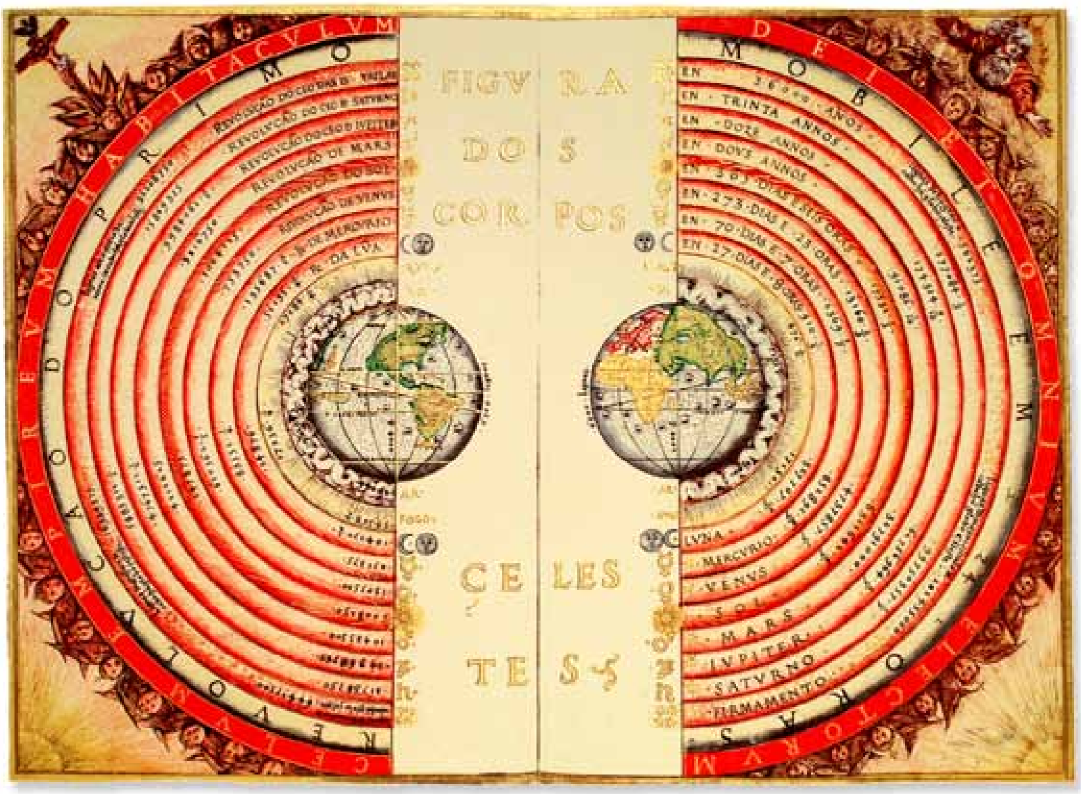


Figure 4: The 16th century geocentric model of the cosmos, depicted in Bartolomeu Velho's *Cosmographia* (1568)

Image courtesy of Carla Isabel Ribeiro

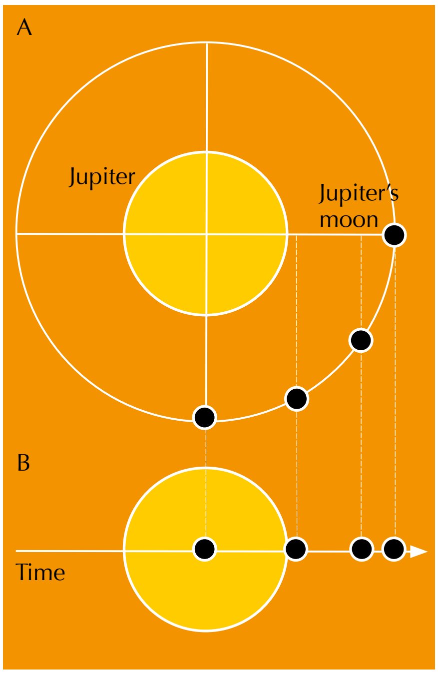


Figure 3: The movement of one of the Galilean moons around Jupiter: A) as seen from above the orbit plane and B) as seen from Earth (viewed parallel to the orbit plane). The black dots represent the Galilean moon's positions at equal intervals of time.

Simple harmonic motion and uniform circular motion

Simple harmonic motion (SHM) is the term used to describe regular periodic motions such as the swinging of a pendulum or the oscillations of an object attached to a spring. Plotting a graph of these motions (distance from the central point against time) produces the characteristic form of a sine wave (figure 2).

SHM can be interpreted as a projection onto one axis of an object that is moving with a uniform circular motion (UCM). For example, imagine an object moving in a circle in a horizontal plane. If we view this from the side at 'eye level' (equivalent to projection onto the x axis), we see a to-and-fro motion exactly the same as that of an oscillating object attached to a spring. Only when viewing the motion from above would we see the movement as circular.

This relationship between SHM and UCM can be applied to the Galilean moons as seen from Earth: their movement appears to be SHM, due to the projection of their UCM around the planet onto our direction of vision (figure 3). (The orbits are slightly eccentric, but only to a small degree, so the moons can be considered to have a circular orbit and to move at constant speed.)

Cosmology in Galileo's time

Galileo's observations of Jupiter's moons were made during a time of scientific transition, from the geocentric (Earth-centred; figure 4) model of Aristotle and the Catholic Church to the heliocentric (Sun-centred) model.

Galileo, of course, was to take up the heliocentric model explicitly some years later, in a direct challenge to Catholic doctrine. However, his telescopic observations, published in his book *Sidereus Nuncius* (*Starry Messenger*) in 1610, were already causing friction by contradicting the teachings of Aristotle. In Aristotle's model, everything in the cosmos orbits Earth – so the idea of moons orbiting the planet Jupiter was at odds with this.

The project step by step

Step 1: 17th century cosmology

Ask your students to research the cosmological ideas that were current in early 17th century Europe. What effect might they have had on Galileo, his investigations and conclusions? Students should also read excerpts from *Starry Messenger*[w1], in which Galileo describes his observations and conclusions.

Images courtesy of Stellarium

Images of Jupiter and the Galilean moons on 7, 8, 10 and 11 January 1610 as simulated by the freeware programme Stellarium.

Step 2: choose the planetarium software

You will need to download the freeware planetarium programme Stellarium[w2] or a similar simulation. Then divide your students into four groups, and assign each group to one of the four Galilean moons (Io, Callisto, Ganymede or Europa).

Step 3: tracking Jupiter's moons

Ask your students to use Stellarium to investigate the position of their moon over time: in a table, each group should record the displacement (x) – the distance of their moon from the centre of Jupiter – at a succession of times (t). They will also need to find the maximum displacement (A) of the moon from the planet's centre.

Measurements should be taken at intervals that differ between the four moons, depending on their distance to the planet and, therefore, their orbital period. The students should use trial and error to find the most appropriate interval for their moon. Their aim is to obtain at least 10 measurements, one of which should be A.

For example, Io is the moon that is closest to Jupiter, which means it orbits most quickly. If the students take their measurements at 1 h intervals, the data will not be sufficient; 15 min intervals would be more appropriate. For one of the more distant Galilean moons, 15 min intervals would result in more data than is necessary, so a longer interval should be used.

To find the centre of the planet on Stellarium, your students can use the red marks around Jupiter (figure 5) to draw two lines that cross at its centre. To find the distance from that point to the moon being studied, they can either use an image programme or print off the screenshots and measure the distances with a ruler.

Images courtesy of Stellarium

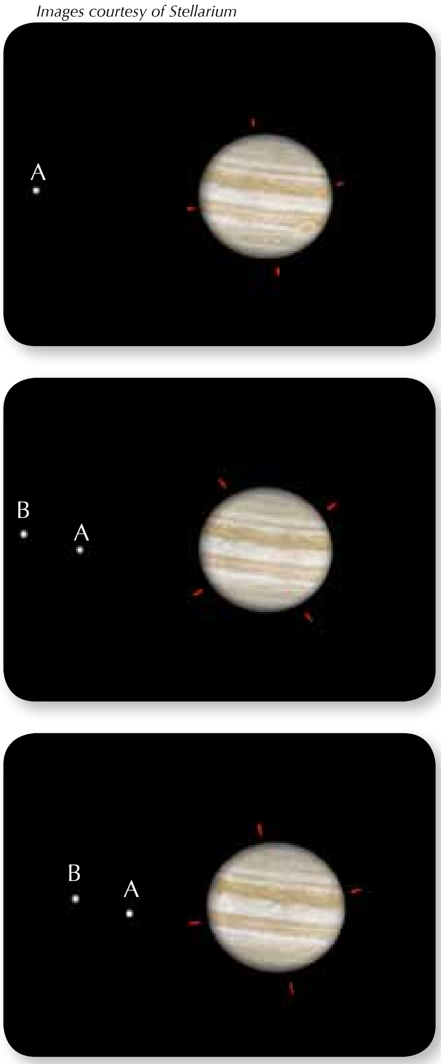


Figure 5: Simulation with the freeware programme Stellarium of Jupiter and its moons Europa (A) and Io (B).

Step 4: testing Galileo's conclusion

The fourth and most complicated step is for students to show that Galileo was right when he concluded that the SHM he observed is produced by a moon's UCM around its planet.

