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Scientists propose a new hypothesis to tackle one of the big remaining mysteries in animal evolution.

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This June, students from around Europe met in Portugal to compete in the European CanSat competition. One of their teachers tells us more.

Image courtesy of john_hawn; image source: Flickr

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Why does it rain? Can we predict it? Give physics students a mass of weather data and some information technology, and they can try working this out for themselves.

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What would it be like if numbers and musical tones had colours?
People with synaesthesia experience the world in this way – and scientists are trying to find out why.

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EDITORIAL

Hannah Voak
Editor
Science in School
editor@scienceinschool.org

Looking back, there's no doubt that my own schoolteachers' enthusiasm for science rubbed off on me. I have fond memories of my science lessons, from creating film-canister rockets in chemistry to scouring the playground for insects in biology. Without these experiences, I might not have followed the path that has led me to where I am today: the *Science in School* office at the European Molecular Biology Laboratory, nestled in the scenic hills of Heidelberg, Germany.

This issue, my first as a *Science in School* editor, is full of ideas to enthuse your students and inspire the next generation of scientists. Explore the neurological phenomenon of synaesthesia, where letters or numbers evoke visual sensations such as colours, sounds and smells (page 8), or the revolutionary gene-editing technique, CRISPR-Cas9 (page 18). Delve deep inside our planet and discover how scientists are reconstructing the behaviour of Earth's mantle (page 15), or travel back in time to tackle one of the big remaining mysteries in animal evolution (page 12).

If you prefer hands-on activities, learn how to bring robotics into a chemistry lesson (page 42) or create a cellophane membrane to simulate a neuron in the classroom (page 28). For something closer to home, how about exploring the nature of fire (page 46) or predicting the weather using thermodynamics (page 36)? And for younger students, there's a fun activity to find out what happens inside magnets (page 32).

To spark your own imagination, meet Andy Brunning, the teacher and mastermind behind the chemistry graphics of Compound Interest (page 25), or hear from a Finnish physics teacher about his students' sky-high adventures in ESA's CanSat competition in Portugal (page 22).

We hope you enjoy using these resources. Do share your experiences, photos and even videos with us on social media, or by dropping us an email (editor@scienceinschool.org) – we love to hear how you use our articles and how your students respond.

Lastly, I'm delighted to be part of the *Science in School* team, of which you – our readers, authors, reviewers and translators – are a fundamental part. In 2017, I hope to meet some of you at forthcoming workshops, festivals and conferences, and I look forward to hearing your ideas for the future of the journal.

Hannah Voak

Proxima b, extremophiles and record-breaking cables

Image courtesy of Maximilian Brice / CERN

CERN: **Global open access initiative**

After three years of successful operation and growth of its SCOAP3 open access initiative, CERN announced that it will continue the global collaboration for three more years. SCOAP3, the Sponsoring Consortium for Open Access Publishing in Particle Physics, is an innovative partnership of over 3000 libraries, funding agencies and research organisations from 44 countries. It has made tens of thousands of scientific articles freely available to everyone, with neither cost nor barrier for any author worldwide.

In co-operation with leading scientific publishers and learned societies, SCOAP3 has supported the transition to open access of key journals in the field of high-energy physics since 2014. In the first three years of SCOAP3 operation, 20 000 scientists from 100 countries have benefitted from the opportunity to publish more than 13 000 open access articles free of charge.

To find out more about SCOAP3, see: www.scoap3.org

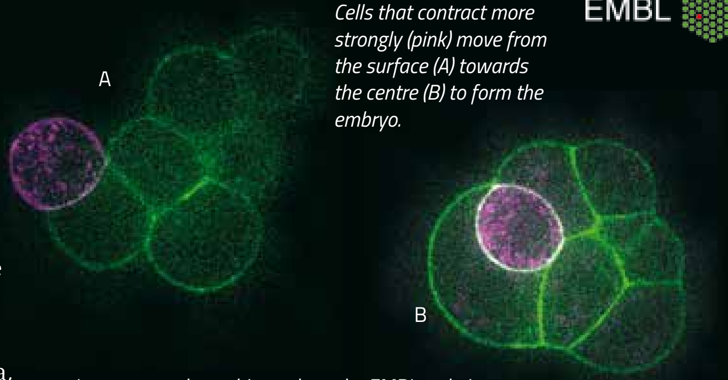
Based in Geneva, Switzerland, CERN is the world's largest particle physics laboratory. To learn more about CERN, see: www.cern.ch

EMBL: **Dancing embryo cells**

For a cell in an embryo, the secret to becoming part of the baby's body instead of the placenta is to contract more and to carry on dancing, scientists at the European Molecular Biology Laboratory (EMBL) have found.

After a sperm cell fertilises an egg cell, the fertilised egg divides repeatedly, forming a ball of cells. Shortly before the embryo implants in the uterus, some of those cells move inwards. These are the cells that develop into all the baby's body parts. The cells left on the surface become the placenta, connecting the embryo to the mother's uterus.

The EMBL scientists found that, in a mouse embryo, whether a cell moves to the middle or stays on the surface depends on how strongly it can contract. The researchers combined experiments and computer modelling, and determined that cells that contract at least one and a half times more strongly than their neighbours move inwards. The findings could one day be relevant for researchers and clinicians doing pre-implantation diagnostic tests on in vitro fertilised (IVF) embryos.



Cells that contract more strongly (pink) move from the surface (A) towards the centre (B) to form the embryo.

Image courtesy of Jean-Léon Maître / EMBL

Learn more about this work on the EMBL website: http://news.embl.de/science/1608-force-embryo

See also the original research paper:

Maître JL et al (2016) Asymmetric division of contractile domains couples cell positioning and fate specification. *Nature* **536**: 344–348. doi: 10.1038/nature18958.

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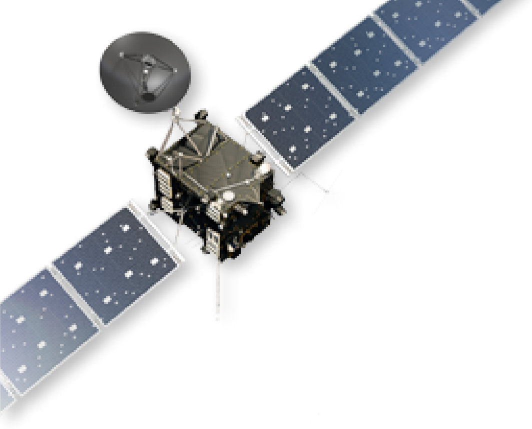
EMBL is Europe's leading laboratory for basic research in molecular biology, with its headquarters in Heidelberg, Germany. To learn more about EMBL, see: www.embl.org



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

ESA: **Rosetta's journey comes to an end**

ESA's historic Rosetta mission concluded as planned, with the controlled impact onto the comet it had been investigating for more than two years.

Launched in 2004, Rosetta was in its sixth orbit around the Sun. Its nearly 8 billion kilometre journey included three Earth fly-bys, one Mars fly-by and two asteroid encounters. The craft endured 31 months in deep-space hibernation on the most distant leg of its journey, before 'waking up' in January 2014 and finally arriving at the comet in August 2014.

On 30 September 2016, Rosetta carried out its final manoeuvre, setting it on a collision course with the comet from an altitude of about 19 km. During the descent, Rosetta studied the comet's gas, dust and plasma environment very close to its surface, as well as taking very high-resolution images. Rosetta's signal was lost upon impact with its target region on the small lobe of Comet 67P / Churyumov-Gerasimenko, and it is now no longer possible to communicate with the spacecraft.

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

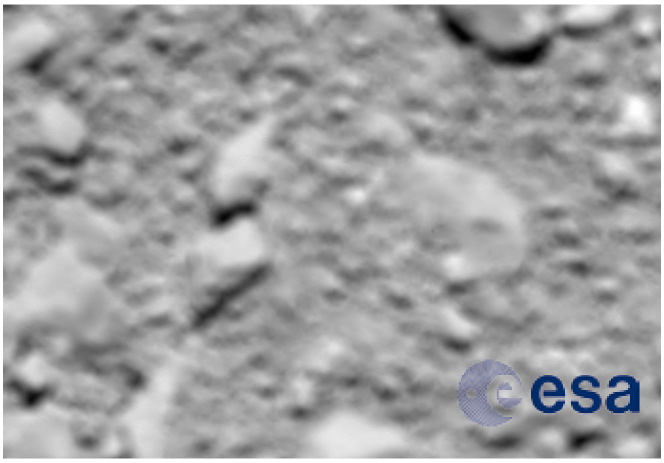


Image courtesy of ESA

Rosetta's last image

ESO: **Planet found orbiting nearest star**

On 24 August 2016, one of the most exciting discoveries ever in the field of exoplanets was announced at the headquarters of the European Southern Observatory (ESO) in Garching, Germany. Using ESO telescopes and other telescopes around the world, astronomers had found clear evidence of a planet orbiting the closest star to Earth, Proxima Centauri. The long-sought world, designated Proxima b, orbits its cool red parent star every 11 days at a distance of just 7 million kilometres.

Although Proxima b orbits much closer to its star than Mercury does to our Sun, the star itself is far fainter than the Sun. As a result, the estimated temperature of Proxima b would allow the presence of liquid water. This rocky world is a little bigger than Earth and could be the closest possible abode for life outside the Solar System.

To read the full press release, see: www.eso.org/public/news/eso1629

ESO is the world's most productive ground-based astronomical observatory, with its headquarters in Garching, near Munich in Germany, and its telescopes in Chile. To learn more about ESO, see: www.eso.org

Image courtesy of ESO / M Kornmesser

An artist's impression of the surface of Proxima b orbiting the red dwarf star Proxima Centauri

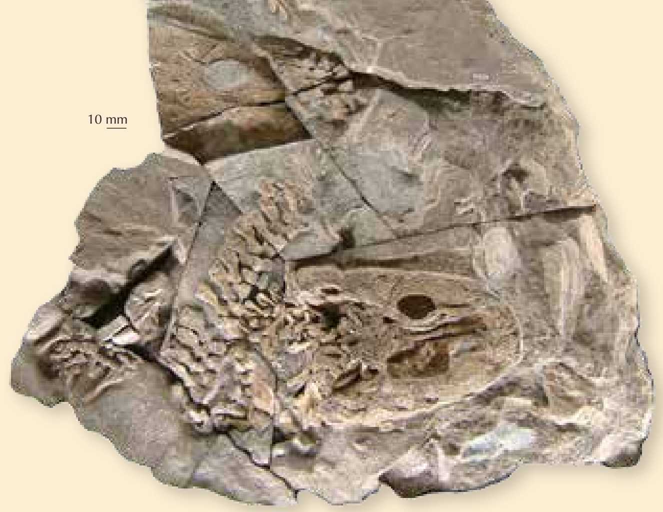


Image courtesy of ESRF / JA Clack

The Acanthostega *fossil*

ESRF:
Tetrapods transition from water to land

New research has shed light on the life-cycle of aquatic tetrapods, the earliest four-limbed vertebrate animals that ventured onto land. Early tetrapods of the Devonian period (419–359 million years ago) are of great interest to palaeontologists: they paved the way for all future terrestrial vertebrate life, today represented by amphibians, reptiles, birds and mammals.

Well-preserved skeletons of tetrapods are rare, and it was previously assumed that the fossils from the mass-death deposit of *Acanthostega* tetrapods in Greenland were all adults. Using high-resolution synchrotron X-ray scans of limb bones, however, a team from Uppsala University in Sweden, the European Synchrotron Radiation Facility (ESRF) and the University of Cambridge, UK, has discovered that they are all in fact juveniles, raising questions about how these vertebrates developed.

Read more in the research paper:

Sanchez S et al (2016) Life history of the stem tetrapod *Acanthostega* revealed by synchrotron microtomography. *Nature* **537**: 408–411. doi: 10.1038/nature19354

Download the article free of charge on the *Science in School* website (www.scienceinschool.org/2016/issue38/eironews) or subscribe to *Nature* today: www.nature.com/subscribe

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

EUROfusion: **Record-breaking cables**

It's been an exciting time in the world of superconducting cables. EUROfusion's Italian consortium member ENEA (*Agenzia nazionale per le nuove tecnologie, l'energia e lo sviluppo economico sostenibile*) has designed and built a cable that can achieve a record electric current of 81.7 kA; that is 10 000 times greater than what a computer cable can handle. In addition, the electric flow can be achieved under extreme conditions: in a magnetic field of 13 T and a temperature of around -266 °C.

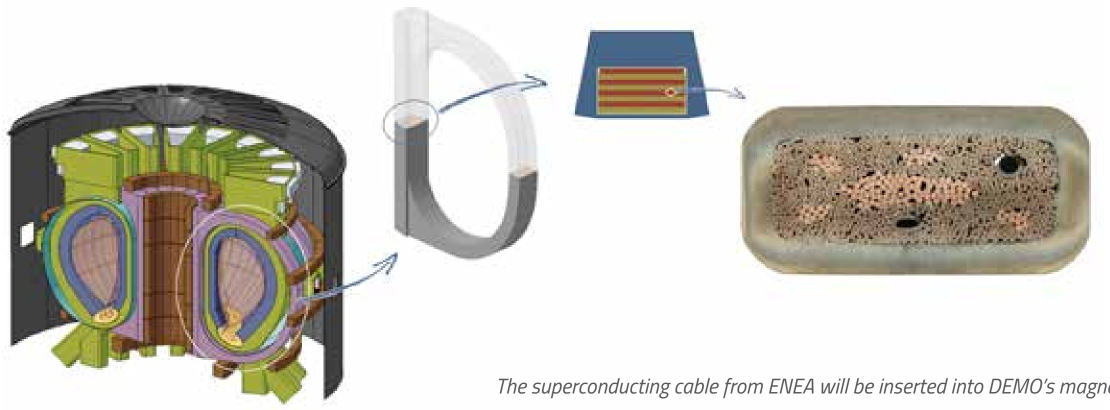
But why does fusion research need such powerful superconducting cables? Tokamak fusion reactors need a large magnetic field to control the very hot plasma of fusion experiments. This requires a high electrical current, which is supplied by superconducting cables. Their unique feature is to transport electricity without losing precious energy to electrical resistance.

The Swiss Plasma Centre, a member of the EUROfusion consortium, carried out the final tests on a rectangular cable-in-conduit conductor. The results showed that the cables exceeded the requirements of the forthcoming world's biggest fusion experiment: ITER. In fact, the current flow is 20% greater than what is needed for ITER's magnetic field. The cable has been designed to meet the requirements of DEMO, the demonstration fusion reactor that will hook fusion electricity to the grid.