To find the orbital period T of their moon, the students will need the mathematical equation for SHM:

$$x = A \times \sin(\omega t + \varphi) \quad (1)$$

where ω is the angular frequency and φ is a constant (the phase constant), together with the equation linking ω and T:

$$\omega = 2\pi / T$$

Image courtesy of Carla Isabel Ribeiro

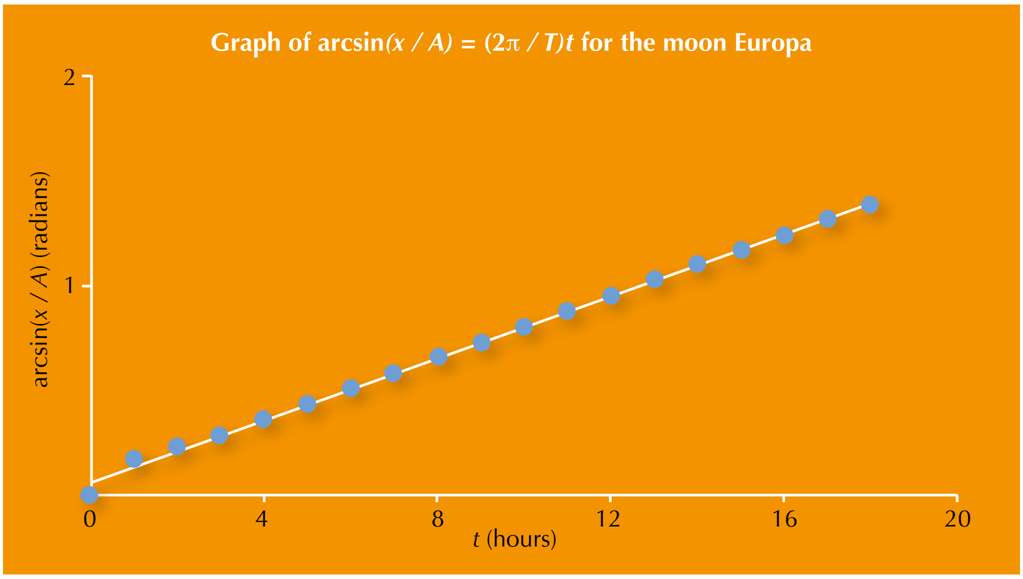


Figure 6: A graph of arcsin (x / A) = (2π / T)t for the moon Europa, using observations made with the software Stellarium. The orbital period, T, of the moon can be calculated from the gradient, 2π / T, and the phase constant of the moon, φ, is the intercept on the y axis.

where x is the displacement, A the amplitude of the motion or maximum displacement, t is the time and φ is a constant (the phase constant).

Equation (1) can be transformed into the linear equation (2), thus:

$x = A \times \sin(\omega t + \varphi)$ (1)

$\Rightarrow x / A = \sin(\omega t + \varphi)$

$\Rightarrow \arcsin(x / A) = \omega t + \varphi$

Since $\omega = 2\pi / T$

$\Rightarrow \arcsin(x / A) = (2\pi / T)t + \varphi$ (2)

If your students observe an object behaving according to equation (2) – which describes SHM – then it is reasonable to conclude that it is orbiting the planet as a moon.

Because equation (2) is linear, we can see that if your students use their data from step 3 to plot a graph of $\arcsin(x / A)$ against t, the gradient will be $2\pi / T$, from which they can easily calculate the orbital period T. The phase constant of the moon, φ, is the intercept on the y axis. Figure 6 shows an example of a graph that your students could plot using data for the moon Europa.

The graph above has a gradient of 0.0741.

Since the gradient is equal to $2\pi / T$, it follows that:

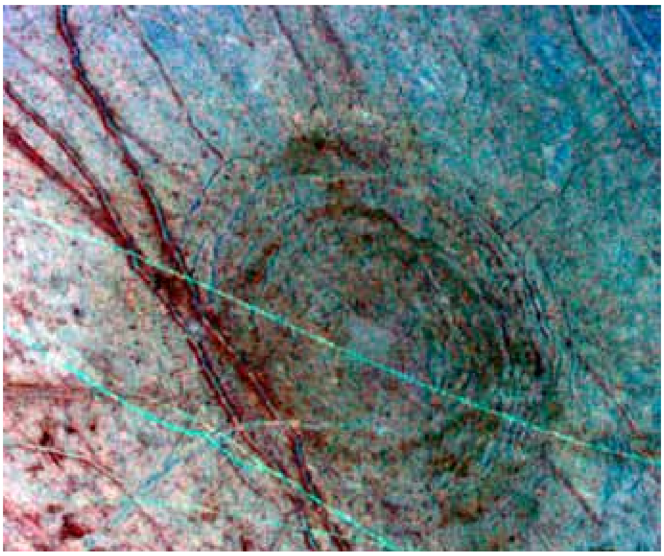
$2\pi / T = 0.0741$

$\Rightarrow T = 2\pi / 0.0741$

$= 84.8$ h

The more mathematically able students could then carry out a regression analysis of the data to test the 'goodness of fit' to equation (2). The value obtained in the case of Europa

Image courtesy of the Lunar and Planetary Institute



An impact scar, 140 km wide, on Europa. It formed as the surface fractured minutes after a mountain-sized asteroid or comet slammed into the satellite.

Image courtesy of NASA Planetary Photojournal

An active volcanic eruption at Tvashtar Catena, a chain of giant volcanic calderas on Io, in November 1999. This image was captured by NASA's Galileo spacecraft.

Public domain image; image source: Wikimedia Commons

Galileo Galilei shows the Doge of Venice how to use his telescope (HJ Detouche, 1754)

Public domain image; image source: Wikimedia Commons

A replica of the earliest surviving telescope attributed to Galileo Galilei, on display at the Griffith Observatory, Los Angeles, CA, USA

($R^2 = 0.998$) shows that the data comply closely with the equation, and thus confirms that this object behaves like a moon in orbit.

The accepted value for Europa is about 3.55 days (85.2 h), which is quite similar to the value calculated above. The difference between the two values can be a good starting point for a discussion about the accuracy of experimental results. What might have gone wrong? Were any errors random or systematic?

In this case, the error may have its origin in the measurement of *A*, since the moon's positions were simulated 1 h apart, and the maximum displacement could have been reached between two measurements. You could ask your students to suggest ways to minimise this error.

Step 5: presenting the results

The last step is for each group of students to present their work, describing the whole investigation and showing their results. In science, it is important to communicate, so you could get your students to make their presentations to students in another class, or perhaps as part of a school fair or open day. They should think about how best to communicate their work. How can they make it simple for others to understand? What images could they use to help explain what they did?

More ambitiously, you could even set up a collaboration with a school in another country. Scientists sometimes have to communicate in foreign languages – often, but not always, English. Based on this project, I am hoping to set up an international collaboration through the eTwinning network[w3]. On a smaller scale, I would also be happy to hear from other schools that would like to work together on the project.

Reference

Ribeiro CI (2012) Io and its simple harmonic motion. *Physics Education* **47**: 268-270. doi: 10.1088/0031-9120/47/3/F04

Web references

w1 – Download a recent English translation of *Sidereus Nuncius* (*Starry Messenger*), Galileo's famous early work describing discoveries made with the telescope. Pages 17 and 18 contain his observations of the moons of Jupiter for the dates featured in this project. See: http://homepages.wmich.edu/~mcgrew/Siderius.pdf

The original edition is also available online. See: www.rarebookroom.org/Control/galsid

w2 – Stellarium, the planetarium simulation used in the project, can be downloaded free of charge. See: www.stellarium.org

w3 – The eTwinning website promotes school collaboration in Europe through the use of information and communication technologies (ICT). Available in 23 languages, it has nearly 50 000 members and more than 4000 registered projects between two or more schools across Europe. See: www.etwinning.net

Resources

The Physclips website offers a clear explanation of simple harmonic motion, with video and animation. See: www.animations.physics.unsw.edu.au

NASA's Solar System Exploration website offers up-to-date information about Jupiter and its moons, including space missions. See: http://solarsystem.nasa.gov/planets

For an article describing a similar project exploring the Galilean moons, using a telescope equipped with a charge-coupled device (CCD) camera, see:

de Moraes IG, Pereira JAM (2009) Using simple harmonic motion to follow the Galilean moons – testing Kepler's third law on a small system. *Physics Education* **44**: 241. doi: 10.1088/0031-9120/44/3/002

The article can be downloaded free of charge from the website of the University of Picardie, France, (www.u-picardie.fr/~dellis/Documents/PhysicsEducation/Not_Experimental) or via the direct link: http://tinyurl.com/blfc4k6

Project CLEA (Contemporary Laboratory Experiences in Astronomy), hosted by Gettysburg College, USA, offers laboratory exercises that illustrate modern astronomical techniques. Each exercise consists of a dedicated computer programme, a student manual, and a technical guide for the teacher. Several of the exercises involve Jupiter's moons. See: www3.gettysburg.edu/~marschal/clea/CLEAhome.html

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

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Carla Isabel Ribeiro teaches chemistry and physics at a public Portuguese school, and is particularly interested in astronomy. For the past 12 years, she has taught students ranging in age from 13 to 18.

Physics

Europa photographed by Voyager 2 during its close encounter on 9 July 1996

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

Science in the open: bringing the Stone Age to life for primary-school pupils

Taking pupils out of the classroom opens up a whole range of activities for teaching young children about the natural world.

By Petra Breuer-Küppers

The Stone Age might not have been a fun time to live in for our ancestors, but finding out about it can be an enjoyable and educational experience for younger children.

For the past decade, my colleagues and I have run an educational initiative called 'a week on the meadow' in our small school, which caters for pupils aged 6-18 who have special educational needs. It started life as a break from routine, a chance to give the younger children a breather from the daily timetable of classroom-based learning. But it has evolved into an educational tool for teaching a wide range of topics centred on science, and one we think can be easily adapted for primary-age children of all abilities.

Every year, for a week in spring or summer, two classes of mixed-aged pupils (ages 6-11), 20 to 30 children in all, swap the classroom for a nearby

Image courtesy of Ramessos; image source: Wikimedia Commons

Replica of one of the Stone Age paintings in the Altamira cave in Spain. The cave's discovery in 1880 sparked a debate about whether prehistoric humans had the intellect to produce any kind of artistic expression.

Image courtesy of Traitor; image source: Wikimedia Commons

A Stone Age arrowhead

Image courtesy of garethwiscombe; image source: Wikimedia Commons

Stonehenge is a famous Stone Age monument in Wiltshire, UK.

Drawing of a typical Stone Age hand axe

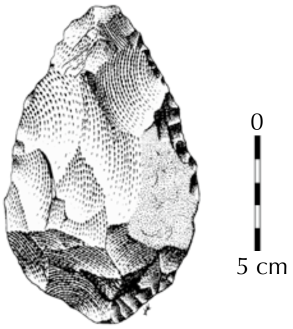
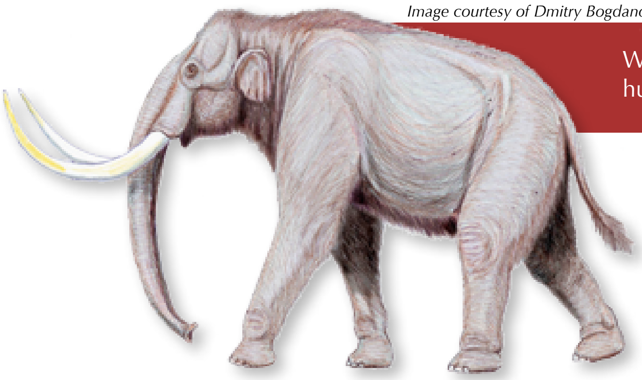


Image courtesy of José-Manuel Benito; image source: Wikimedia Commons

Image courtesy of Dmitry Bogdanov; image source: Wikimedia Commons



Woolly mammoths were hunted in the Stone Age.

meadow to learn in the open air. Initially, my colleague and I ran the project alone; in the past few years, we have had the help of a trainee teacher and a university student. We also have the support of a local farmer, who lends us the meadow and gives us access to his fields, and a local scout group who provide us with a yurt in case it rains. With these simple facilities, we spend our days learning about nature, focusing on a different theme each year. In 2010, we investigated life in the Stone Age.

Although we are teaching children with special needs (such as learning disabilities, concentration problems and movement disorders), the beauty of the week on the meadow is that it can incorporate a whole range of activities pitched at different interests and ability levels.

A meadow with nearby trees and a stream is ideal, because it can be used to teach a range of topics including plants, insects, nutrition and even building simple structures. However, the concept is flexible enough to be adapted to a range of locations and subjects – in previous years, we have used the themes of pirates, knights and ladies, the Middle Ages, horses, farm animals, ships, flight and the Olympic games. And if you don't have access to a meadow, you could perhaps use a local park.

The project begins a week before we head to the meadow, with a box of books about our chosen theme: in this

REVIEW

- **Physics**
- **Environmental education**
- **Technology**
- **Ages 10-15***

Setting up a Stone Age camp for primary-school children is an excellent example of interdisciplinary teaching and learning. It combines physics, environmental education, technology and as many other disciplines as the teacher wishes to include.

The proposed activities are novel and offer an alternative way of teaching many scientific and technological issues such as building a tent, collecting, identifying and naming herbs, and basic mechanics (shooting with an arrow). I am not aware of any school in my country (for either special or mainstream education) that offers such opportunities to its students.

It is probably not easy to organise such an activity but neither would it be impossible. And although the first time might be difficult, the following years should be easier. With proper preparation by the teachers and the appropriate support from the school authorities and the parents, the pupils will gain much more from the project than they would by staying in the classroom setting. In addition, getting help from people or groups (e.g. farmers or scout organisations) outside school should also offer many educational and social benefits to the pupils.

Instead of taking place on a meadow, the activities can undoubtedly also be transferred to a nearby park or riverbank, which are easier to find in a city.

Christiana Nicolaou, Cyprus

*Note that the author performs the activity with students aged 6-11.

General science

Primary

We used a yurt as a shelter from rain and to store our materials.

Image courtesy of Petra Breuer-Küppers

Image courtesy of Petra Breuer-Küppers

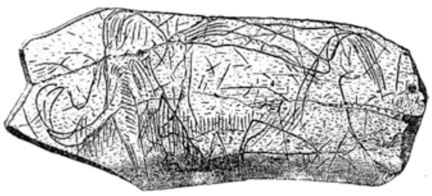
The children dug a latrine and then built a screen around it. Gathering materials and building a screen turned into an interesting activity in its own right. The children had to think about design requirements – such as withstanding moderate wind and rain, and hiding the user from sight. Such activities are an opportunity to learn about basic science and technology through trial and error.

Our pupils first tried building a tent-like structure, but that proved too small to get into. A second, more successful attempt taught them that using long, thick sticks, they could build a bigger and more solid structure, but that for privacy, the gaps needed to be filled with smaller things like grass, moss and leaves.

case, the Stone Age. As a class, we talk about different aspects of our chosen topic: for example, about the landscape, the wildlife that roamed over it and how humans lived at the time – hunting animals, gathering plants, living arrangements, family life, tools and so on. Keen children can do some extra reading in their free time.

The real fun starts when we arrive at the meadow on the first day. On arrival, the children can freely explore the area they will be getting to know

Image courtesy of Project Rastko; image source: Wikimedia Commons



over the next few days. Conditions are a lot more basic than the kids are used to. For the first few years that we ran the project, we didn't even have toilets; instead, the children dug a latrine and built a screen out of sticks, grass and leaves. Even once the farmer had provided portable toilets, we still managed without clean running water: for washing hands and food, we took water in canisters; for washing paintbrushes, we used water from the stream. It is certainly useful to have a shelter (we used a yurt) to store equipment overnight, or for the pupils to shelter in during the day if it rains, but otherwise the infrastructure requirements are minimal. Indeed, the basic conditions can actually be turned into a learning experience. And of course, it makes the pupils appreciate their return to the 21st century when they go home each evening.

For several of our themes, a big part of the project has been finding out about how people fed themselves. This is a great chance for interdiscipli-

Image courtesy of Locutus Borg

Stone Age tool from the Western Sahara desert, Africa

Image courtesy of josem.rus; image source: Flickr

The gantija temple is a Stone Age temple complex on the island of Gozo, Malta. It is more than 5500 years old, making it older than the pyramids of Egypt.

nary learning, which combines a wide range of activities that can be tailored to different levels, covering different topics across science and technology.

For example, in our Stone Age project, one group activity involved learning about hunting. The hunters' group – which was popular with girls as well as boys – made bows and arrows out of branches and string[w1], and learned how to use them. Having a small forest nearby to gather sticks and branches from was a big help, but of course it would also be possible to provide the raw materials from elsewhere if necessary.

This activity offers considerable opportunity for experimentation and problem solving[w2]. Which kind of wood works best? How thick? How dry? And how best to shoot the arrows? Is it better to fire upwind or downwind? Should you aim horizontally or upwards? Do feathers make the arrow fly straighter? The pupils spontaneously asked many of these questions themselves, but teachers can also help to structure the exercise by making suggestions and pointing the children in the right direction.

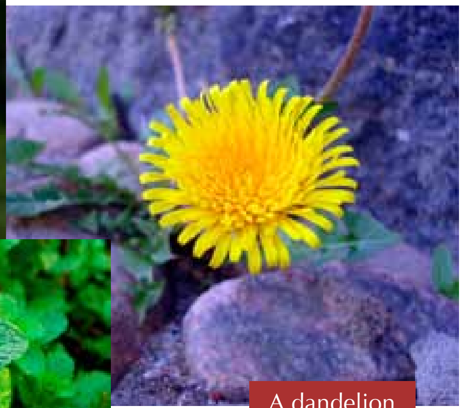
Of course, the companion to hunting is gathering. We have tried a range of gathering activities in several of our weeks on the meadow, as a way to

Image courtesy of Project Rasko; image source: Wikimedia Commons

Image courtesy of Fir0002; image source: Wikimedia Commons

Chamomile

Image courtesy Anja Jonsson; image source: Flickr



A dandelion

Mint

Image courtesy of Zeetz Jones; image source: Flickr

learn more about plants and food. For example, one group collected herbs, such as chamomile, mint and lemon balm for infusions. A lot of children were not familiar with these, so we held a tasting session and smelled the plants before and after steeping in hot water[w2].

Another group gathered edible leaves such as dandelions to make a salad, which the class ate together. A third group gathered wheat grains from the farmer's fields, ground them into flour and made flatbreads[w3], testing different cooking methods, including over an open fire and on hot stones.

As well as contributing to the bread-making activity, building a fire is a way of learning about which materials

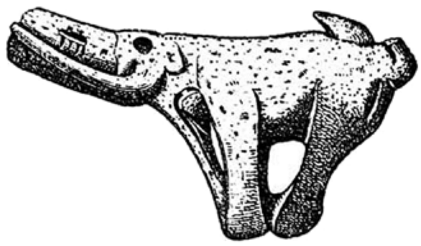


Image courtesy of Project Rasko; image source: Wikimedia Commons

burn well, and how to avoid damaging the landscape by using local material like sand, earth and water from the stream to tidy up afterwards. It also plays a role in the final stage of our week on the meadow: inviting the parents to see what their children have learned.

With this sort of project, safety is obviously an important consideration. However with sensible precautions we have had only one minor accident in 10 years. Our meadow is fenced, and we use barrier tape to restrict the children to just part of it; pupils who do not stay within the limits of the tape are sent back to school. At all times, each child is part of a group that is the responsibility of one adult.

We also take specific precautions depending on the activities. For example, it is vital to correctly identify edible plants[w4], be aware of any local parasites or other health hazards, and not to allow the children to eat anything without the permission of a teacher. Similarly, activities involv-

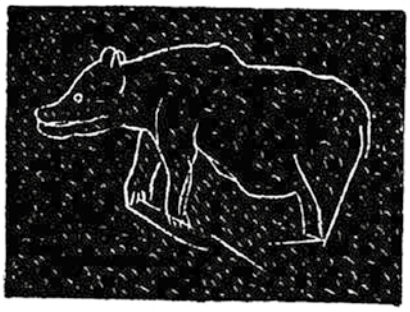
Image courtesy of Petra Breuer-Küppers

Bows made by the children.

Image courtesy of Petra Breuer-Küppers

Investigating what makes a good bow and arrow.

Image courtesy of Project Rastko; image source: Wikimedia Commons



ing fires or bows and arrows must be closely supervised.

The precise activities you choose for your project will depend on your theme and on the site you use. We have always strived, however, to include hands-on activities. For instance, the year that our theme was horses, we had a real horse that the children could ride and groom, we made horses out of wood and created jewellery for the horse's mane, to name just a few activities. When we used the theme of pirates, the children made paper boats and raced them on the stream, learned how to sword fight, played games that involved boarding other ships, and made pirate clothes and eye patches.

Whatever the current year's theme, on the last day, we set up exhibitions of what the different groups have been doing. For example, parents get to see the bows and arrows, and the children explain how they are made and used. The class presents the different types of fuel that they have experimented with in the fire, and demonstrate which ones burn better or less well. The gatherers invite the parents to try the different types of herbs and plants they have collected throughout the week.