For more information, see www.euro-fusion.org/newsletter/superconducting-cables-for-demo or use the tinyurl http://tinyurl.com/jdtxgwu

EUROfusion comprises 28 European member states as well as Switzerland and manages fusion research activities on behalf of Euratom. The aim is to realise fusion electricity by 2050. To learn more about EUROfusion, see: www.euro-fusion.org

Image courtesy of EUROfusion / Luigi Muzzi



The superconducting cable from ENEA will be inserted into DEMO's magnets.

European XFEL:
Accelerator ready for action

Image courtesy of European XFEL

European XFEL Director Professor Massimo Altarelli, Polish Science Vice Minister Dr Piotr Dardziński, and Hamburg Science Senator Katharina Fegebank set up the last beamline at the ceremony officially beginning the facility's commissioning.

The 1.7 km long superconducting linear accelerator, a crucial component of the European X-ray Free Electron Laser (European XFEL), is ready for action. The accelerator will energise electrons to extremely high energies, which are needed to generate the European XFEL's brilliant X-ray laser flashes.

In October 2016, the European XFEL Accelerator Consortium, led by the X-ray laser facility's largest shareholder DESY, completed manufacturing, testing and installing all of the accelerator's components. This includes 96 large modules, each 12 m long, in which the electrons are accelerated at a temperature of -271 °C, close to absolute zero.

Commissioning of the accelerator has now started. The electron injector, where the electrons are isolated and given their initial boost, had already been successfully tested in the months before and is performing better than expected.

Now that the accelerator and most of the other components are installed in the underground tunnels, scientists are busily preparing the facility for operation. In October, high-ranking guests from the 11 European XFEL partner countries attended a ceremony marking the start of European XFEL's commissioning. In mid-2017, European XFEL will open its doors to the first users, supplying them with the unique X-ray laser light that will create new opportunities to study matter.

European 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 about European XFEL, see: www.xfel.eu

ILL:
Neutrons unlock the secrets of extremophile bacteria

Microbial life has an amazing flexibility for adapting to extreme environments, and understanding their adaptations has important implications for biotechnology.

One species of high biotechnological potential is the recently discovered *Halomonas titanicae*, a rust-producing extremophile bacterium found in the hull of the sunken ship RMS *Titanic*. A range of specialised neutron-scattering experiments conducted at the Institut Laue-Langevin (ILL) has estimated that *H. titanicae* could bring about the total deterioration of the *Titanic* by 2030; it also poses a problem to oil rigs and other human-made objects in the deep seas. But the rusting property could also be harnessed in bioremediation or waste management, for example to accelerate the decomposition of shipwrecks littering the ocean floor.

H. titanicae isolated from the oceans or salt marshes can reversibly accumulate high concentrations of the osmolyte ectoine within its cells, to counterbalance fluctuating external salt concentrations. The experiments were designed to understand how ectoine permits *H. titanicae* to survive in its extreme environment. They revealed that within the microbial cells, ectoine enhances the dynamic nature of the hydrogen bonds in the intracellular water, enabling cell functions to proceed unhindered by the external environment.

To find out more, read the press release (www.ill.eu) or use the direct link: www.tinyurl.com/j4xjnsu

See also the original research paper:

Zaccai G et al (2016) Neutrons describe ectoine effects on water H-bonding and hydration around a soluble protein and a cell membrane. *Scientific Reports* **6**: 31434. doi: 10.1038/srep31434

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

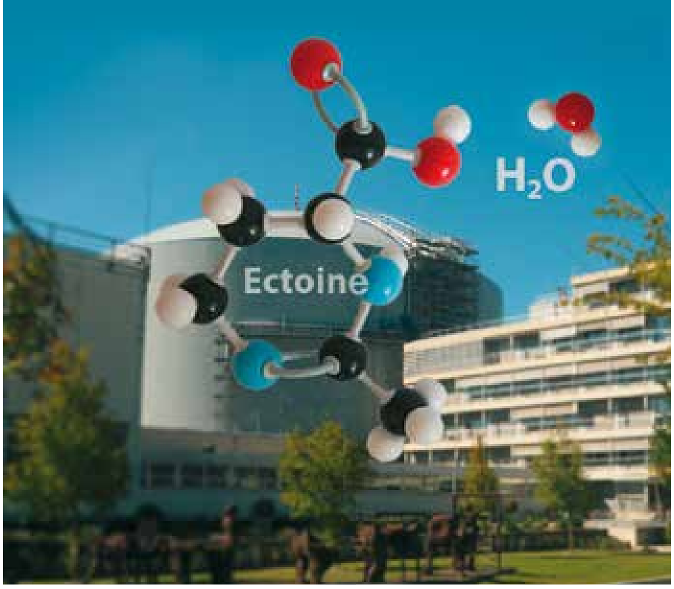


Image courtesy of MPI-ILL

Blended senses: understanding synaesthesia

What would it be like if numbers and musical tones had colours? People with synaesthesia experience the world in this way – and scientists are trying to find out why.

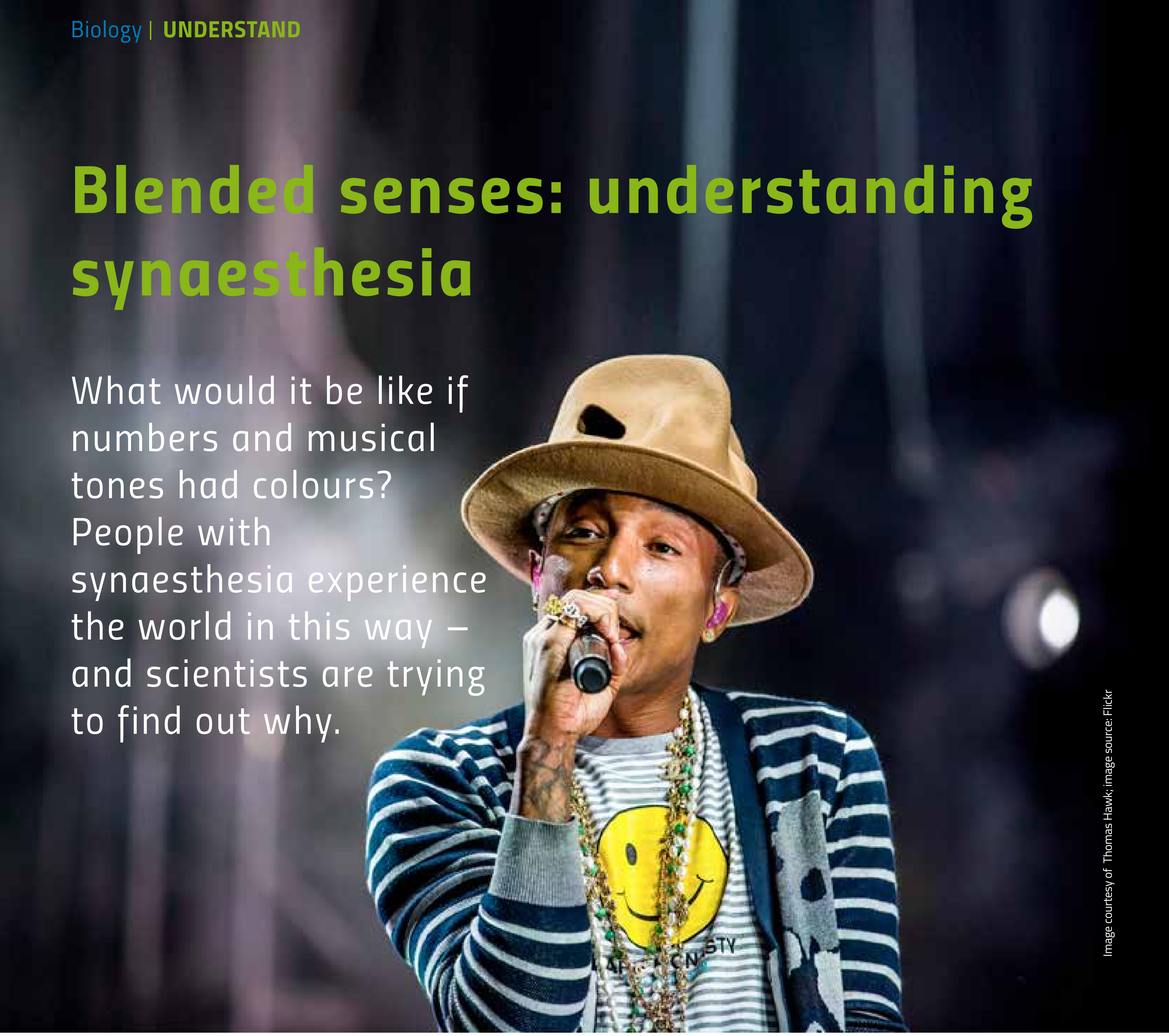


Image courtesy of Thomas Hawk; image source: Flickr

Singer Pharrell Williams uses his coloured hearing (auditory-visual synaesthesia) in his music.

By Amanda Tilot

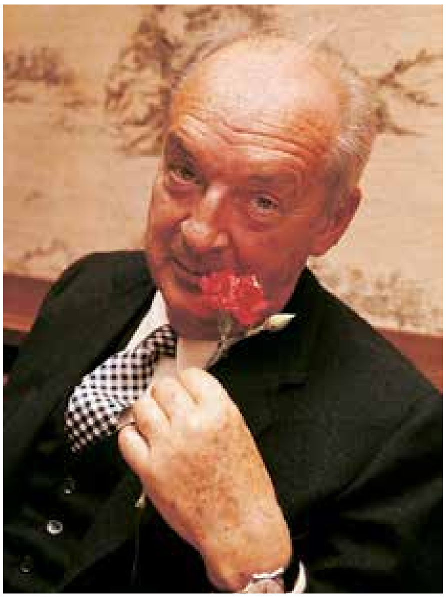
What colour is Tuesday? This question may not make sense to most people – but to some people, known as synaesthetes, it's perfectly understandable, although each is likely to have a different answer.

Synaesthesia literally means 'joined perception'. It is a neurological phenomenon whereby a perception in one sense automatically evokes a sensation in another – so, for example, thinking about abstract ideas like numbers or days of the week evokes associations with specific colours. It's not clear why this happens, but synaesthesia is increasingly being studied scientifically to unravel the factors involved. So far, links in order to both neurological and genetic factors have been found.

Types of synaesthesia

A large study in the UK revealed that about four per cent of the population experiences a form of synaesthesia (Simner et al, 2006). Often, synaesthetes have no idea that their cross-sensory associations are unusual, even though they may experience several different types. Cross-sensory associations evoked by stimuli such as letters, numbers and musical tones are known for every physical sense – from visual sensations such as colour, to sounds, smells, textures and even tastes.

One of the most common forms is grapheme-colour synaesthesia, which is the association of letters and numbers with specific colours. At the other extreme are the captivating stories of people for whom words have tastes (lexical-



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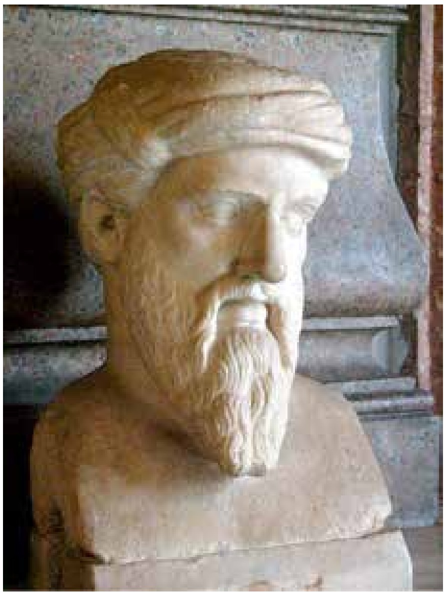

Image courtesy of Gallilea; image source: Wikimedia Commons / German Wikipedia

Left: "The long ā of the English alphabet [...] has for me the tint of weathered wood, but the French à evokes polished ebony." (Excerpt from synaesthete Vladimir Nabokov's autobiography, Speak, Memory, *1951)*

Right: The Greek philosopher and mathematician Pythagoras is believed to have experienced a form of synaesthesia in which he associated each number with its own personality.

gustatory synaesthesia), and musicians like Pharrell Williams who use their coloured hearing to shape their music (auditory-visual synaesthesia).

Grapheme-colour synaesthesia is the most widely researched form, because it is easy to study using simple tests. Large studies comparing grapheme-colour synaesthetes to each other and to non-synaesthetes have revealed much diversity even within this one type of synaesthesia. For example, some grapheme-colour synaesthetes see the evoked colours projected into their surroundings, while others perceive them only mentally, with their 'mind's eye'. Another finding is that most synaesthetic associations are very personal, and each grapheme-colour synaesthete's vibrant alphabet is unique to them. Perhaps surprisingly, however, the letters I, O, X, and Z tend to be labelled as black or white by most grapheme-colour synaesthetes, even within an otherwise rainbow-coloured alphabet.

So what type of people are most likely to experience synaesthesia? One recent study that screened thousands of people for synaesthesia has overturned a long-held belief that the phenomenon is more common in women (Simner & Carmichael, 2015). Leading autism researcher Simon Baron-Cohen has found that synaesthesia is more common among people with autism (Baron-Cohen et al, 2013), a finding that links to the extraordinary case of Daniel Tammet, a high-functioning autistic man with multifaceted synaesthesia. In 2004, Tammet used his synaesthesia to help him memorise and recite the mathematical number π (pi) to over 20 000 decimal places.

What causes synaesthesia?

While many synaesthetic experiences seem quite exotic, we all have a tendency to link qualities of different senses together – a phenomenon known as cross-modal association. For instance, people tend to agree that higher-pitched sounds should 'go with' lighter colours, and sounds that are deeper belong with darker colours.

So what exactly is different about the synaesthetic brain? Neuroimaging studies show differences between synaesthetes and non-synaesthetes in how the brain is structured, pointing to a biological basis for this phenomenon. A study in 2007 showed that people with grapheme-colour synaesthesia

REVIEW

- ✓ Biology
- ✓ Mathematics
- ✓ Neurobiology
- ✓ Music
- ✓ Art
- ✓ Ages 14–19

This article challenges the reader to learn more about synaesthesia and to admire the complexity of the human brain. It could be used for discussions about:

- How do humans respond to sensory stimulation?
- Is a perception the same for every person triggered with the same stimulus?
- What do we define as normal?