As well as being a chance to show off what they have learned, this session reinforces learning by enlarging the children's vocabulary and teaching them how to present the results of an experiment. At first, we feared this more transparently didactic element of the week on the meadow might make the activities less fun for the children, but in fact it turned out to be a source of motivation. Moreover, it helps broaden the scientific and technical learning of the week by adding a linguistic dimension.

The central part of the final day is cooking up a big pot of soup out of freshly picked vegetables and plants from the meadow and the fields – another opportunity to learn about plants, but also a more general introduction to healthy eating, and a shared experience for children, parents and teachers. For most of our pupils, many of whom come from disadvantaged backgrounds, this is the first time they have tried soup prepared from fresh ingredients. Over the years, we have seen that pupils take the idea of freshly prepared food back home with them – a perfect example of how practical and theoretical elements come together.

Image courtesy of Petra Breuer-Küppers

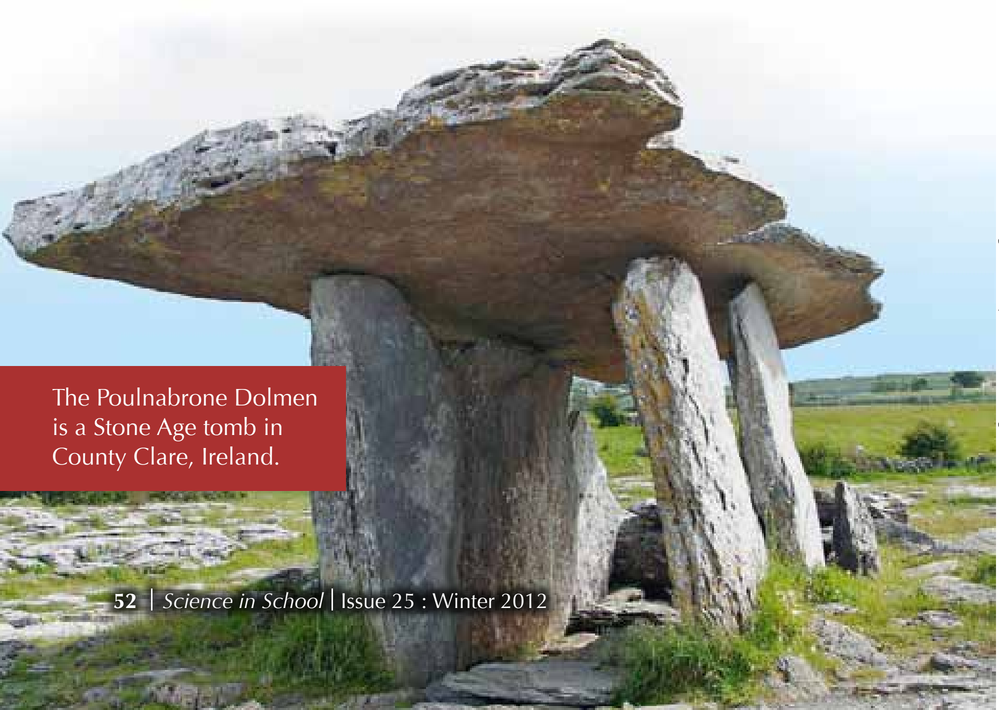
This was the first homemade soup that some of our pupils had ever tasted.

The week on the meadow provides a flexible framework in which a range of activities can be anchored, and which can be developed and chosen by the teachers and pupils together. For instance, in addition to the core science content of our week in the meadow, we also find time for songs and games, handicrafts, and have even fitted in a visit from a local beekeeper. It is also an opportunity to bring in outside partners – in our case, the farmer, the beekeeper and the local scout group – further breaking the routine of classroom learning.

Finally, it represents a holistic way of teaching, combining different aspects of science with practical activities that have a real impact on the children's lives.

Web references

w1 – The Internet offers a wealth of instructions for building bows and arrows of different levels of sophistication. The Instructables website offers one example of how to make a simple bow and arrow. See www.instructables.com/id/How-to-Make-a-Bow-and-Arrow or use the shorter link: http://tinyurl.com/c6wap4w



The Poulnabrone Dolmen is a Stone Age tomb in County Clare, Ireland.

Image courtesy of Soerfm; image source: Wikimedia Commons

Image courtesy of Project Rastko; image source: Wikimedia Commons

Cuevas de las Manos (Spanish for 'cave of the hands') in the province of Santa Cruz, Argentina. The artwork in the cave dates back 9300 years and was created by spraying paint from a bone pipe onto the artists' hands.

Image courtesy of Marianocecowski; image source: Wikimedia Commons

w2 – More details of how we organised the activities can be downloaded from the *Science in School* website: www.scienceinschool.org/2012/issue25/stoneage#resources

w3 – We used a recipe for flatbread (Preetzer Stockbrot) on the Chefkoch website (in German). See www.chefkoch.de or use the direct link: http://tinyurl.com/cnaxzk6

A similar recipe (for chapattis, in English) is available on the BBC website. See www.bbc.co.uk/food or use the direct link: http://tinyurl.com/3yduntu

w4 – When looking for resources to help you identify herbs, you will need one that describes the plants found in your part of the world. As one of our resources, we used a Swiss guide, *Essbare Wildpflanzen*. See the Ökoforum website (www.oeko-forum.ch) or use the direct link: http://tinyurl.com/78eoqe5

Resources

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Danks F, Schofield J (2007) *Nature's Playground: Activities, Crafts, and Games to Encourage Children to Get Outdoors*. Chicago, IL, USA: Chicago Review Press. ISBN: 978-1556527234

Danks F, Schofield J (2009) *Go Wild!: 101 Things to Do Outdoors Before You Grow Up*. London, UK: Frances Lincoln Publishers. ISBN: 978-0711229396

Hurdmann C (2012) *Hands-On History! Stone Age: Step Back to the Time of the Earliest Humans, with 15 Step-by-Step Projects and 380 Exciting Pictures*. San Francisco, CA, USA: Armadillo Books. ISBN: 978-1843229742

Fischer-Rizzi S (2012) *Cook Wild: Year-Round Cooking on an Open Fire*. London, UK: Frances Lincoln Publishers. ISBN: 978-0711232815

Kallas J (2010) *Edible Wild Plants: Wild Foods From Dirt To Plate*. Layton, UT, USA: Gibbs Smith. ISBN: 978-1423601500

Karlin M (2009) *Wood-Fired Cooking: Techniques and Recipes for the Grill, Backyard Oven, Fireplace, and Campfire*. Berkeley, CA, USA: Ten Speed Press. ISBN: 978-1580089456

Meyer K (2011) *How to Shit in the Woods: An Environmentally Sound Approach to a Lost Art*. 3rd Edition. Berkeley, CA, USA: Ten Speed Press. ISBN: 978-1580083638

If you found this article inspiring, why not browse the rest of the *Science in School* articles for primary school? www.scienceinschool.org/primary

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Petra Breuer-Küppers has been a schoolteacher for 25 years. After studying biology, physics and music, she worked as a teacher in both mainstream and special-needs schools. She is now based at the University of Cologne, Germany, studying for a PhD and teaching university students. She is particularly interested in teaching science to primary-school classes, doing experiments and improving language skills. She can be contacted at pbreuerk@uni-koeln.de, and is happy to give insights or advice to teachers who want to adapt the week on the meadow concept.

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

General science

Primary

Image courtesy of Nicholas_T; image source: Flickr

Your local meadow might not be as spectacular as this one in New Jersey, USA, but that doesn't matter – it's how you use it that counts!

Orthodontists hold the key to a nice smile.

Image courtesy of lanuiop; image source: Flickr

Image courtesy of Trypode; image source: Flickr

The changing face of orthodontics

Many of us have had our teeth straightened with braces. Few people know, however, that orthodontics involves a great deal of fundamental science and fast-moving technology.

By Sophie and Georges Rozencweig

Image courtesy of Jenn and Tony Bot; image source: Flickr

Most of us are familiar with orthodontics as a kind of mechanical engineering inside the mouth – all those metal braces, plates and wires. But how many of us are aware of the different sciences involved in this area of dentistry? Today's orthodontists have to understand and apply a good deal of specialist science – everything from genetics to metallurgy.

What is orthodontics?

Orthodontics is the branch of dentistry concerned with diagnosing and correcting irregularities of the teeth and jaws. It is used for far more than achieving a perfect Hollywood smile: our jaws and teeth are used for talking as well as chewing, so orthodontics is concerned with how facial anatomy affects these functions, as well as with cosmetic improvements.

As orthodontists, we are always seeking the latest insights and techniques from relevant scientific fields and applying them to our work.

In this article we will look at several examples. Some are on the opposite page.

Growth and development: faces change as they mature and age, due to alterations in body tissues. Understanding these processes allows us to positively influence them.

Physics: many orthodontic resins can be cured (polymerised) using light. Four main types of polymerising light source are available: halogen bulbs, plasma arc lamps, argon ion lasers, and light-emitting diodes.

Genetics: we need to be able to diagnose whether a problem has a genetic cause, so we can treat it effectively.

Image courtesy of Joël Rozencweig

Metallurgy and materials science: as well as metals, we use alginates and silicones for taking impressions, composites and glass ionomer cements for sealing and sticking, plaster for making casts, and resins for creating removable appliances. We need to understand each material's physical and chemical properties to use them in the best way for each patient.

Radiology: radiographs help us to diagnosis complex problems. We use many different types of radiographs, to provide views from different angles (frontal, profile or panoramic) or exploit different imaging techniques (scanners, magnetic resonance imaging and cone beam computed tomography).

Physiology: everyone is different in precisely how they breathe, chew, swallow and speak. Function and form are closely related, so these processes form part of each patient's diagnosis and treatment plan (figure 1, page 56).

Microbiology: by teaching our patients about oral health and plaque removal, we help prevent tooth decay and gum disease.

Biomechanics: we apply the laws of mechanics to adjust the position of teeth. We need to ensure that the forces resulting from our work produce only the movements that are needed.

Biology

Physics

REVIEW

- Physics
- Biology
- Chemistry
- Dentistry
- Molecular biology
- Genetics and inheritance
- Transcription and translation
- Stem cells
- Properties of metals, alloys, composites, smart materials
- Ages 16+

Everybody has an experience of visiting the dentist: for some, these visits involve nothing more than a quick poke around and a polish; for others, it can be a very traumatic experience.

However, to what extent do we understand the role of a dentist? In the UK, all dentists must undergo a 5-year period of study to gain a primary dental qualification. Those who wish to specialise in orthodontics will need both dentistry experience and a further 3-year specialist qualification. In addition to clinical training and practice, the dental student will learn about molecular biology, anatomy and physiology, materials science and human disease. As a dental student with whom I was at university put it, "It's all connected, you know!"

Dentistry is a career many young people choose to study at university. However, certainly in UK schools, very little (if any) time is spent studying the mouth, teeth or dental science. This article provides excellent reading material for those students who are thinking of a career in dentistry. It could be used by teachers to provide an introduction to dentistry and its subspecialties, and to help students make an informed choice about their prospective careers.

In addition, the article provides an alternative context for biology lessons on transcription and translation of DNA, cell signalling and cell differentiation, and totipotent stem cells. Teachers may wish to use the article as a basis for a group discussion or research project; alternatively they may wish to recommend it as background reading material before the commencement of teaching. For physics and materials science lessons, the article also provides an insight into real-life applications of alloys, composites and smart materials. In a social context, the article can serve as a basis to discuss health care in the developing world, using the treatment of cleft palates as an example.

Jonathan Schofield, McAuley Roman Catholic High School, Doncaster, UK

Images courtesy of Sophie and Georges Rozencweig

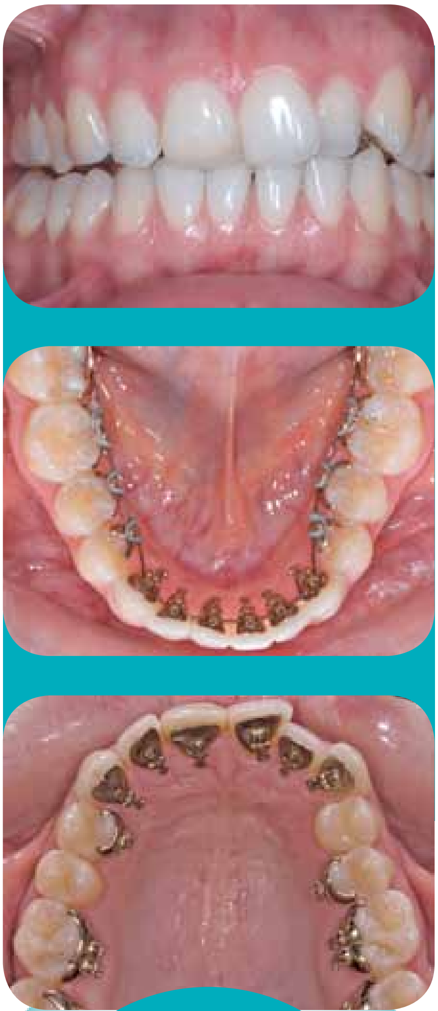


Figure 1:
These state-of-the-art braces are almost invisible, even when the wearer smiles, because they are hidden on the inside of the teeth. In this technique, called lingual orthodontics, every brace is custom-made to fit the teeth using computer and robotic technology.

Genetics and molecular biology in orthodontics

Some of the problems that orthodontists deal with are genetic in origin (figure 2). Although most of these are minor, others result from genetic abnormalities in the way that the head and face develop before birth[w1]. In the embryo, the development of facial structures begins with neural crest cells forming at the site of the brain. These cells then migrate to form a tissue that differentiates into cells called osteoblasts, chondroblasts and odontogenetic cells. These then develop to form the hard tissues of the head and neck – the bones, cartilage and teeth.

During this process, molecules called signalling factors and transcription factors play an important part. Signalling factors are a cell's way of triggering a response in another cell, while transcription factors control which specific DNA sequences are used to produce mRNA and thus proteins. For example, we now know that if the signalling factor TGF-β is inactive, this causes cleft palates[w2] and upper jawbone malformations. Mutations in the receptor sites (where the response is triggered) for the signalling factor FGF also cause a large number of craniofacial abnormalities.

Another example is the transcription factors associated with the homeobox genes. These transcription factors are especially important in enabling the neural crest cells to develop into the skeletal structures of the head and face, so defects in the way these genes are transcribed can lead to abnormalities in facial development.

Another example of the importance of molecular biology to orthodontics is the recent discovery that dental pulp (the area of connective tissue at the centre of a tooth) contains valuable adult stem cells, which can be induced to form other types of cells. Thus when a tooth is extracted or falls out, the stem cells may be harvested and stored for future treatment. Stem cells are already being used to treat some cancers, and additional applications may be on the horizon. For example, researchers are exploring whether stem cells can be used to grow a natural replacement for a missing tooth.

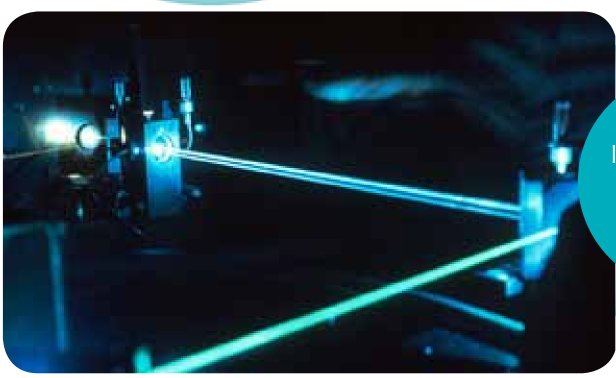
Biomechanics and orthodontics

The amount of force needed to move a tooth depends on its size and the type of movement (turning or sliding). The moving force also needs

Images courtesy of Sophie and Georges Rozencweig

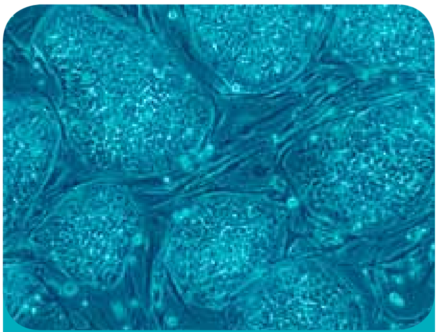
Figure 2:
This patient has mandibular prognathism (a protruding lower jaw) with a genetic cause.

Public domain image; image source: Wikimedia Commons



Argon ion lasers are used to polymerise orthodontic resins.

Images courtesy of Nissim Benvenisty; image source: Wikimedia Commons



Human embryonic stem cells. Researchers are investigating whether stem cells can be encouraged to grow into teeth.

an anchor, so a group of teeth and appliances are selected and used as anchorage (figures 3 and 4).

As orthodontists, our task is to decide on the best combination of forces and anchorage to achieve the right movements, without any adverse effects. We review each stage of treatment to make sure this is happening; if it is not, we need to change the treatment plan.

In traditional orthodontics, appliances such as headgear and intra-oral elastics are used to reinforce anchorage, which require a good deal of patient co-operation. Today, titanium mini-screws can be used instead in some cases (figure 4).

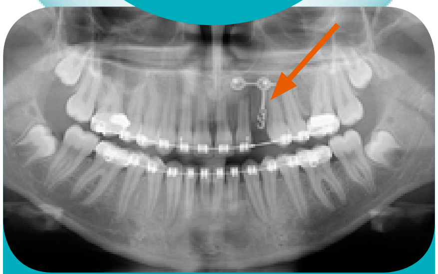
Metallurgy and orthodontics

The forces used in orthodontics come from the archwires (figure 5). At the beginning of the treatment, the wires need to be quite elastic to start individual teeth moving. Later on, the wires have to be more rigid to ensure stability while a whole block of teeth is moved.

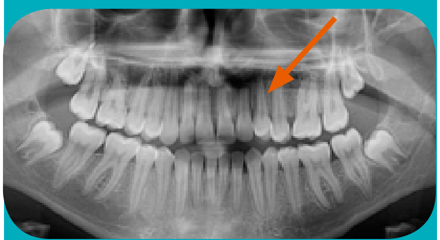
Orthodontists can choose wires made from a variety of metallic materials:

- Stainless steel: this is easy to shape and has high rigidity so it provides stability.
- Nitinol alloys: these nickel-titanium alloys have very high elasticity. They produce a weak but constant force suitable for the initial alignment phases. However, they cannot be soldered.
- Shape-memory alloys[w3]: these metals have variable elasticity depending on the temperature. They can be bent for insertion into the mouth; once there, they 'try' to recover their initial shape, exerting a force on the teeth.

Figure 3:
We removed this patient's ankylosed (abnormally rigid) upper left canine and closed the resulting space using a mini-plate. This system enabled us to close the space without shifting the midline of her smile.



An X-ray taken after the extraction, showing the hole where the upper left canine was removed, and the mini-plate that was used to close the gap.



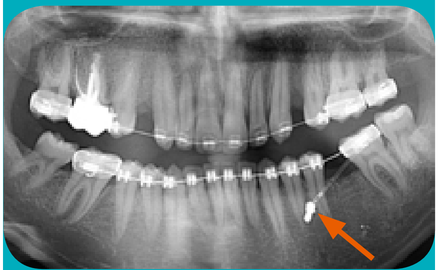
The result: the first upper left premolar has been moved forward to replace the missing canine.

Images courtesy of Sophie and Georges Rozencweig

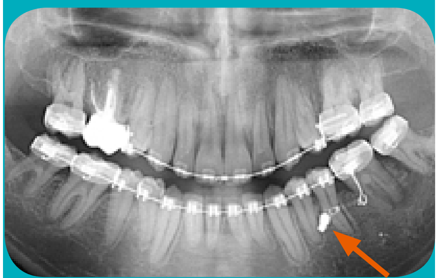
A dynamic discipline

As you can see, orthodontists need to be good all-round scientists to keep up with the changing knowledge and technological innovations in their discipline. So, if a student in your class misses a science lesson because of an appointment with an orthodontist, don't worry – it might be the perfect opportunity to learn about the latest findings in molecular biology, or provide inspiration to a budding materials scientist.

Images courtesy of Sophie and Georges Rozencweig



Early in the treatment, showing the gap left by the removal of the tooth.



The gap has been successfully closed.

Figure 4:
We removed this patient's first left lower molar, then closed the gap using a mini-screw as a fixed, temporary anchorage. The spring attaching the mini-screw to the second left molar is the active mechanism that pulls that tooth forward.

Image courtesy of bluebike; image source: Flickr

Figure 5: The archwires are what connect the braces, acting like an engine to guide and move the teeth. Without the wire, the teeth would never move.