Alina Giantsiou-Kyriakou,
Livadia High School,
Larnaca, Cyprus

Background

Musical textures

Svetlana Rudenko, an accomplished, Ireland-based pianist, experiences a complex form of musical-space synaesthesia in which sounds become textured images in the space around her. Describing how music and vision are tied together in her perception, she says, "I see the screen of sound waves, and I control my memory by reading it during playing and manipulating it in time ... to hear all the elements of musical texture." This led to some challenges while she was learning to play the piano. "I could not do crescendo and diminuendo (gradually becoming louder or quieter) like other students do," she says. "For me, image is very connected with sound; in order to change the sound, I have to rethink the image". Today, Svetlana uses her cross-sensory perceptions in her teaching, adapting her impressions to help her students learn to perform complex pieces. "I use a lot different coloured pencils to mark layers of musical texture," she says. "By marking those changes with different colours, I am giving my students guidance to create their story of the piece and boost their imagination." She finds that this multisensory approach to piano instruction works best with her youngest students.

have stronger connections in some areas of the cortex (Rouw & Scholte, 2007), while other studies have found that these people have more activity connecting the colour-processing areas of the brain to other regions (Tomson et al, 2013).

Could there also be a genetic basis for synaesthesia? In 1883, Francis Galton reported that synaesthesia seemed to run in families (Galton, 1883). The current view is that synaesthesia is at least partially genetic: studies of families with multiple synaesthetes have found several areas in the genome associated with the phenomenon (Asher et al, 2009; Tomson et al, 2011). These studies were too small-scale to point to specific genes, so a large-scale genetic study of grapheme-colour synaesthetes is now underway, led by Simon Fisher at the Max Planck Institute for Psycholinguistics in the Netherlands.

Synaesthesia in the classroom

As the place where alphabets, numbers and the calendar are committed to memory, the classroom can play a central role in the development of synaesthesia. Studies in the UK following children in primary schools over several years have revealed that synaesthesia can take time to develop: the few children in each primary school who became grapheme-colour synaesthetes began forming the associations during early school years, and settled on the colours of their alphabet gradually (Simner & Bain, 2013). Such children chose consistent colours for 34% of the alphabet at ages 6–7, 48% by ages 7–8, and 71% by ages 10–11.

Teachers or parents often become aware of a child's synaesthetic associations when he or she makes a comment that seems to blend two senses – for example, an upset stomach that "feels yellow", or someone using the "wrong colour" to write the word Tuesday. Unless a child reports that her or his perceptions are interfering with their learning, synaesthesia is likely to be just part of the background of how they experience the world with no adverse consequences.

But can synaesthesia be beneficial in the classroom? Anecdotes and research suggest yes, sometimes. People with grapheme-colour synaesthesia often say that the colours help them remember phone numbers or other numerical information; and in psychological studies, synaesthetes perform better than non-synaesthetes on some memory tasks when they can use the extra features to help them remember (Watson et al, 2014). In his book *Born on a Blue Day*, Daniel Tammet describes how his sense of each number's unique colour, shape and location in space helps him to solve complex mathematical equations with lightning speed (Tammet, 2006).

Past and present

Synaesthetic sensations have sometimes been interpreted as supernatural, due to the seemingly other-worldly nature of this phenomenon. Neuroscientist and author VS Ramachandran reported the unusual case of a young man whose synaesthesia took the form of seeing coloured halos around people's faces. This case perhaps suggests an explanation for stories from folklore about people who see auras (Ramachandran et al, 2012).

Today, our advancing knowledge of synaesthesia's biological basis in the brain is moving these associations out of the spooky realm and into the laboratory. Synaesthesia is remarkable in that the impressions it generates are both deeply subjective and quite stable for each individual. In this way it reminds us that, while we may agree that (for example) a tomato is red or that two plus two equals four, our inner experience of the ideas involved in such apparently factual statements is varied and personal.

Public domain image; image source: Wikimedia Commons

The abstract paintings of artist Vassily Kandinsky (left) reflect his experience of seeing music in colour.

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Resources

For popular accounts of synaesthesia, see:

Ward J (2008) *The Frog Who Croaked Blue: synesthesia and the mixing of the senses*. London, UK: Routledge. ISBN: 9780415430135

Cytowic R, Eagleman D ( )*Wednesday is Indigo Blue: discovering the brain of synesthesia*. Cambridge, USA: MIT Press. ISBN: 9780262012799

For more about his paintings depicting particular numbers and his book *Born on a Blue Day*, visit Daniel Tammet's website. See: www.danieltammet.net/artwork.php

For answers to some frequently asked questions about synaesthesia, visit the website of the University of Sussex. See: www.sussex.ac.uk/synaesthesia/faq

Visit the website of the UK Synaesthesia Association. See: www.uksynaesthesia.com

Visit the website of the American Synesthesia Association. See: www.synesthesia.info

To take part in a study to investigate the genetic basis of synaesthesia, visit the website of the Max Planck Institute for Psycholinguistics. See: www.mpi.nl/synaesthesia

For some tests to identify many different types of synaesthesia, have a look at Baylor College of Medicine's Synesthesia Battery. See: www.synesthete.org

To learn about scientific research into another seemingly other-worldly experience, see:

Paterlini M (2010) Exploring out-of-body experiences: interview with Henrik Ehrsson. *Science in School* **15**: 4–7. www.scienceinschool.org/2010/issue15/ehrsson

Dr Amanda Tilot is a postdoctoral researcher in the Language and Genetics Department at the Max Planck Institute for Psycholinguistics in Nijmegen, the Netherlands. She works with Professor Simon Fisher studying the genetics of synaesthesia in large populations and single families. Amanda completed her PhD research at Case Western Reserve University (USA) in 2014, where she studied autism genetics.

What happens when cells embrace damage?

Scientists propose a new hypothesis to tackle one of the big remaining mysteries in animal evolution.

A 3-day-old larva of Platynereis*: muscles are shown in red and the nervous system in green.*

Image courtesy of Thibaut Brunet / EMBL

By Giorgia Guglielmi

Kintsugi is an ancient Japanese art of repairing broken ceramics with gold or other precious materials. The underlying philosophy is that breakage and repair are integral parts of an object's life, and they can actually result in more valuable items. According to a hypothesis developed by scientists Detlev Arendt and Thibaut Brunet at the European Molecular Biology Laboratory (EMBL)[w1] in Heidelberg, Germany, ancestral eukaryotic cells might have undergone a similar process of damage and repair that, over the course of evolution, gave rise to highly specialised brain and muscle cells (Brunet & Arendt, 2016).

A cellular poison

When a neuron or a muscle cell in our body detects a signal, it responds by allowing some ions, such as sodium and calcium, to enter through the cell membrane. These inward flows of molecules trigger precise responses, which cause muscle cells to contract and neurons to release chemicals responsible for cell-to-cell communication. How our central nervous system evolved to use these chemical triggers is still a mystery, but Detlev and Thibaut are edging closer to an answer.

At high concentrations, calcium is harmful for all living cells, as it forms insoluble aggregates with molecules that are key for cell survival. This is why calcium can be 10 000 times less abundant inside the cell than it is in blood.

The chemical composition of modern cells is thought to be a 'fingerprint' of the composition of the environment in which life began more than 3.5 billion years ago. As they were permeable to small molecules, the first cells had the same chemical composition as the aquatic environment in which they lived, where the concentration of calcium was low. But when ancestral cells first became exposed to environments rich in calcium, probably around 1.5 billion years ago, they had to develop a response to protect themselves from this toxic molecule. Since one of the major routes of calcium influx is cell membrane rupture, the scientists believe that a very important cellular response had to be counteracting membrane damage.

"If you look at eukaryotic cells, from algae to neurons, the majority of the molecules that make a cell contract are sensitive to calcium, so we speculated that cell constriction first evolved in response to an influx of external poison to close the membrane upon breakage," says Thibaut. "This was a bit of a shot in the dark, but when we looked at the literature to test this hypothesis, we were excited to see it is actually the way it works!"

The path to neurons and muscles

Following a rupture of the cell membrane, two calcium-sensitive proteins, called actin and myosin, organise in a ring around the membrane wound. The mesh created by actin and myosin shrinks, causing the cell membrane to constrict and gradually seal the wound. Calcium also triggers the release of bubble-like structures called vesicles. These vesicles are rich in fatty molecules, which provide the broken cell membrane with new building blocks. The scientists believe that this wound healing mechanism could have been the ancestral cells' first 'emergency response' to calcium influx.

As is often the case in evolution, this mechanism – which had evolved for membrane repair – turned out to be useful in other contexts. Membrane contraction, which deforms the cell, became a way for cells to move. The release of molecules by secretion from vesicles became a powerful way to communicate with other cells.

As they increased in complexity, ancestral cells built systems that control contraction and secretion by mimicking membrane rupture, promoting a controlled calcium influx. This system developed further, and ion influx could be actively amplified into an action potential – a short electrical signal that can rapidly spread across the cell membrane, triggering the activation of contraction and secretion. Ancestral cells were multitasking: they were now able to generate an action potential that caused a portion of the same cell to contract. Action potentials also stimulated the release of vesicles packed with chemicals necessary for cell-to-cell communication, which resulted in the spreading of the contractile activity to neighbouring cells.

Some of these cell progenitors later gave rise to two distinct cell types through

REVIEW

- ✓ Biochemistry
- ✓ Biology
- ✓ Evolution
- ✓ Ages 14–19

Can you think about a difficulty you managed to overcome that ultimately made you stronger? According to this article, ancient eukaryotic cells may have undergone damage and repair processes that led to more specialised cells – thanks to evolution.

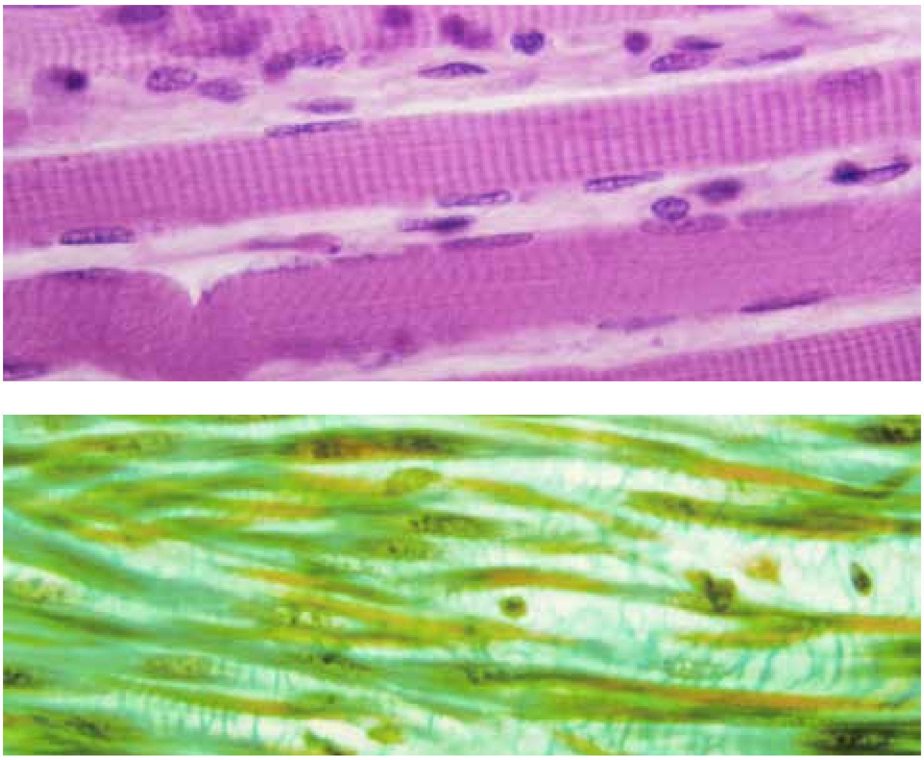
The ideas mentioned in the article could be used in biology lessons in secondary school, particularly when studying biochemistry and evolution. The text also highlights the fact that chemical reactions and physical processes have an essential role in cellular processes.

Before reading the article, students could think about what triggered the evolution of simple eukaryotic cells to more complex ones.

Apart from being used as a comprehension exercise, this article can help to raise awareness of the importance of evolution in the development of life on our planet. Potential discussion questions include:

- How do neurons or muscle cells in the human body react when they detect a signal?
- Why are high concentrations of calcium harmful for all living cells?
- What is the role of actin and myosin proteins following cell membrane rupture?
- How do cells communicate with one another?
- What is an action potential?

Mireia Güell Serra, Spain



Images courtesy of Rollroboter; image source: Wikimedia Commons

Light micrographs of longitudinally sectioned skeletal muscle fibres the division of labour: they literally split into two branches, contractile cells and mechanosensory cells. On one branch, contractile cells, whose primary activity was contracting, have evolved into muscle cells. On the other branch, mechanosensory cells, which specialised in generating action potentials and releasing cell-to-cell communication vesicles, have evolved into the neurons we see today. But the ancient pathways were maintained: even now, our neurons and muscles still rely on a controlled influx of a strong cellular poison – calcium – to decide when to secrete and to contract.

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Web reference

w1 To read more about the Arendt Group at EMBL, visit: www.embl.de/research/units/dev_biology/arendt/

Born in Apulia, a sunny region in the south of Italy, Giorgia Guglielmi obtained her bachelor's and master's degrees in biology from the University of Rome Tor Vergata. She then joined the Developmental Biology Unit at the European Molecular Biology Laboratory (EMBL) in Heidelberg, Germany, to find out how embryos are shaped. Giorgia's efforts to control contraction in individual *Drosophila* cells using lasers have earned her the nickname 'fly zapper' and a PhD in biology *summa cum laude*. A science communication enthusiast, Giorgia is now enrolled in the Massachusetts Institute of Technology's Graduate Program in Science Writing. When not at MIT (guglielm (at) mit.edu), she can be found on Twitter guglielm@mit.edu or on a bike somewhere in Massachusetts.

Image courtesy of Scott Ingram; image source: Flickr

Artistic representation of nerve cells. The branched extensions, known as dendrites, transmit impulses to the cell body.