Web references

w1 – See a BBC video clip about facial development in the womb. http://youtu.be/wFY_KPFS3LA

w2 – This animation shows how a cleft palate develops (voiceover in Russian). http://youtu.be/WAU13syh-w4

w3 – The website of the UK's National STEM Centre offers a free downloadable booklet about metals and shape-memory alloys, together with suggestions for teachers on how to introduce the ideas in the classroom, plus student activity sheets and notes for teachers and technicians. See the National STEM Centre website (www.nationalstemcentre.org.uk; 'Metals and smart alloys') or use the direct link: http://tinyurl.com/8gcagcr

Resources

The Archwired website (www.archwired.com), maintained by an adult wearer of orthodontic braces, hosts articles on various orthodontic topics. See: www.archwired.com

For example, how braces work (www.archwired.com/how_braces_work.htm) or a brief history of orthodontics (www.archwired.com/HistoryofOrtho.htm).

Another short history of orthodontics is available on the About.com website (http://inventors.about.com) or via the direct link: http://tinyurl.com/9n2f8cw

The Braces Knowledge Base website, also maintained by a braces wearer, offers comprehensive illustrated information about orthodontic devices. See: www.tanos.co.uk/braces/bkb

The website of the British Orthodontic Society offers information about education and research as well as careers in orthodontics. See: www.bos.org.uk

Dentistry has a surprisingly long history. Recently, a filling was found in the fossilised jawbone of a man who lived 6500 years ago in what is now Slovenia. To learn more, see:

Bernardini F et al. (2012) Beeswax as dental filling on a Neolithic human tooth. *PLOS One* **7(9)**: e44904. doi: 10.1371/journal.pone.0044904

PLOS One is an open-access research journal, so this and all other articles in it are freely available.

Barras C (2012) Oldest dental filling is found in a Stone Age tooth. *New Scientist*. www.newscientist.com or use the direct link: http://tinyurl.com/stoneagefilling

To learn more about how light can be used in polymerisation, see:

Douglas P, Garley M (2010) Chemistry and light. *Science in School* **14**: 63-68. www.scienceinschool.org/2010/issue14/chemlight

To find out more about how stem cells can be used in medicine, see:

Hadjimarcou M (2009) Review of *Potent Biology: Stem Cells, Cloning, and Regeneration*. *Science in School* **11**: 92. www.scienceinschool.org/2009/issue11/potentbiology

Funded by the European Commission, the Eurostemcell website offers information and educational resources on stem cells and their impact on society. See: www.eurostemcell.org

If you found this article useful, you might like to browse the other medicine-related articles in *Science in School*. See: www.scienceinschool.org/medicine

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Sophie and Georges Rozencweig both trained in orthodontics in Paris, France, after which they gained master's degrees in orthodontics from Case University in Cleveland, Ohio, USA. Since 1991, they have shared an orthodontic practice in Grenoble, France.

Both Georges and Sophie are involved in continuing education: they give university lectures, write articles for publication and are on the editorial board of several French orthodontic journals. Georges is the editor of the journal l'Orthodontie Française.

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

Image courtesy of ben matthews ::::; image source: Flickr

A trip to the dentist wouldn't be complete without having every crevice of your mouth explored with a small circular mirror.

Weighing up the evidence: what is a kilo?

We all know what a kilogram is – or do we? Researchers worldwide are working to define precisely what this familiar unit is.

Image courtesy of Stockmonkeys.com; image source: Flickr

Physics

By Eleanor Hayes and Marlene Rau

How much does it weigh? What is its surface area? What is its temperature? These questions may seem simple but the answers only make sense when we have defined a value and a unit. The more widely accepted this unit is, the better the measurements are understood. Just imagine – if I walked seven furlongs to work this morning and you travelled 10 km, who had the longest journey? This is why we need an international system of units.

The first unit to be internationally defined was the metre (figure 1, page 60). It also led to the first international agreement on units, when the 1875 Convention of the Metre in Paris, France, established the International Bureau of Weights and Measures (BIPM, or *Bureau International des Poids et Mesures*) – an organisation that exists to this day.

REVIEW

- **Physics**
- **Chemistry**
- **History of science**
- **Ages 11-19**

This article highlights the importance of having and using an international system of units. It could be very suitable for introductory lessons in physics or chemistry, and could also be used in non-scientific subjects such as languages and history to explain how important it is to follow established conventions (e.g. grammar).

Before reading the text, the following questions could be asked to students to make them start thinking about the concepts explained in it:

1. Is it important to have standard measurement units in science?
2. When do you think the international system of units was established?
3. What could happen if scientists do not use standard units?
4. Can you find an analogy between the international system of units and a concept in a non-scientific subject such as English, history or art?

As the article includes some historical data of the evolution of the international system of units, it could be used for a discussion of the history of science, a topic rarely seen in secondary school. Moreover, these historical details could make students who are not usually keen on science read the article with interest.

Mireia Güell Serra, Spain

Image courtesy of the National Institute of Standards and Technology; image source: Wikimedia Commons

Figure 1: The international prototype metre bar, made of an alloy of platinum and iridium. This bar embodied the international definition of a metre from 1889 to 1960.

Image courtesy of clipart.com

Figure 2: The international prototype of the kilogram: a cylinder of platinum-iridium alloy, 39 mm high and 39 mm in diameter

Initially, the only common units were for length and mass, but the system has evolved over the years. Thus the initial set of units for length and mass was extended to include the standards of electricity, photometry and radiometry, ionising radiation, time and chemistry. The complete set of standardised units is referred to as the International System of Units (SI for *Système International d'Unités*)[w1].

The SI is based on the metric system and consists of both *base units* and *derived units*. The seven *base units*[w2] define a system of independent quantities and their units (see box on page 61). The derived units of the SI define all other quantities in terms of the base units. For example, the SI unit of force, the newton, is defined as the force that accelerates a mass of one kilogram at the rate of one metre per second squared.

A universal system?

A universal set of units has clear advantages, but there is still some way to go before the SI is established globally and to the exclusion of all other systems. Initially established by 17 countries, the BIPM now has 55 member states. Nonetheless, the degree to which the SI has been adopted varies between the members. In both the UK and the USA, for example, miles, pints, and degrees Fahrenheit are still commonly used. Furthermore, even in fully metrified countries, some non-SI units remain popular. These include the minute, day and hour, as well as the hectare, litre and tonne.

The case of the kilogram

The kilogram is the only one of the seven base units to have a prefix ('kilo') in its name. It is also the only one that is still officially defined by a material artefact – all others are defined by fundamental constants or atomic properties (see box on page 61). The international prototype of the kilogram is a cylinder of platinum-iridium alloy, machined in 1878 and preserved at BIPM (figure 2).

Over the years, several official copies have been produced and distributed to various national metrology offices (metrology is the scientific study of units and measurement). With the aid of modern technology, the mass of the prototype and its copies can now be compared with very high precision (up to 1 microgram), revealing significant variation (figure 3, page 61).

It is, therefore, high time for an absolute definition of the kilogram. This will not involve changing the mass of the kilogram. What will change is the way in which the kilogram is defined:

Image courtesy of the Swiss Federal Institute of Metrology METAS

Even in a vacuum where there are relatively few atmospheric gas molecules, some of them will adsorb to the surface of a prototype kilogram, adding to its weight. By using two prototypes, each with the same volume but different surface areas, scientists can account for the contribution that adsorbed gas molecules make to a prototype's weight.

BACKGROUND

Physics

The definitions of the SI base units

Base quantity	Base unit	Definition according to the International Committee of Weights and Measures (CGPM)	Date of the current definition
Length	Metre (m)	The length of the path travelled by light in a vacuum during a time interval of 1/299 792 458 of a second	1983
Mass	Kilogram (kg)	The mass of the international prototype of the kilogram	1901
Time, duration	Second (s)	The duration of 9 192 631 770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of a caesium-133 atom	1967/68
Electric current	Ampere (A)	That constant current which, if maintained in two straight parallel conductors of infinite length, of negligible circular cross-section, and placed 1 m apart in vacuum, would produce between these conductors a force equal to 2 x 10^{-7} newton per metre of length	1946
Thermodynamic temperature	Kelvin (K)	The fraction 1/273.16 of the thermodynamic temperature of the triple point of water	1967/8
Amount of substance	Mole (mol)	The amount of substance of a system which contains as many elementary entities as there are atoms in 0.012 kg of carbon-12	1971
Luminous intensity	Candela (cd)	The luminous intensity, in a given direction, of a source that emits monochromatic radiation of frequency 540 x 1012 hertz and that has a radiant intensity in that direction of 1/683 watt per steradian	1979

rather than being defined as the mass of an object stored in a Paris vault, it will be a reproducible definition based on atomic properties and fundamental constants. Using this new definition, a well equipped laboratory will be able to create from scratch, without reference to the prototype, an object that weighs exactly 1 kg. Or, of course, to test and calibrate scales very precisely.

Furthermore, redefining the kilogram will also affect three other base units: the ampere, the mole and the candela, the definitions of which depend on the kilo (see box above).

Since the 1990s, several approaches have been pursued, two of which

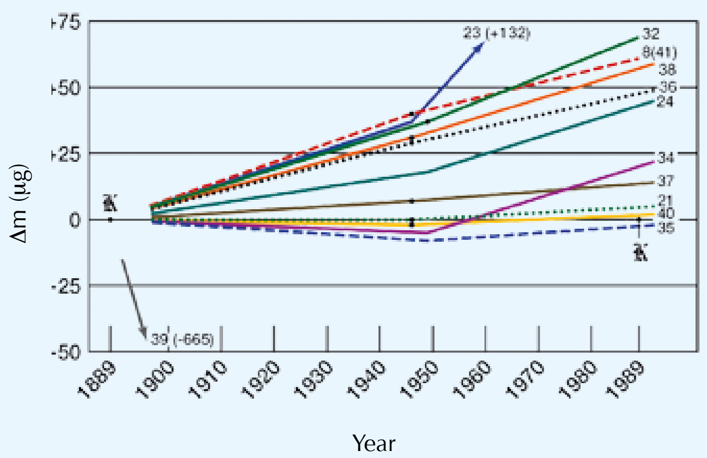


Image source: Wikimedia Commons

Figure 3: A graph of the relative change in mass of selected kilogram prototypes (from Girard, 1994)

Image courtesy of CSIRO; image source: Wikimedia Commons

Figure 4: One of the scientists at the Australian Centre for Precision Optics holding a 1 kg silicon sphere for the Avogadro project, an international collaboration to define the kilogram. This sphere is one of the roundest man-made objects in the world.

Strict rules govern the way in which scientists can handle the platinum-iridium mass prototypes.

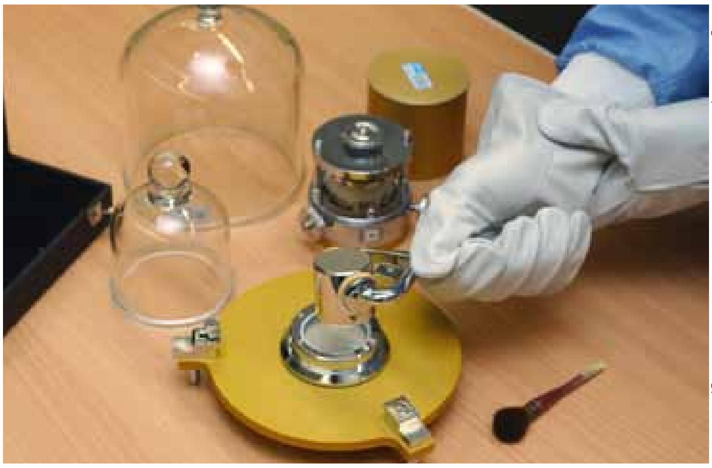


Image courtesy of the Swiss Federal Institute of Metrology METAS

seem promising. Both involve defining the kilogram in terms of an invariant natural quantity: in one case the Avogadro constant, in another, the Planck constant. Both of the approaches also involve measuring the relevant constant to an unprecedented degree of precision.

Defining the kilogram in terms of the Avogadro constant

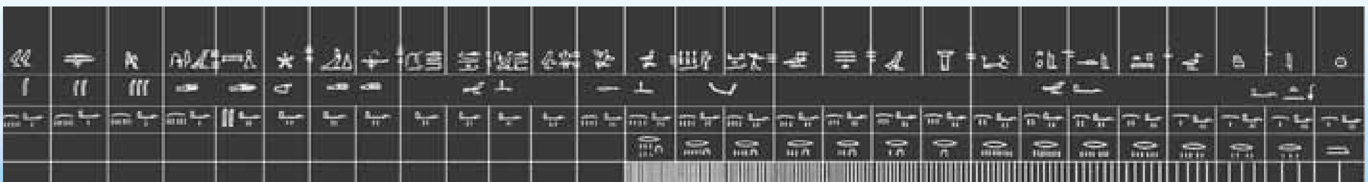
The aim of the international Avogadro project is to define the kilogram as the mass of a specific number of carbon-12 atoms. Under the current definition, Avogadro's number is the number of atoms in 0.012 kg of carbon-12. Thus if we rearrange the equation, we could define a kilogram as the mass of an Avogadro number of carbon-12 atoms x 1000 / 12.

To do this, the project team aims to measure the value of the Avogadro constant (N_A, which has the same numerical value as the Avogadro number, expressed in moles) more precisely than ever before. At the heart of the project is a nearly perfect sphere of silicon (figure 4) weighing exactly 1 kg, as defined by the platinum-iridium prototype. Silicon, rather than carbon-12, was chosen because large, high-purity and almost perfect single crystals can be produced.

The scientists are using a variety of techniques to determine the distance between atoms (the lattice parameter), the crystal density and the mean molar mass of the silicon (which has several isotopes). Using these data, they will be able to calculate the number of atoms in the 1 kg silicon sphere and derive a new and more precise measurement of the Avogadro constant. This could then be used in a new definition of the kilogram (Andreas et al., 2011; Becker et al., 2003):

$$1\ \text{kg} = \text{atomic mass of C-12} \times 0.0012 \times N_A$$

An Egyptian cubit rod, used for measuring length. The Egyptian cubit – like all cubits, based on the length of a forearm – was divided into 7 palms of 4 digits each.



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More about CERN

EIROforum

The European Organization for Nuclear Research (CERN)[w7] 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.

CERN is a member of EIROforum[w8], the publisher of *Science in School*.

See all CERN-related articles in *Science in School*: www.scienceinschool.org/cern

Defining the kilogram in terms of the Planck constant

The other approach to defining the kilogram uses a watt balance[w3, w4]. The watt balance, which compares mechanical and electrical energy, was invented in 1975 and used in the 1980s to better determine the Planck constant by weighing the platinum-iridium prototype of the kilogram. Then scientists realised they could turn the idea around and use the instrument to define the kilogram.

Currently, the Planck constant has been measured to be:

$h = 6.626\ 068\ 96 \times 10^{-34}\ \mathrm{kg\ m^2\ s^{-1}}$

The *values* of fundamental constants, such as the Planck constant, are invariants of nature. However their *numerical values* (e.g. $6.626\ 068\ 96 \times 10^{-34}$) depend on the units (e.g. kg, m, and s) in which they are expressed. Fixing the numerical value of the constant therefore defines the units. In the case of the Planck constant, the metre and second are already defined in the SI. As can be seen in the equation above, therefore, precisely measuring the Parisian kilogram prototype – as will be possible with the watt balance – will allow h to be measured more precisely than before. Once that value is fixed, the kilogram can then be defined in terms of h, m and s, independently of the original prototype.

Worldwide, several metrology institutes are working to develop increasingly precise watt balances. One project, led by the Swiss Federal Institute of Metrology (METAS), includes CERN (see box to the left), which is developing a type of magnet that is crucial to the operation of the balance[w3]. The aim of all the watt balance projects is to reach a new definition of the mass unit – known provisionally as the electronic kilogram – by reducing the uncertainty in their experimental setups to $\leq 5 \times 10^{-8}$. This, however, is no mean feat, due to the precision of the measurements and complexity of the instruments required.

The watt balance built by METAS to perform previous measurements of the Planck constant. A new balance is currently under development.

Image courtesy of the Swiss Federal Institute of Metrology METAS

The outlook

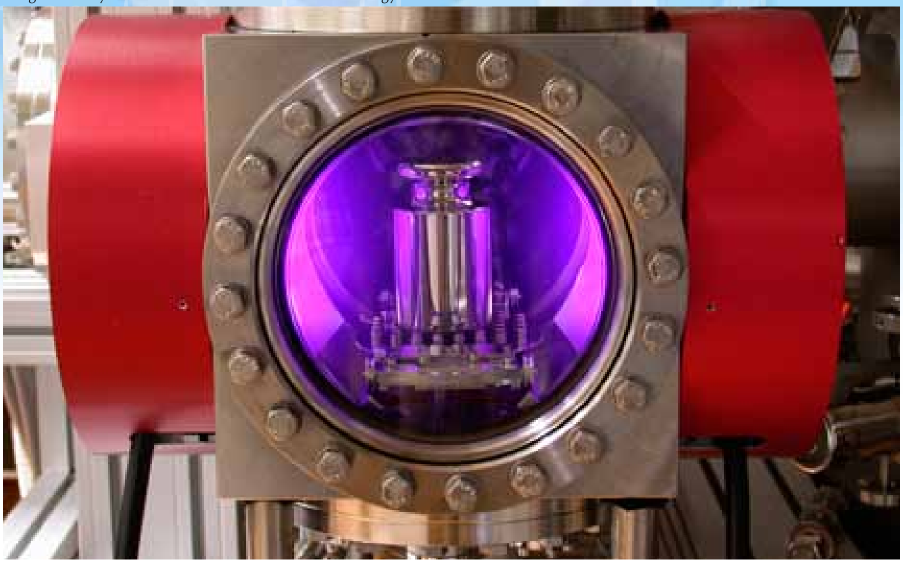
So which of the two approaches will be used to redefine the kilogram? At the BIPM's 24th general conference on weights and measures in 2011, it was proposed that the definition based on the Planck constant should be used. Nonetheless, if the proposal were accepted, the work on the Avogadro constant would not go to waste. For one thing, the Avogadro constant may be used in a new definition of the mole[w5]. And for another, the Avogadro constant provides an alternative method to determine the Planck constant[w6] – thus indirectly feeding into the definition of the kilogram. But that is another story.

Acknowledgement

The authors would like to thank Simon Anders, a physicist based at the European Molecular Biology Laboratory, for his helpful comments on the article.

Physics

Image courtesy of the Swiss Federal Institute of Metrology METAS



A mass prototype is getting a thorough clean in low pressure plasma.

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Web references

w1 – The definitive international reference on the SI is published in French, although an English translation is also available. Both versions can be found on the BIPM website: www.bipm.org/en/si/si_brochure

w2 – Learn more about the seven base units of the SI system. See: www.bipm.org/en/si/base_units

w3 – From the *Science in School* website (www.scienceinschool.org/2012/issue25 /metrology#resources), you can download an explanation of the watt balance (in Word® or as a PDF).

w4 – Visit the BIPM website for more details of the watt balance: www.bipm.org/en/scientific/elec/watt_balance

w5 – To learn more about how the kilogram and the mole may be redefined, see resolution 1 of the BIPM's 24th general conference on weights and measures in 2011. www.bipm.org/en/si/new_si/what.html

w6 – Learn more about the international Avogadro project. www.bipm.org/en/scientific/mass/avogadro

w7 – More information about CERN: www.cern.ch

w8 – EIROforum is a collaboration between eight of Europe's largest inter-governmental scientific research organisations, which combine their resources, facilities and expertise to support European science in reaching its full potential. As part of its education and outreach activities, EIROforum publishes *Science in School*. To learn more, see: www.eiroforum.org

Image courtesy of Arthena; image source: Wikimedia Commons

The flow of sand in an hourglass was one way in which people used to measure time. You may use one today to time how long to boil an egg.

Resources

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

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

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

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Hint: the apps work 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.

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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

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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

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The mystery of altruism

Does true altruism exist? And can science provide the answer?

By Oren Harman

The origin of kindness is a mystery. Where do giving and altruism come from? Were they inherited on the wings of natural selection – a gift bestowed upon us via the inching, evolutionary march of sacrificial amoeba, selfless penguins and charitable baboons? Or is altruism a unique refinement, a singular human triumph over 'nature red in tooth and claw'? Charles Darwin called this the greatest single riddle, and thinkers ever since have tried to crack it.