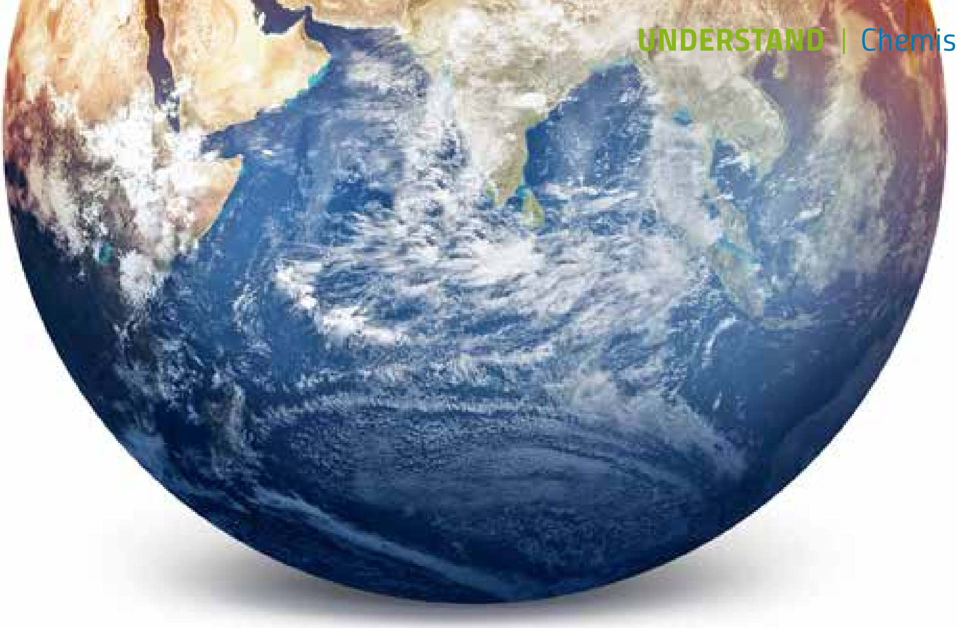

Image courtesy of NASA Goddard Space Flight Centre; image source: Flickr

Under pressure: the role of Earth's mantle in our climate

Studies of iron oxides under extreme conditions are shining a light on Earth's interior and its role in our climate.

By Montserrat Capellas

Earth's climate is affected by gases in the atmosphere, such as carbon dioxide, water vapour and methane. Less obvious, however, is the effect of rocks that lie deep below Earth's surface. That's not surprising: taking direct measurements of Earth's interior is difficult, as is reproducing experimentally the conditions of high pressure and temperature that are found there. However, an international team of scientists has recently reconstructed the behaviour of the iron oxides inside Earth's mantle using state-of-the-art equipment at the European Synchrotron Radiation Facility (ESRF)[w1] in Grenoble, France (Bykova et al, 2016). With this information, the researchers are now beginning to understand the role of these chemical compounds in our climate.

Naturally occurring iron oxides are found in many different forms. "The most common iron oxide is hematite, Fe_2O_3, which is the end product of many geological processes and the main source of iron for our civilisation," explains team member Elena Bykova from the University of Bayreuth, Germany. In recent years, scientists have discovered other iron oxides, such as Fe_4O_5, Fe_5O_6 and $Fe_{13}O_{19}$, that also form at high pressures and temperatures.

Previous geochemical studies have focused on hematite because, despite its simple chemical composition, it undergoes mysterious structural and electronic changes at high pressures and temperatures. Until recently, however, many investigations had failed to provide a consistent picture of the high-pressure behaviour of this material.

Image courtesy of ESRF / Format Editions

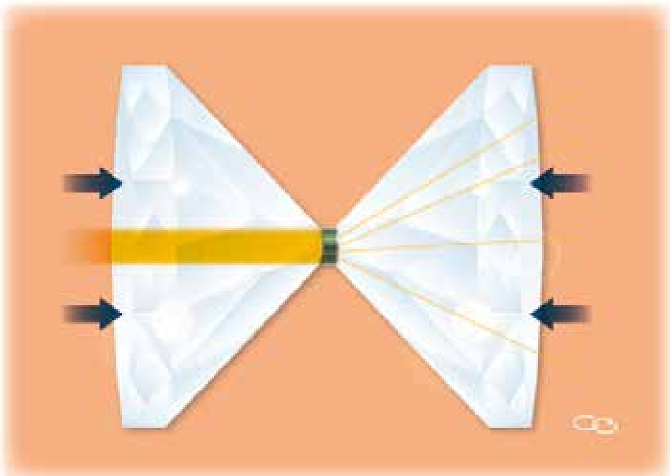

Figure 1: A diamond anvil cell, used to compress microscopic samples to pressures of over 300 GPa. The black arrows represent the direction of the compressive force. Pulsed laser beams heat the sample from both sides and an X-ray beam (orange) is used to investigate the states of matter.

Elena and her colleagues used what is known as a diamond anvil cell (figure 1) to apply a pressure of more than 67 GPa to a hematite sample and heat it to more than 2400 °C. Using X-ray diffraction, the scientists showed that under these conditions, which correspond to those found 1500 km below

Image courtesy of Natalia Dubrovinskaia

Maxim Bykov and Leonid Dubrovinsky preparing a diamond anvil cell experiment with laser heating at ESRF

REVIEW

- ✓ Chemistry
- ✓ Earth science
- ✓ Ages 16-19

This article describes how, under very high temperatures and pressures similar to the conditions in Earth's interior, previously unknown iron oxides are formed. The formation of these compounds, identified with state-of-the-art equipment, releases oxygen – a discovery that has significant implications for models of Earth's interior and our climate.

The article could be used as part of a lesson on the internal structure of Earth, or on the evolution of climate. Suitable comprehension and extension questions include:

- What are the differences between the iron oxides mentioned in the article?
- Explain why and how temperature and pressure can affect crystal structure.
- Describe the process of subduction.
- What information can we get from X-ray diffraction?

Monica Menesini, Liceo A Vallisneri, Lucca, Italy

Earth's surface, hematite decomposes and forms Fe_5O_7, a previously unknown iron oxide, releasing oxygen in the process:

$$10\ Fe_2O_3 \rightarrow 4\ Fe_5O_7 + O_2\uparrow$$

High-pressure experiments with another naturally occurring iron oxide, Fe_3O_4, showed that it also decomposes when heated at pressures above about 70 GPa (which represents conditions approximately 1670 km below the surface), forming $Fe_{25}O_{32}$ and releasing oxygen:

$$25\ Fe_3O_4 \rightarrow 3\ Fe_{25}O_{32} + 2\ O_2\uparrow$$

These results have important implications not only for fundamental high-pressure chemistry, but also for geology. One of our main sources of iron are huge sedimentary rock formations known as banded iron formations (BIFs), which consist of up to 50% hematite as well as magnetite (Fe_3O_4). BIFs are found on all continents and can be several hundred metres thick and hundreds of kilometres long. Deposited on the ocean floor about two billion (10^9) years ago, they have since been forced further down by tectonic plate movement to depths of up to 2880 km below Earth's surface, at the core-mantle boundary. The results of Elena and her colleagues' study suggest that during this subduction process, the hematite and magnetite in the BIFs decomposed, producing oxygen (figure 2).

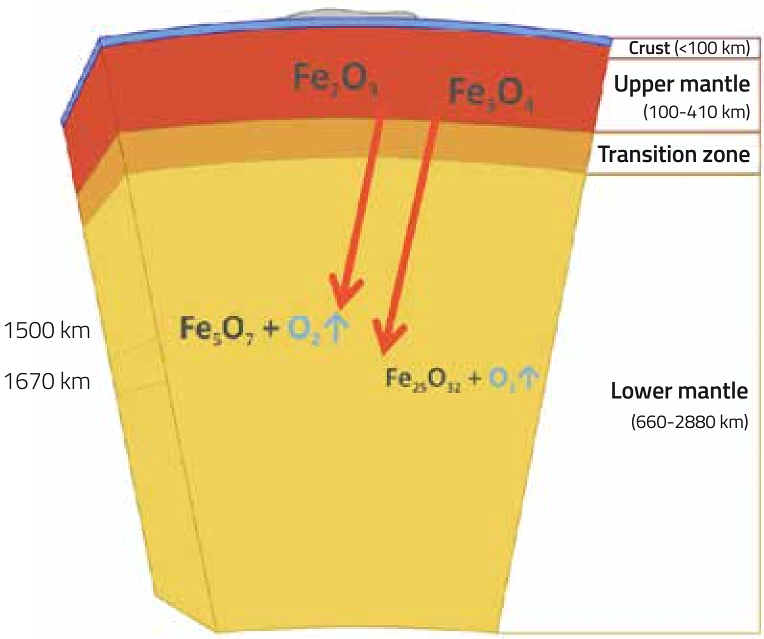

Image courtesy of Elena Bykova

Figure 2: Decomposition of iron oxides and production of oxygen in Earth's interior

Image courtesy of Natalia Dubrovinskaia

Elena Bykova and Leonid Dubrovinsky working at ESRF

Image courtesy of NASA Goddard Space Flight Centre; image source: Flickr

The quantities of oxygen involved are huge: based on the estimated rate at which BIFs are subducted, the decomposition of hematite alone in that time could have produced 8 to 10 times the mass of oxygen in the modern atmosphere. Under the conditions found in Earth's lower mantle, Elena and her colleagues believe that this oxygen would exist in a liquid state. They suggest that over time, this has formed an enormous – and previously unimagined – reservoir of oxygen-rich fluid deep in Earth's interior.

This fascinating idea also means that researchers will need to substantially rethink their ideas about the geochemical processes in Earth's interior. In the presence of so much oxygen, the oxidation states of the elements in the lower mantle – and thus the chemical reactions between them – will be very different to what scientists have imagined. Furthermore, as it moves, the oxygen-rich fluid will transport other compounds, including the many trace elements present in Earth's interior, producing a very different chemical distribution to what has previously been assumed. According to Leonid Dubrovinsky, the leader of the group that performed this study, "The effects of carbon dioxide, water and other greenhouse gases on the atmosphere are widely discussed, but the contributions of deep geochemical processes to the atmospheric composition have so far received little attention. Any global models of the past and future of Earth, including models of the evolution of our climate, will need to take into account these new findings."

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Web references

w1 The European Synchrotron Radiation Facility (ESRF) is one of the most intense sources of X-rays in the world. Thousands of scientists come every year to the ESRF to carry out experiments in materials science, biology, medicine, physics, chemistry, environmental science and even palaeontology and cultural heritage. See: www.esrf.eu

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

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*. See: www.eiroforum.org

Resources

To learn more about the technique of X-ray diffraction, see:

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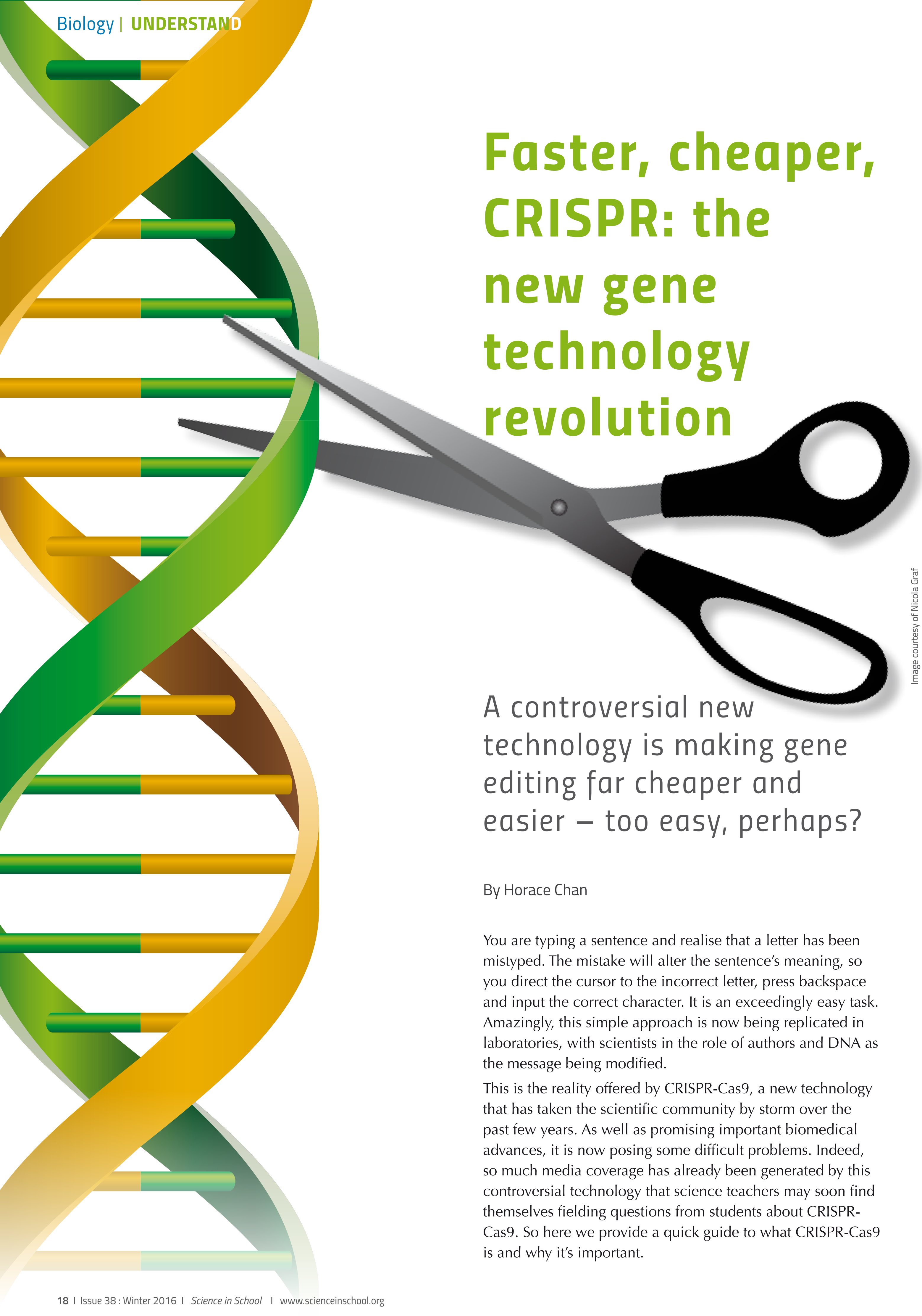
Montserrat Capellas is a senior science communicator at the European Synchrotron Radiation Facility (ESRF) in Grenoble, France.



Faster, cheaper, CRISPR: the new gene technology revolution

Image courtesy of Nicola Graf

A controversial new technology is making gene editing far cheaper and easier – too easy, perhaps?

By Horace Chan

You are typing a sentence and realise that a letter has been mistyped. The mistake will alter the sentence's meaning, so you direct the cursor to the incorrect letter, press backspace and input the correct character. It is an exceedingly easy task. Amazingly, this simple approach is now being replicated in laboratories, with scientists in the role of authors and DNA as the message being modified.

This is the reality offered by CRISPR-Cas9, a new technology that has taken the scientific community by storm over the past few years. As well as promising important biomedical advances, it is now posing some difficult problems. Indeed, so much media coverage has already been generated by this controversial technology that science teachers may soon find themselves fielding questions from students about CRISPR-Cas9. So here we provide a quick guide to what CRISPR-Cas9 is and why it's important.

What is CRISPR-Cas9?

CRISPR-Cas9 is a system that bacteria use to defend against viral attacks, but it has been exploited recently as a technology to snip genomes at precise points. The system comprises two components: CRISPR and Cas9. CRISPR stands for 'clustered regularly interspaced short palindromic repeats' and refers to locations on a genome where the DNA sequence repeats. Near these repeats are Cas genes, which code for important enzymes in the system. One of these, Cas9, is a nuclease – that is, an enzyme that cuts nucleic acid (DNA or RNA).

When a virus attacks a bacterium, it injects its nucleic acid into the bacterium, which responds by producing Cas enzymes to snip out pieces of the viral nucleic acid and incorporate them into its own genome at the CRISPR locations (figure 1). This provides some useful acquired immunity for the bacterium: the next time the same species of virus attacks, the CRISPR locations, along with the viral nucleic acid, are copied into

REVIEW

✓ Biology

✓ Ages 16–19

CRISPR-Cas9 is a powerful 'GPS-like' gene editing tool. It has the potential to open doors to many scientific, medical and agricultural applications. The relative simplicity and low cost of the technique raises important ethical issues. It has also resulted in a high-profile lawsuit between scientists over the valuable patent rights.

The article clearly describes the identification of palindromic repeats as a basic bacterial defence system for the application of the programmable CRISPR-Cas9 gene editing tool. The article can be used to explain, in conjunction with animations, the molecular biology techniques involved and why CRISPR-Cas9 has replaced earlier gene editing methods. It can also form the basis for discussions on ethical issues around germline editing and intellectual property. Comprehension questions around the article could include:

- What does CRISPR stand for?
- How does CRISPR-Cas9 work?
- What type of diseases can be treated using CRISPR-Cas9?
- What are the potential risks of using CRISPR-Cas9?
- What are the ethical issues surrounding the use of CRISPR-Cas9?
- Who should be awarded the Nobel Prize for the discovery of CRISPR-Cas9?

Mary Brenan, Concord College, UK

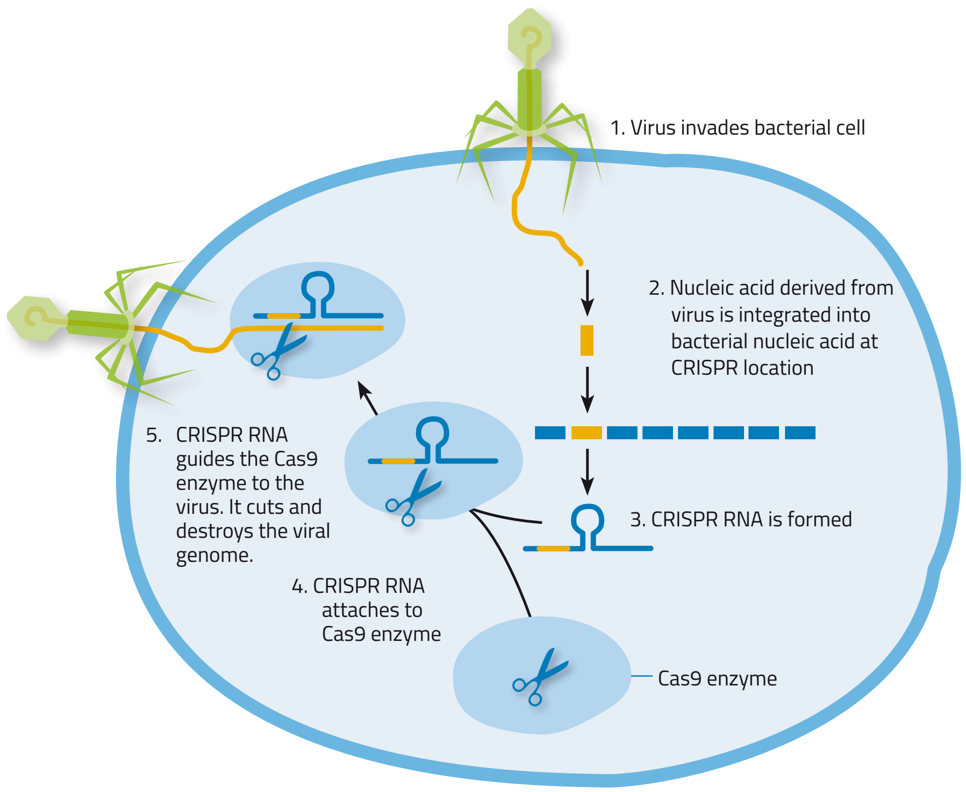


Image courtesy of Nicola Graf

Figure 1: CRISPR-Cas9: the bacterial defence mechanism

short RNA molecules. These short RNA molecules first attach to the Cas9 enzyme and then guide the resulting complex to the invading nucleic acid, identifying it by its matching sequence. Cas9 then cuts the targeted nucleic acid, thus disabling the virus's ability to hijack the bacterium for its own replication.

But how was this bacterial system adapted to provide a new genetic technology? In 2012, the teams of Jennifer Doudna at University of California Berkeley, USA, and Emmanuelle Charpentier, then at Sweden's Umea University, modified and pieced together the short RNA molecules into a single 'guide' RNA (figure 2). This retained one end that could link to Cas9, but the sequences on the other end could be made to pair with any known target DNA. With this customising capacity, CRISPR-Cas9 could specifically cut DNA sequences of choice. Shortly afterwards, Feng Zhang's lab at the Massachusetts Institute of Technology, USA, took CRISPR-Cas9 further by showing its capacity to induce precise genomic cuts in human and mouse cells (Cong et al, 2013). In addition, they tweaked Cas9 so that it would cut DNA in a slightly different way, stimulating a specific DNA repair mechanism in cells. This means the researchers successfully inserted a new DNA sequence precisely into the cut site, replacing the original sequence (figure 2).

Image courtesy of Nicola Graf

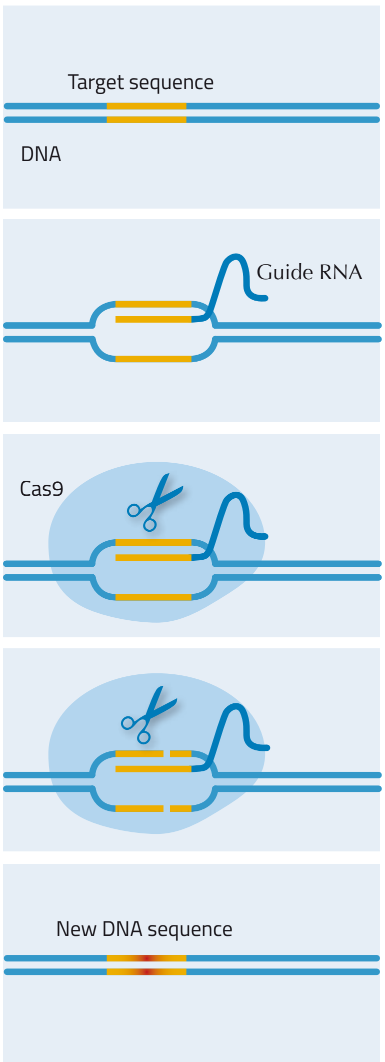


Figure 2: Gene editing using CRISPR-Cas9

With these pioneering efforts, CRISPR-Cas9 was transformed from being a niche topic in microbiology into an exciting research tool that enables researchers to edit genes for different purposes with great specificity and ease.

What is it used for?

To study genetic function, scientists often try to produce cell lines or model organisms in which the gene of interest is mutated or inactivated (a technique known as gene knockout). CRISPR-Cas9 provides a rapid and precise way of doing this. Additionally, the Cas9 enzyme can be modified so that it loses its DNA cutting ability but is still able to target and bind to specific DNA sequences, thanks to the guide RNA. This has the effect of physically blocking the binding of RNA polymerase, thus allowing scientists to control gene transcription – the starting point for gene activity.

While these are important techniques in biomedical research, CRISPR-Cas9 also promises more direct applications in health care. Scientists have already used CRISPR-Cas9 gene editing to excise HIV sequences and prevent the virus from replicating in human cell lines. It has also been used to remove mutated sequences in mice afflicted with Duchenne muscular dystrophy, which causes muscle weakness, thus presenting therapeutic hopes for patients and families suffering from this and similar genetic diseases. Recently, pig embryos have undergone extensive gene editing using CRISPR-Cas9 in the hope of providing safer organs for human transplantation.

So if editing has been done in pig embryos, could it also be done in human embryos? This is precisely what Chinese researchers did in 2015, when they used CRISPR-Cas9 to modify the β-thalassaemia gene in 86 human embryos (Cyranoski & Reardon, 2015). The technique turned out to be rather inefficient, as the DNA sequence was changed successfully in less than a quarter of the embryos. Nonetheless, the announcement of this finding generated much controversy because of the ethical implications.

Ethical issues – and the future

The ethical concerns relate not only to human embryo experimentation, but also to the uneasy prospect of germline engineering. With CRISPR-Cas9, it is theoretically possible to make genetic changes in germ cells (sperm and ova), which could be passed down to future generations. While this idea has great potential to eradicate genetic diseases, it also prompts the question of which modifications should be permitted as a medical treatment in the future. Could traits such as intelligence or eye colour be considered appropriate for medical improvement? These fears may seem far-fetched, but there is another worry: that germline engineering could have completely unanticipated and irreversible effects on future generations. This is particularly relevant since recent genetic research has found that interactions between genes and other hereditary mechanisms are far more complex than previously expected.

These implications have not escaped the attention of scientists. Some agree that germline engineering is fraught with ethical landmines and believe that any CRISPR-Cas9 research using human embryos should be halted. Others, however, believe that a complete moratorium would not only be difficult to enforce, but would also hinder research progress. Despite such differing viewpoints, the scientific community appears to have taken dialogue and transparency as the way forward, as evidenced by the many summits and meetings on this topic worldwide.

Meanwhile, the development of CRISPR-Cas9 continues surging forward. Pharmaceutical companies are investing in the technology to aid drug development research, and technical flaws are being addressed and improved – while a bitter patent dispute is playing out for the technique's pioneers (Doudna/Charpentier and Zhang). Regardless of what happens there, the meteoric rise of CRISPR-Cas9 is only just beginning.

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Download the article free of charge on the *Science in School* website (www.scienceinschool.org/2016/issue38/crispr) or subscribe to *Nature* today: www.nature.com/subscribe

Resources

For an article on the potential use of CRISPR in RNA gene editing, see: www.nature.com/news/crispr-gene-editing-system-unleashed-on-rna-1.20030?WT.mc_id=FBK_NatureNews> or use the tinyurl: http://tinyurl.com/jouvq8y

For more on the patent dispute regarding the CRISPR-Cas9 technology, see: www.statnews.com/2016/03/08/crispr-patent-fight

For more on the use of CRISPR-Cas9 technology to treat Duchenne muscular dystrophy, see: www.theguardian.com/science/2015/dec/31/breakthrough-offers-hope-to-those-with-duchenne-muscular-dystrophy or use the tinyurl: http://tinyurl.com/hdrkm6s

For more on the use of CRISPR-Cas9 in producing human transplant organs in pigs, see: www.nature.com/news/gene-editing-record-smashed-in-pigs-1.18525

For an accessible article on the ethical issues of gene editing in germ cells, see: www.statnews.com/2015/11/17/gene-editing-embryo-crispr

For an article featuring comments from international gene scientists on ethical issues of gene editing in germ cells, see: Bosley K et al. (2015) CRISPR germline engineering – the community speaks. *Nature Biotechnology* **33**: 478–86

To read more about Emmanuelle Charpentier's revolutionary gene editing technique, and listen to her discussing her work, see: www.news.embl.de/science/1608-charpentier/ and www.news.embl.de/science/nothing-blue-skies/

Horace Chan recently completed his master's degree in molecular and cellular biology at University of Heidelberg, Germany. He is currently a communications intern at the German Cancer Research Center, Heidelberg, and has previously contributed scientific articles to *Asian Scientist*, an online magazine reporting on research from the Asia-Pacific region.

The German team, in close co-operation, finishing their CanSat for the test drop

European CanSat Competition 2016

This June, students from around Europe met in Portugal to compete in the European CanSat competition. One of their teachers tells us more.

By Markus Norrby

When I first told my students about the European Space Agency (ESA) CanSat competition[w1] and asked if anyone might be interested, they were eager and hesitant at the same time. A CanSat is a working model of a real satellite that is fitted in a standard 330 millilitre soda can. CanSats do not go into space, but instead are released from a rocket or a balloon at an altitude of about 1 kilometre. According to the rules of the competition, it should contain an on-board computer, sensors for different measurements, and a radio transmitter to communicate with a ground station.

So while my students at Vasa Övningsskola in Finland thought it sounded exciting, some were concerned that the competition would be too complicated for them, as they hadn't really studied any electronics or programming. But one group decided to go ahead anyway, learning all the necessary skills along the way – and they found themselves in Portugal for the 2016 European finals on 22–25 June. As my students discovered, it is surprisingly simple to get started and build a functioning CanSat – but enormously complicated to build something one hopes will be the best in Europe.

The 2016 final hosted 14 teams from across Europe. Most of the teams had made it to Portugal by winning a national competition, although a few teams from countries without an active CanSat community were also selected to take part. Each team consisted of four to six students and at least one accompanying teacher, so in total almost 100 ‘space geeks’ filled the hangars at Torres Vedras airfield near Lisbon during the competition.

My team’s table in the hangar was buzzing with activity for the first two days of the competition. Persistent problems with our GPS unit meant the students soldered and re-soldered connector after connector in a last-minute frenzy, hoping to identify the problem and find a reliable GPS fix. On the first day, the students ran out of spare parts, but with the help of several other teams they found a working combination of chips and antennas. By the end of the second day, the friendly little green LED on the GPS chip finally started blinking to indicate an acquired satellite fix.

As a teacher, this exemplifies what I think makes the European CanSat Competition a fantastic experience. The students worked through the night, if needed, to solve seemingly impossible problems, before finally succeeding. And students from different countries, but with the same passion for science and technology, got to know each other, learn from each other and help each other throughout the competition.