Here is the mystery: if evolution is a process of survival of the fittest, and altruism is a behaviour that reduces fitness, why do we find altruistic acts wherever we look in nature? Consider the honey-pot ants of the American deserts, hanging upside down like great big pots of sugared water, perennially, waiting to be tapped by the queen and her brood when they are thirsty; or gazelles, conspicuously jumping up and down to signal to the troop that a lion lurks in the grass; or, for that matter, yellow jewelweed plants (*Impatiens pallida*), which, when sunlight becomes scarce, do not hog it by investing in the creation of leaves, but rather invest in stems and roots so as to share the sunlight with everyone. These are just a few of thousands of examples from across the natural world.

Biological altruism is defined by the result of an action: if an amoeba acts in such a way as to reduce its own fitness while providing a fitness benefit to another, it is an altruist. (Certain species of social amoeba are known to sacrifice themselves for their brethren.) Human, or psychological altruism, on the other hand, is all about intent: if I help an old lady cross the

Commonly referred to as slime mould, *Dictyostelium discoideum* is a soil-living amoeba. When starved, the normally free-living cells aggregate into a 'slug', consisting of viable spores and an altruistic, non-reproducing stalk.

Images courtesy of Owen Gilbert

Image courtesy of D Gordon E Robertson; image source: Wikimedia Commons

Image courtesy of Rick Wilhelmsen; image source: Wikimedia Commons

Gazelles conspicuously jump up and down to signal to the troop that a predator is lurking in the grass.

Biology

- Biology
- Social studies
- Evolution
- Natural selection
- Genetics
- Ages 15+

Altruism is a behaviour observed in all types of organism, yet its causes remain a mystery. In this article, Oren Harman explores the plausible causes of altruism and whether true altruism exists in humans.

This is not a science article in the strict sense; it could be used just as easily in a social studies lesson. Teachers could use the article as the basis of a discussion of many topics that link science and social studies subjects: for example, natural selection and altruism; the genetic basis of altruism; altruism and the fitness of the group; and mathematical formulations for altruism. The article could be used for any age group of secondary-school students, in particular those aged 15-19.

The article could be used in a comprehension exercise, with potential questions including:

1. Why is altruism considered to be a behaviour that reduces fitness for the individual organism?
2. Some people believe that true altruism does not exist in humans. Why is this?
3. Altruism is a behaviour that could play a role in natural selection. Use a specific example to support this idea.
4. 'If altruism could be explained by mathematics, it was never really what it seemed.' Explain what this means.

Michalis Hadjimarcou, Cyprus

REVIEW

road because I have secret designs to be written into her will, then I am not considered an altruist, even if a truck hits and kills me during the process. Still, is there a connection between altruistic acts in amoeba and altruism in humans? After all, just like the actions of the brainless miniature amoeba, the brain that allows us humans to act selflessly is a product of evolution.

Ever since Darwin, and really much earlier, we have sought to answer these riddles. In particular, we have been interested in whether true altruism even exists. 'Scratch an altruist and see an egoist bleed,' some philosophise. Is that how we should explain the lives of Nobel Peace Prize winners Albert Schweitzer and Mother Theresa? Or a soldier jumping on a grenade to save his mates? Cynics would say that, whether consciously or not, sacrifice is always driven by ulterior motives.

History teaches that when considering the relationship between nature and morality, we often stumble into what is called Hume's Guillotine (described by the Scottish philosopher David Hume [1711–1776] and often mistakenly referred to as 'the naturalistic fallacy'). That is, the mistake of confusing that which *is* with that

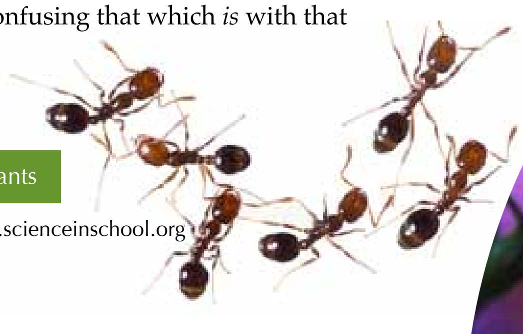
Bees, wasps and ants (the Hymenoptera) exhibit haplodiploidy, whereby females are more genetically similar to their sisters than to their own offspring.

Image courtesy of Richard Bartz; image source: Wikimedia Commons

A German wasp *(Vespula germanica)*

Image courtesy of CrazyD; image source: Wikimedia Commons

A honeybee, *Apis mellifera*



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Fire ants

Image courtesy of Greg Hume; image source: Wikimedia Commons

In a colony of honey-pot ants, some individuals have vastly swollen abdomens, providing a food resource for the rest of the colony.

Image courtesy of the UK Ministry of Defence

How can altruistic behaviour such as a soldier jumping on a grenade to save his comrades be explained scientifically?

Image courtesy of Rolf Unterberg; image source: Wikimedia Commons

Albert Schweitzer (1875-1965) won the Nobel Peace Prize in 1952 for his philosophy of 'reverence for life'.

which *ought to be*; or, what we observe in nature with a rule for our own behaviour (Hume, 1739). This is important when it comes to altruism, because in the years since Darwin, science has provided a number of explanations for the evolution of sacrificial traits.

One of these explanations is nepotism: the closer the genetic relatedness, the greater the chance of altruism. This was formalised in algebra by the late British evolutionary biologist Bill Hamilton, who stated that a genetic trait for altruism should spread through a population if:

$rB > C$

where r is the genetic relatedness of the two individuals, B is the reproductive benefit gained by the recipient of the altruistic act, and C is the reproductive cost to the individual performing the altruistic act (Hamilton, 1964a, 1964b). Does this mean that it is natural to help kin, but unnatural to help strangers?

Perhaps not. Another explanation is simple reciprocation: one individual should help another in the expectation of being helped in return. Related to this is the matter of trust: if I cannot signal to others that I can be trusted, I won't survive in a world that depends on co-operation.

A third explanation is group selection: those groups that use altruism as a social glue to help to cement cohesion will outcompete groups of non-co-operative individuals.

But do these explanations leave room for true altruism? The explanations satisfy the sceptic, as they all ultimately hinge on the logic of egotism: it's worth helping others or even the group if it benefits yourself. And if that is what models and theories show, supported by empirical observation, then perhaps true altruism is really just a dream. More dangerous still is the idea that if we evolved to be altruistic only for selfish reasons, perhaps we shouldn't even attempt to behave as true altruists.

One scientist who tried to solve the mystery of altruism was the US population geneticist George Price. Deriving an equation in the late 1960s that would later carry his name, Price came to believe that if altruism could be explained by mathematics, it was not true altruism. Selflessness was always interested – this is what he believed his equation seemed to indicate (Price, 1970).

For George Price, this was a terrible realisation and he descended on the homeless people of London, UK, like an angel, determined to disprove the very maths that he had constructed. In the end, having given away all his possessions, he became a homeless derelict himself, committing suicide in a cold London squat in 1975.

Science is a powerful tool for understanding the world. Neurogenetics and functional magnetic resonance imaging studies are attempting to find the genes for altruism and the particular regions of the brain that play a role in altruistic behaviour (Churchland, 2011). But precisely because of this, we need to remember the fate of George Price: his story is a personification of the very paradox of altruism. It

Image courtesy of Ltshears; image source: Wikimedia Commons

Naked mole rats are sometimes referred to as the social insects of the mammal world.

Image courtesy of Evert Odekerken; image source: Wikimedia Commons

Mother Teresa of Calcutta (1910-1997) won the Nobel Peace Prize in 1979 for serving the poorest of the poor.

Image courtesy of Amos Oliver Doyle; image source: Wikimedia Commons

In low light conditions, yellow jewelweed plants (*Impatiens pallida*) are thought to grow tall and leggy, to share the sunlight with other plants of the same species.

shows that the tools of science are not always relevant to the kinds of questions we are interested in, such as how we should behave. If we are able to answer all the scientific questions we can pose, will it explain everything that we want to understand? George Price's story demonstrates that the answer to this question is 'no'.

Acknowledgement

This article was adapted from a previous article by Oren Harman[w1], published on the Forbes website.

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The text is freely available online via Project Gutenberg. See: www.gutenberg.org/ebooks/4705

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Download the article free of charge on the *Science in School* website (www.scienceinschool.org/2012/issue25/altruism#resources), or subscribe to Nature today: www.nature.com/subscribe

Web reference

w1 – This article is based on an article by Oren Harman[w1] on the Forbes website (www.forbes.com). See the direct link: http://tinyurl.com/orenharman

Also on the Forbes website, watch a video of Oren Harman discussing the story behind his latest book, *The Price of Altruism*. http://video.forbes.com/fvn/booked/price-of-altruism

Resources

Philosopher Elliott Sober and biologist David Sloan Wilson attempt to reconcile altruism, both evolutionary and psychological, with the scientific discoveries that seem to portray nature as 'red in tooth and claw'.

Sober E, Wilson DS (1998) *Unto Others: The Evolution and Psychology of Unselfish Behavior*. Cambridge, MA, USA: Harvard University Press. ISBN: 978-0674930476

To find out why psychologist Steven Pinker does not support the idea of group selection, see his essay 'The false allure of group selection'. http://edge.org/conversation/the-false-allure-of-group-selection

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

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Oren Harman is a writer and professor of the history of science. He studied history and biology at the Hebrew University in Jerusalem, Israel. After a master's degree and a doctorate from Oxford University, UK, he spent two years at Harvard University, USA, in the department of history of science. Oren is currently a professor of science, technology and society at Bar Ilan University, Israel, and chair of the graduate programme there. He focuses on the history and philosophy of modern biology, evolutionary theory, the evolution of altruism, 20^{th} century genetics, and historical biography.

As a writer, Oren has contributed to *The New Republic*, *Science*, *Nature*, *The New York Times*, *The Times*, the *Times Literary Supplement*, the *New York Review of Books*, the *Economist*, *Forbes*, *The Huffington Post* and many others. He used George Price's story in his book *The Price of Altruism* (Harman, 2010) to illustrate 150 years of efforts to find the origins of kindness. The book won the 2010 Los Angeles Times Book Prize.

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