During the second day of the competition, the judges inspected

Background

About CanSat

- CanSat started in the 1990s in the United States and Japan as a way of increasing interest in space research among university students.
- The European CanSat Competition targets secondary school students and has been organised by the Education Office at the European Space Agency since 2010, although several European countries have worked with CanSats at a national level for even longer.
- The best way to get involved in CanSat is to enter a national competition, usually organised by local European Space Education Resource Office (ESERO) partners (see www.cansat.eu for a list of national competitions).
- The same organisations also hold workshops for teachers interested in starting a CanSat project.

Many hands are needed to pack all the electronics correctly.

The Finnish team setting up their test drop ground station under the supervision of the author

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The Intruder rocket launched with two CanSats on board.

the technical aspects of the cans and parachutes. Then drop tests were carried out from an aeroplane to ensure the cans could be safely loaded into the rockets and fired up to a height of about one kilometre.

The third day was launch day, but as with real rocket launches, the weather caused several delays. In the end, only five of the planned seven rockets could be safely fired, and some CanSats had to be dropped from a plane at lower altitude instead. A short night followed, with all the teams working hard on data analysis to prepare their final presentations for the following morning.

Listening to these presentations, I was amazed at the high standard of every project. Ultimately, the Portuguese team were crowned the CanSat 2016 winners, followed by Germany and Ireland. There is no doubt, however, that every participating team had worked hard for months to prepare their missions and had learned so much in the process, and they all presented fantastic results. This, I think, makes every team a winner!

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Frantic activity at the launch site as data starts streaming back from the descending CanSats

Web reference

w1 For more information on the CanSat competition, visit the website or Facebook page: www.cansat.eu and www.facebook.com/cansatsineurope

Markus Norrby is a physics teacher at Vasa Övningsskola in Finland.

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The European CanSat Competition participants and crew achieve lift-off!

Compound Interest: communicating chemistry with engaging graphics

UK chemistry teacher Andy Brunning talks about juggling school life with his famous online alter ego, 'Compound Interest'.

Image courtesy of Andy Brunning / Compound Interest

Andy Brunning, the mastermind behind Compound Interest

By Hannah Voak and Laura Howes

By day, Andy Brunning teaches chemistry at a secondary school in Cambridge, UK. But by night, he single-handedly runs the website 'Compound Interest', creating educational infographics that explore everyday chemistry.

What started as making a poster for his own classroom has led Andy to produce nearly 400 graphics, all of which are available to download free of charge from his website[w1]. Answering questions such as 'Why is coffee bitter?' and 'Why does bacon smell so good?' and explaining the chemistry behind honey, cosmetics and Christmas trees, Andy's graphics have been featured on websites including The Guardian, Huffington Post and Smithsonian. His social media following is rather impressive too, with over 227 000 Facebook likes and 17 700 followers on Twitter – figures that are still rapidly growing.

Starting out

Despite his Internet fame, Andy is first and foremost a teacher. After a gaining a degree in chemistry, Andy found he was not interested in pursuing laboratory work. "I was much more enthusiastic about explaining chemistry concepts to students," he says. "That was the reason I went into teaching in the first place." He worked in two schools during his year of teacher training before he arrived at a school in Bournemouth, UK. "It was there that Compound Interest got started," he says.

"When I arrived, they had stripped the classroom of the displays. I had a periodic table on the wall and that was about it," Andy recalls. In an attempt to inject some inspiration into his classroom, he started searching online for posters. He soon saw the problem. The resources Andy found were "boring, dry, or didn't look visually appealing". His solution was to "throw something together" on his laptop. "If it is colourful and interesting, it will be fine," he thought.

With only a basic school qualification (GCSE) in graphics behind him, Andy set about creating his first infographic. "The

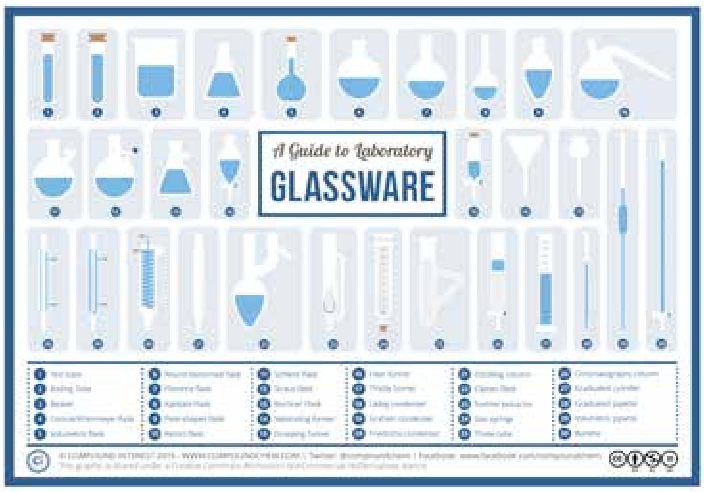


Image courtesy of Andy Brunning / Compound Interest

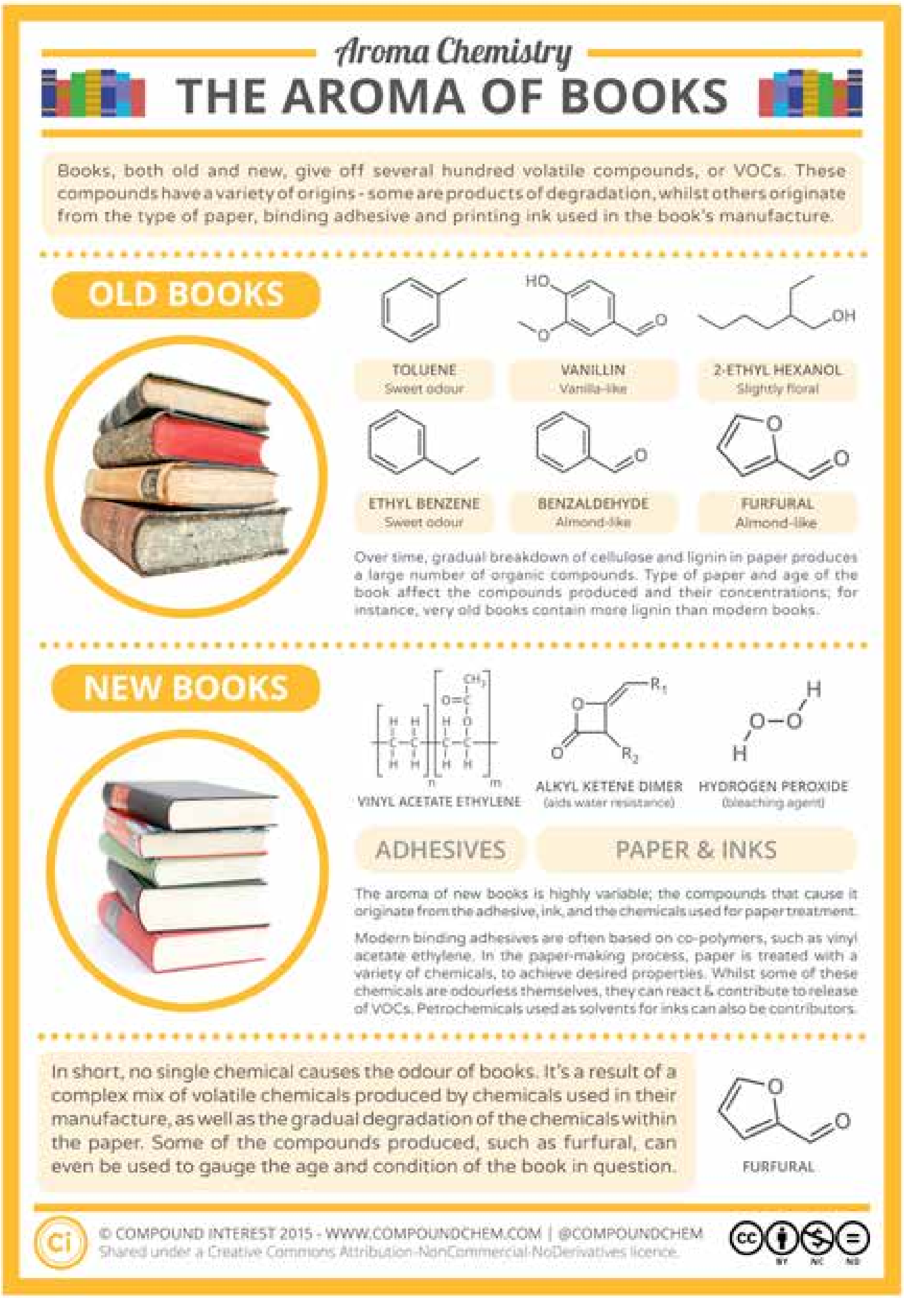


Image courtesy of Andy Brunning / Compound Interest

first bunch I did," he says, "were on the groups of elements in the periodic table." He showed them to a handful of teachers, who suggested he post them somewhere on the Internet for others to download. "That is how Compound Interest began: just off the back of a few posters. Completely accidentally!"

Graphics in the classroom

Now Andy aims to create at least one new graphic a week, but it can depend on his workload at school. How does he balance a full teaching career with Compound Interest? "With difficulty," he laughs. "Usually I'll stay for at least an hour at the end of the day, catching up with marking and planning," he says. "Then I'll spend an hour or two working on graphics at home, although my fiancée would probably argue it was a bit more!"

His two careers, however, complement each other well. Andy started creating his graphics with his students in mind, so his work is very relevant to his lessons. He also enjoys researching topics that aren't necessarily part of the syllabus but that can be brought into his teaching. One of Andy's favourite graphics to use is of the periodic table, but he also loves his 'Guide to laboratory glassware'.

His students like using the posters as references too. "My year 12 class [16- to 18-year-olds] loves the organic chemistry functional groups graphic. They all have a printed copy of it – not at my behest, I might add!" Andy has also created teaching versions of some of his work, removing parts of the graphics for students to fill in the blanks. "Teachers could easily adapt the graphics themselves to use as teaching resources," he suggests.

The graphics are not limited to the walls of a chemistry classroom, however. Andy describes how one school used several graphics for their 'chemistry week', displaying posters in different areas of the school. The English department featured a graphic explaining the aroma of books, while the school canteen presented food-related graphics. Andy's work is undoubtedly relevant to the other sciences too, and of course to our everyday lives.

It's not just chemistry students that enjoy Andy's work. "That's part of the idea, to get people who aren't chemists interested as well," he says. However, despite his audience growing beyond the classroom, he still produces content that is more directly applicable to topics that students are studying. "It makes sense to keep catering for them as well," he says. "I know there are a lot of chemistry students either at university or still at school who are following the Facebook page."

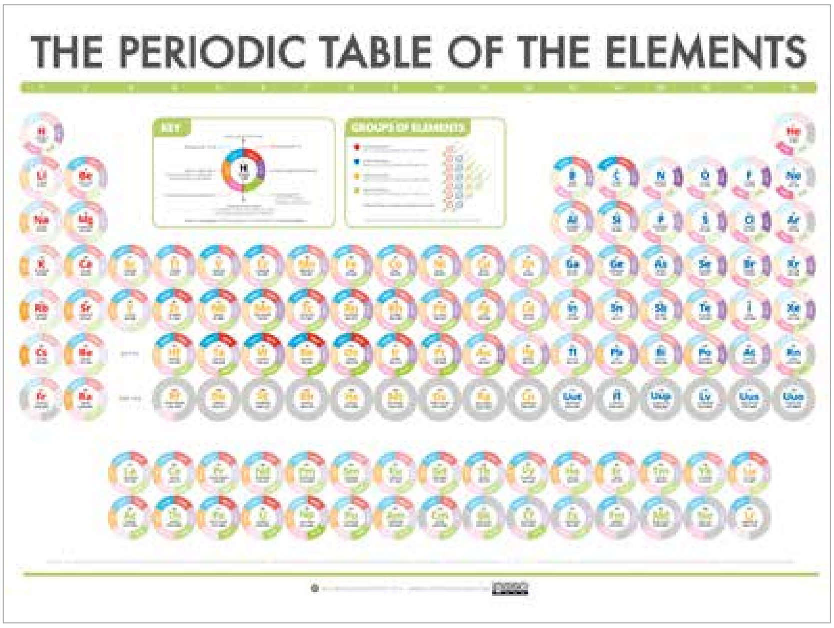
Inspiring students

Over the past three years, Andy has built up an impressive collection of graphics, as well as publishing his first book *Why Does Asparagus Make Your Wee Smell? And 57 Other Curious Food and Drink Questions*. So how does he constantly come up with new ideas? "I get my inspiration from a variety of places," he says. His ideas often arise from teaching or from questions asked by his students; and reading articles can sometimes plant an idea in his head. Inspiration can strike from everyday occurrences too; putting in contact lenses in the morning, for example, resulted in a graphic explaining the polymers that make up different types of lenses. Andy's general approach, however, is to create content that he finds fascinating, and he hopes others will too. "I really love the food ones," he says. "There was a reason why I focused on food chemistry for the book."

As for inspiring his students to enjoy science, Andy's tip is to show them how it is applicable to their own interests. If students are keen on sports, for example, Andy suggests showing them how chemistry fits into the picture. "They often don't realise that chemistry is involved in some aspect," he explains.

You would imagine having a chemistry teacher with such online success was inspiration enough for his students, but Andy says their interest in his work varies. "Generally they are quite interested, but it depends how excited by science they are. One of my year 10 classes [14- to 15-year-olds] is particularly keen though, and they like to look at my book in lessons." Andy will often find students reading his 'about' page on the Compound Interest website, but he's not one to shout about his accomplishments. Some students are yet to realise the connection, unaware that their own teacher has created the charts and posters they are using in lessons.

It won't be long before the rest of his students make the link, especially with the grand plans Andy has for Compound Interest. He aims to produce a second book and has recently started a new project, 'Chemunicate[w2], in which he works with researchers to communicate their studies in a more accessible way. On top of that, Andy wants to complete a set of chemistry playing cards he's been working on, which will surely go down a treat in any classroom or staffroom!



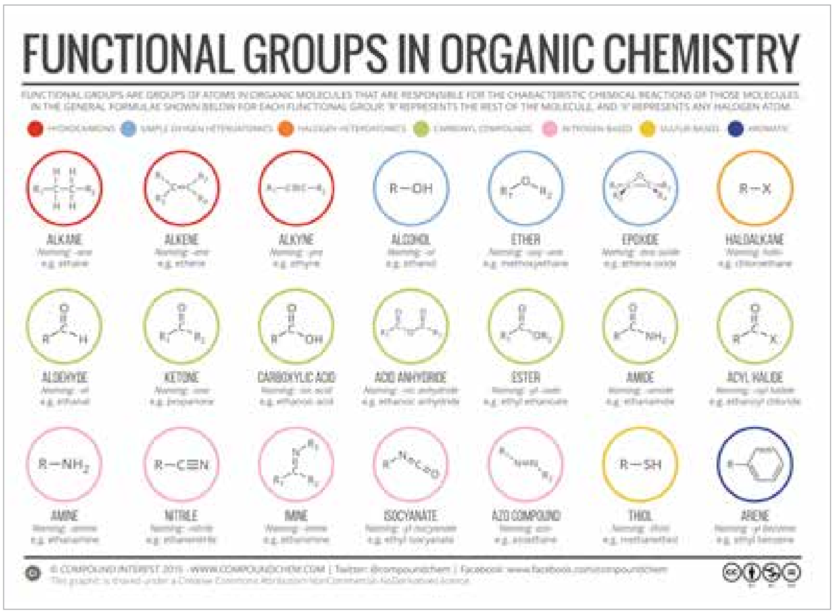


Image courtesy of Andy Brunning / Compound Interest

Web references

w1 Use the search button on the Compound Interest website to find any of the graphics mentioned in this article, including fill-in-the-blanks teaching versions. All the graphics are free to download for educational purposes from the Compound Interest website at: www.compoundchem.com

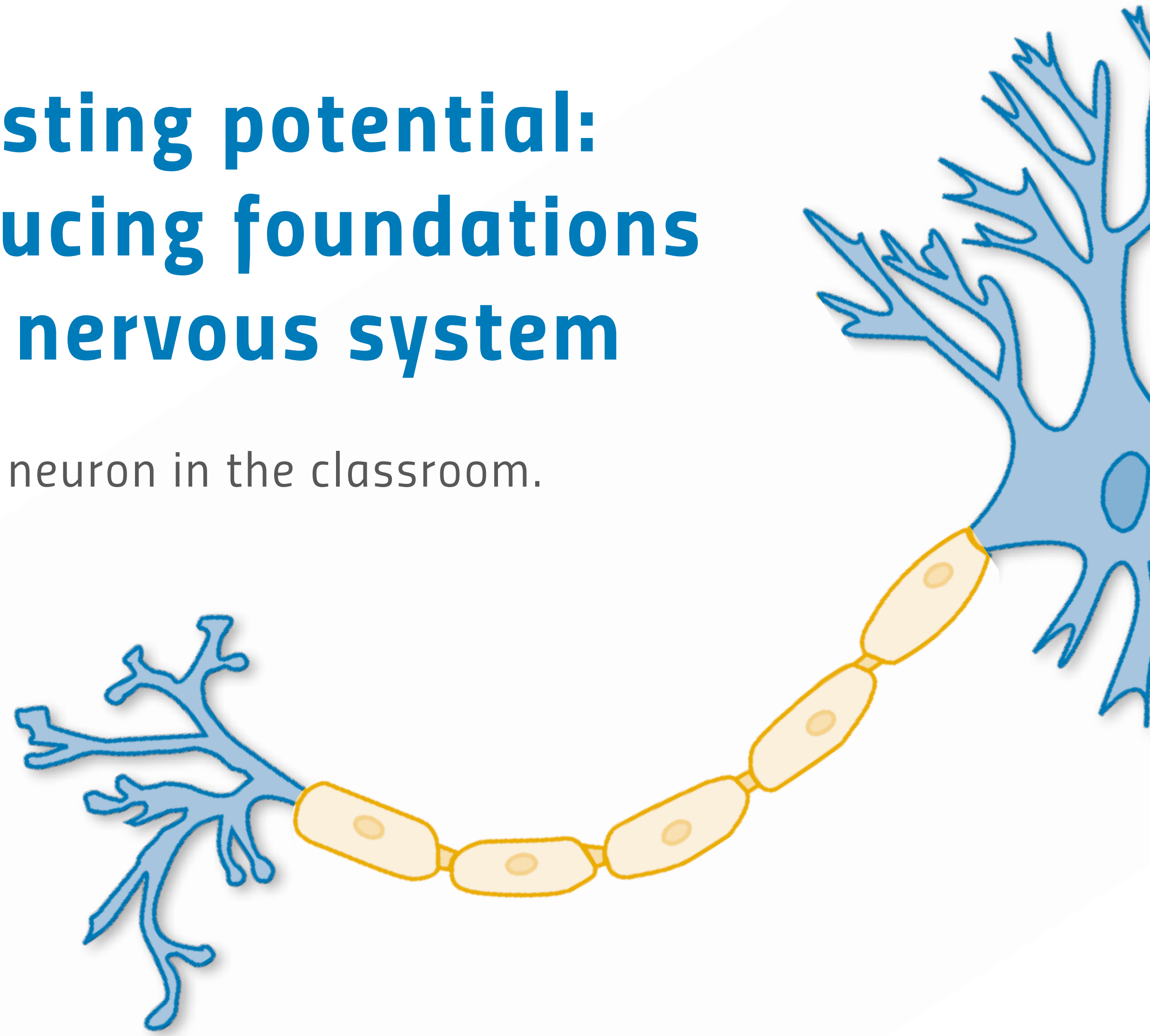
w2 To find out more about 'Chemunicate', see: www.compoundchem.com/chemunicate

Hannah Voak is one of the editors of *Science in School*. With a bachelor's degree in biology and an enthusiasm for science communication, she moved to Germany earlier this year to join *Science in School* at the European Molecular Biology Laboratory.

Laura Howes is a previous editor of *Science in School*. She studied chemistry at the University of Oxford, UK, and then joined a learned society in the UK to begin working in science publishing and journalism. In 2013, Laura moved to Germany and the European Molecular Biology Laboratory, where she worked for *Science in School* until September 2016.

The resting potential: introducing foundations of the nervous system

Simulate a neuron in the classroom.



By Claas Wegner, Roland Kern, Jennifer Kahleis and Alexander Maar

The nervous system is not only fascinating but also probably one of the most complex topics in school biology lessons, particularly because working with real neurons is not feasible at school. In this article, we describe an activity that uses a cellophane membrane to explore how the resting potential is generated in a neuron. Suitable for students aged 16–19, the activity takes approximately 90 minutes.

An artificial membrane potential

To transfer information, neurons need to be able to generate and maintain a membrane potential: a voltage difference between the intracellular and extracellular media that is focused along the cell membrane. The voltage difference in an unexcited neuron is referred to as the resting potential. Stimulating this neuron can alter the resting potential, causing an action potential: the electrical impulse by which the neuron transmits information. Before the neuron can fire again, the resting potential needs to be re-established (figure 1). But how is the resting potential generated and maintained? The answer lies partly with the semi-permeable nature of the cell membrane.

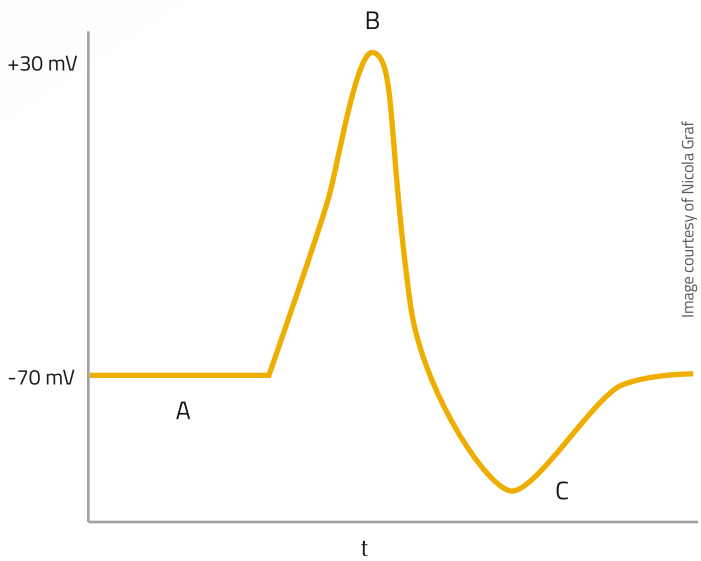


Figure 1: Voltage difference across the cell membrane over time, when a neuron is stimulated. A: the resting potential; B: an action potential; C: the resting potential is re-established; t: time

Image courtesy of Dhp1080; image source: Wikimedia Commons

REVIEW

- ✓ Biology
- ✓ Chemistry
- ✓ Physics
- ✓ Ages 16–19

Simple models can be very helpful for understanding complex processes that take place in nature. This article describes a practical activity to unravel how neurons work. All the materials required can easily be obtained and the instructions are easy to follow, making the experiment suitable for students to perform in groups.

The activities could be used to combine different topics in biology, chemistry and physics.

Those interested in deepening their knowledge about the subject can also find complementary teaching activities in the web references section.

Mireia Güell Serra, Spain

Image courtesy of Alexander Maar

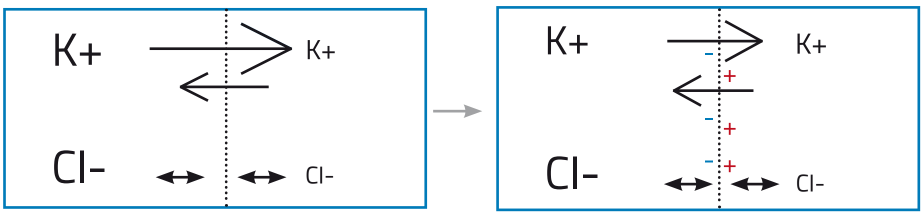


Figure 2: When the solutions on either side of a semi-permeable membrane have different concentrations (top), the distribution of negative and positive charges across the membrane becomes unbalanced (bottom), causing a voltage difference. Note that the concentration of K cations remains higher on one side of the membrane, due to their attraction to the anions, which are trapped by the membrane.

Among other constituents of the intracellular and extracellular media are dissolved ions including sodium (Na^+), chloride (Cl^-), organic anions (A^-) and, most importantly, potassium (K^+). Once a neuron has fired and the resting potential begins to be re-established, the concentration of K^+ ions is higher inside the neuron than outside. Unlike most other ions, K^+ ions can pass freely into and out of the cell, via specialised ion channels in the membrane. Driven by the concentration gradient, K^+ ions diffuse out of the neuron, causing a net movement of positive charge (figure 2). This causes a voltage difference across the membrane, with the intracellular medium being more negatively charged than the extracellular medium. This is the resting potential, with a value of around –70 mV.

Although there are additional factors involved in establishing the resting potential in a neuron, the combined contribution of the concentration gradient and the electrical properties of anions and cations can easily be demonstrated in the classroom using cellophane as a semi-permeable membrane, as described below.

Before the activity, it is useful to cover the basic principles of diffusion and cell membranes with your students.

Instructions for hands-on activities involving the properties of the cell membrane and diffusion through membranes can be downloaded from the *Science in School* website[w1].

Materials

For each group of 2–4 students, you will need:

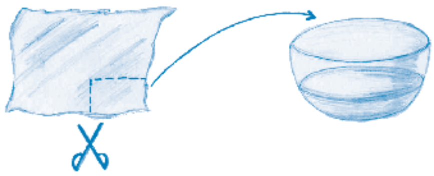
- 300 ml 0.01 M potassium chloride (KCl) solution
- 100 ml 0.1 M potassium chloride (KCl) solution
- Distilled water
- Voltmeter
- Electrodes (chlorinated silver wire)
- Glass bowl (200–300 ml)
- Funnel
- Cellophane wrapping
- Rubber band
- Clamp stand and three clamps
- Two cables with crocodile clips
- Pipettes
- Scissors

Procedure

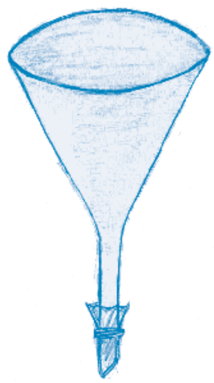
Before beginning the activity, discuss with your students how they think a voltage difference can occur in the cell, and which cell components are important in establishing it. Briefly introduce the resting potential. Then, ask your students to:

1. Fill the glass bowl with about 200 ml of the 0.01 M potassium chloride (KCl) solution, which represents the extracellular medium of the membrane.

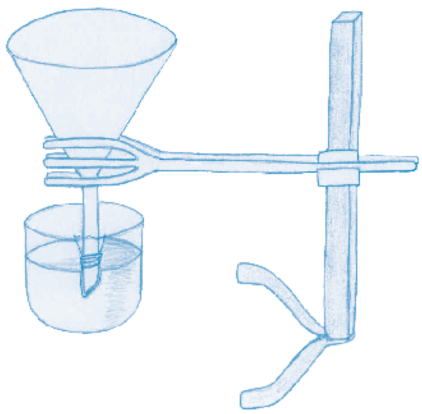
2. Cut a piece of cellophane wrapping large enough to cover the base of the funnel, then rinse the cellophane in distilled water to make it more flexible. The cellophane serves as the semi-permeable membrane.



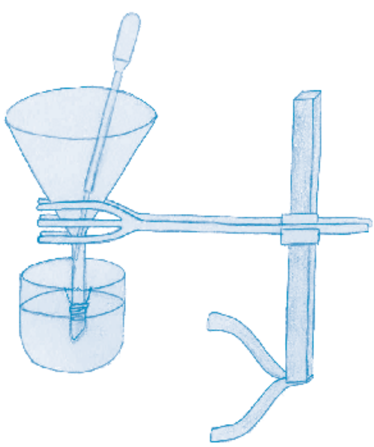
3. Wrap the piece of cellophane tightly around the base of the funnel and seal it with the rubber band.



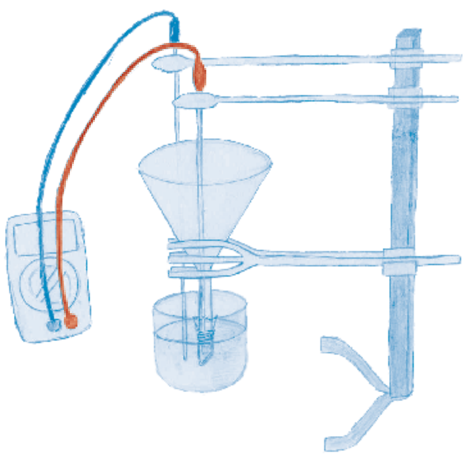
4. Clamp the funnel to the clamp stand, submerging the base of the funnel in the KCl solution in the glass bowl.



5. Using a pipette, add 0.1 M KCl solution to the funnel until the liquid levels inside and outside the funnel are level. The solution inside the funnel represents the intracellular medium.



6. Attach the two electrodes to the voltmeter with crocodile clips. Using a clamp, place the electrode that is connected to the cathode of the voltmeter in the solution in the glass bowl. Supported by a further clamp, place the second electrode, connected to the anode, in the solution in the funnel.



Discussion and further investigations

Ask your students:

- What voltage do they predict that the voltmeter will show? Some students may think that it will be positive, as is an action potential. Ask them to set the voltmeter to approximately 200 mV.
- Within about 10 seconds, the voltage will decrease, stabilising after about 5 minutes at about –50 mV to –60 mV.
- What causes the voltage difference between two solutions? Why is the value negative? What would have happened if the solution in the glass bowl had been the more concentrated of the two?
- Why do they think the membrane and the two solutions generated an unequal distribution of ions?

As in the real-life neuron, this experiment relies on two components: a concentration gradient and the semi-permeable properties of the cellophane wrapping. Like the membrane of a neuron, the cellophane is permeable to K^+ ions but almost non-permeable to Cl^- ions. As a result, as in the neuron, there is a gradual, net diffusion of K^+ ions out of the funnel (0.1 M KCl) and into the glass bowl (0.01 M KCl). If the electrodes are placed carefully, without puncturing the cellophane, the voltage of the solution in the funnel can be seen to become more negative. The initial setting of 200 mV on the voltmeter is arbitrary, to ensure that the final reading is similar to that of the real-life resting potential.

While realistic, this experiment is not a complete model of how the resting potential is established and maintained. In a neuron, the extracellular and intercellular media contain more than just K^+ and Cl^- ions, and there are additional mechanisms that determine the membrane's permeability. However, this activity offers an opportunity to discuss the accuracy of the model, and to introduce other aspects of neurobiology such as ions channels, the sodium–potassium pump and the action potential.

Alternatively, you could ask your students to discuss hypothetical scenarios, for example, using additional solutions, a membrane with different properties or different concentrations of KCl.

Web reference

w1 Worksheets covering the properties of the cell membrane and diffusion through membranes can be downloaded from the *Science in School* website. See www.scienceinschool.org/2016/issue38/membrane

Resources

For more details on electrochemistry and membrane potentials, see:

Tasaki I (1982) *Physiology and electrochemistry of nerve fibers.* Biophysics and bioengineering series. Volume 3. New York, USA: Academic Press. ISBN: 978-0126837803

For more general information about neurobiology, see Neuroscience Online, an electronic neuroscience textbook:

neuroscience.uth.tmc.edu

For a closer look at neurons, see:

Shepherd GM (1983) *Neurobiology.* New York, USA: Oxford University Press. ISBN: 978-0195088434

For a simple explanation of resting and action potentials, see the Neuroscience for Kids website: www.faculty.washington.edu/chudler/ap.html

Dr Claas Wegner is a member of Bielefeld University's Department of Biology Didactics and a lecturer for pedagogical practice in this subject. He is the founder and head supervisor of Kolumbus-Kids, a project for teaching biology to gifted students at Bielefeld University. Additionally, he teaches biology and physical education as a senior teacher at the Ratsgymnasium Bielefeld.

Dr Roland Kern has been a dedicated member of Bielefeld University's Department of Neurobiology since 1996. In his position as a lecturer in human and animal physiology, he teaches neurobiology subjects to students of natural sciences.

Jennifer Kahleis is a graduate from Bielefeld University who studied biology, chemistry and educational sciences. She worked as an academic assistant for the Department of Biology Didactics during her master's studies and currently works as a trainee teacher.

Alexander Maar is studying educational sciences along with English and biology for secondary school. He is active as an undergraduate assistant for Bielefeld University's Department of Biology Didactics.

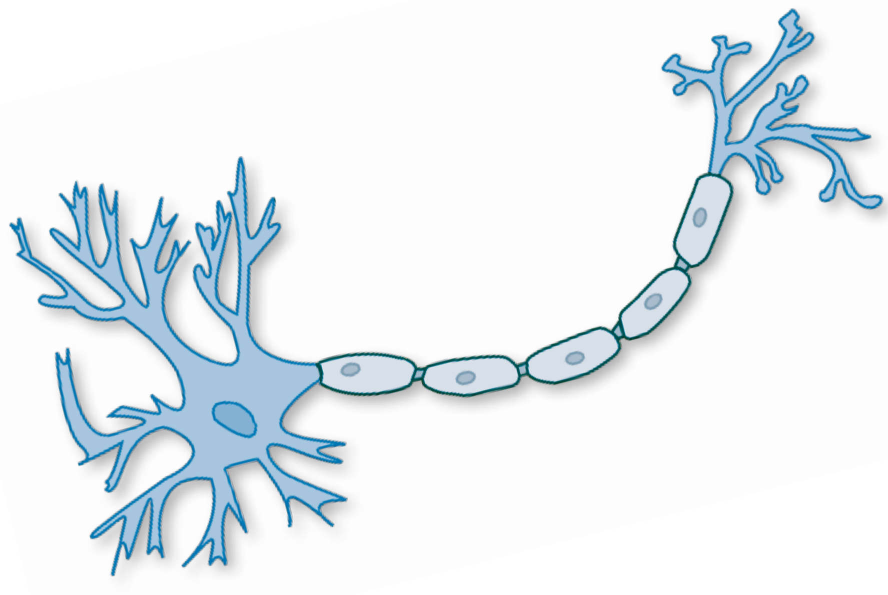


Image courtesy of Dhp1080; image source: Wikimedia Commons

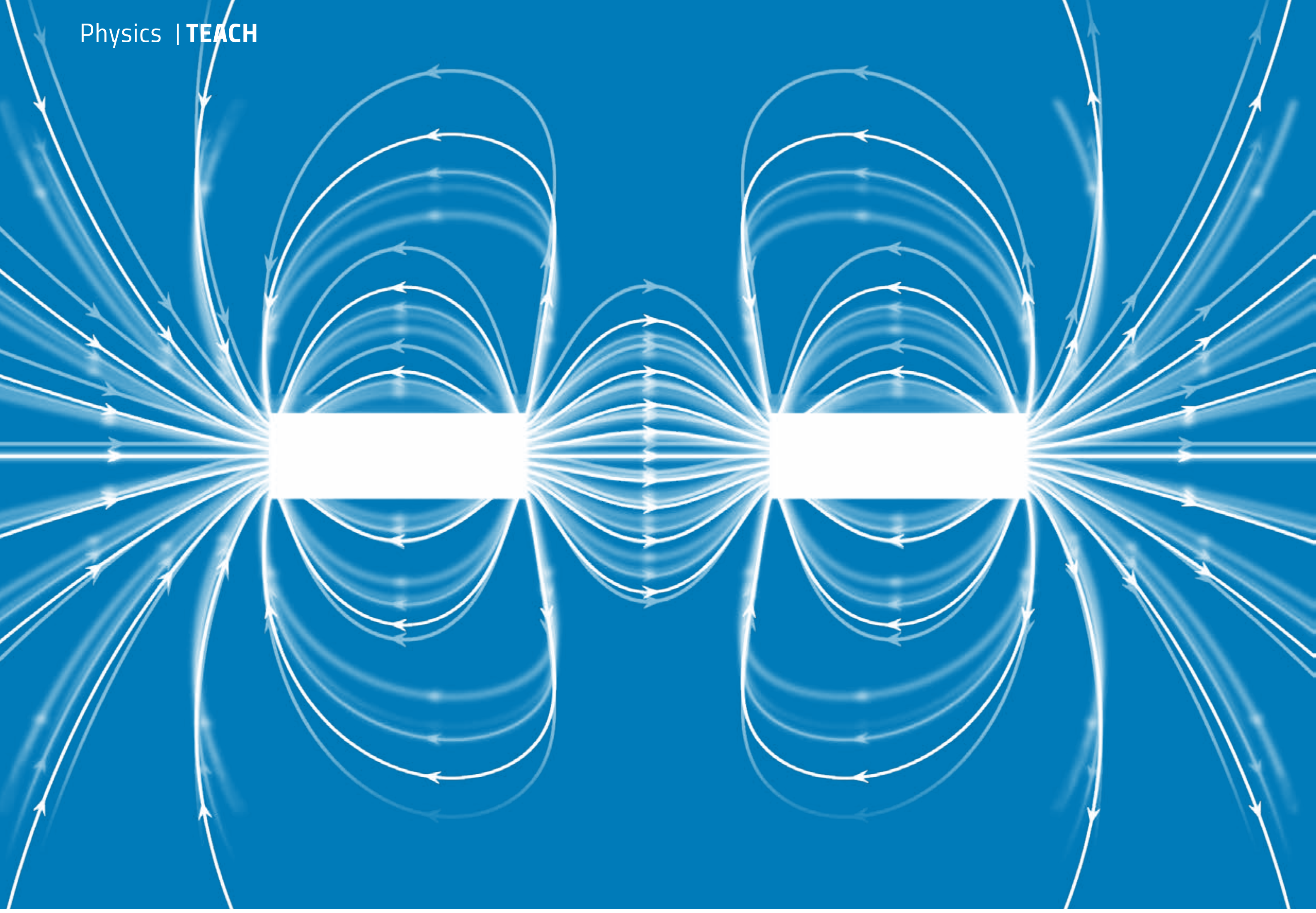


Image courtesy of Geek3; image source: Wikimedia Commons

Be a magnet for a day

What happens inside magnets? This fun activity for primary school pupils helps them find out – by turning themselves into a magnet.

By Katarína Krišková

Generations of children have discovered that magnets are great fun to play with. The way in which the unseen power of magnetism pulls them together or pushes them apart is so intriguing – an active force that seems to come from nowhere. Magnets are useful too – they can hold things together but it's easy to break them apart again: the engine and carriages of a toy train, magnetic alphabet letters, fridge magnets, cabinet latches, and so on – not to mention magnets inside appliances and electronic devices.

But what do pupils learn about magnets just by playing with them? When they experiment with bar magnets, what ideas do they form about the nature of magnets – such as their magnetic poles and internal structure?

On one level, the rules of how magnets behave are simple to discover and understand: opposite poles – north or south – attract each other, while similar poles push against each other, or repel. But there is a common misconception about bar magnets: that you can separate the north and south poles of a magnet by breaking it in half in the middle. In fact, this would just create two new magnets, each with its own north and south poles – as you can demonstrate by doing this experiment.

Of course, the design of bar magnets – with an N for north at one end and an S for south at the other – encourages this misconception because it suggests that the poles are located just at each end of the magnet. So teachers often find that it is

Background

What's inside a magnet?

This activity helps children to understand that magnets have internal structure – rather than just a north pole at one end and a south pole at the other.

So what does science tell us about the inside of magnets? Magnetism comes from the structure of the atoms within a material – which is why some materials (such as iron and steel) are magnetic, but most are not. Each atom of a magnetic material is a magnetic dipole, like a tiny magnet, which lines up with the direction of a magnetic field – just as the needle of a compass aligns itself to Earth's magnetic field.

If a piece of iron has not been magnetised, the magnetic dipoles inside it point in random directions. Across the whole material, they will cancel each other out and it will not act as a magnet. But placing the iron in a strong magnetic field encourages the magnetic dipoles to line up in the same direction, making the material into a magnet: now it has a north and a south pole, and it can attract other objects made from magnetic materials. This is due to its internal structure, in which the dipoles are aligned – as we act out in the activity.

REVIEW

✓ Physics

✓ Ages 14 and under

The activity described in this article includes a good way to illustrate magnetism and to encourage students to move. For older students, the activity could lead into a discussion about where we encounter magnetism in everyday life, for example in Earth's magnetic field or in medical uses.

Erland Andersen, Denmark

hard to explain why the poles could not be separated in this way. While there are some simulations and videos that can help to make this clear (see the resources section at the end of this article), we believe that the best way to explain the phenomenon is by engaging pupils in an activity that shows the internal structure of magnets.

We have carried out this activity with children aged 10–12, but it could also be worthwhile with slightly younger children. The activities plus discussion typically take less than an hour.

First, we show what a non-magnetised material looks like, and then we magnetise it. After magnetisation, we discuss the internal structure of the magnet. Finally, we 'break' the magnet and talk about what has happened.

Materials

- At least 10 pupils
- Red / blue vests, one for each pupil

The vests are red on one side (the front) and blue on the other side (the back). You can make these using 30 cm x 30 cm squares of red and blue cloth, joining them by sewing on tape for the shoulder straps (figure 1). Alternatively,

Image courtesy of Katarína Krišková

Figure 1: Red and blue vests


Image courtesy of Katarína Krišková

Figure 2: A material before magnetisation: pupils face different directions

use squares of red and blue paper pinned onto the pupils' normal shirts.

Procedure

Each pupil represents a small part of a magnet, like a magnetic dipole. This dipole cannot be divided into halves – just as a person cannot be divided into two parts.

Activity 1: Before magnetising

Each pupil should put on a vest, making sure that the red side is facing the front and the blue side is facing the back.

At the start of the activity, the pupils line up so that they form two or three parallel rows. Ask them to face random directions. This means we should not see any dominant colour (red or blue) from any direction (figure 2).

In this situation, the pupils represent a non-magnetised material, such as a piece of steel before it has been made into a magnet. Like the pupils, the magnetic dipoles face random directions, so the material does not act as a magnet.

Activity 2: Magnetising the material

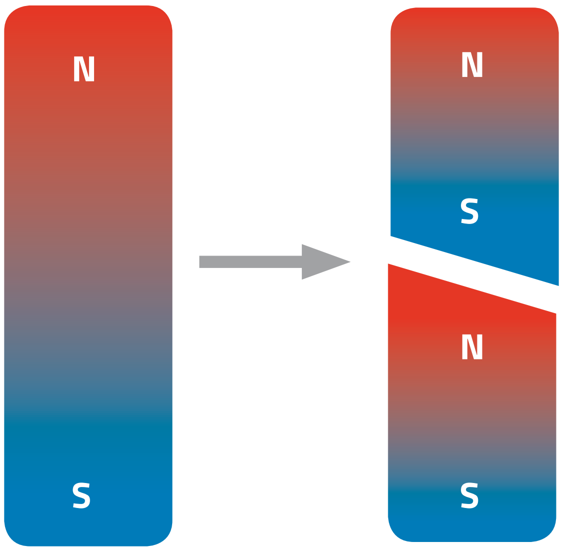
When we apply a magnetic field to the non-magnetised material, it makes the magnetic dipoles line up to point in the same direction. Staying in their rows (which represent the shape of a bar magnet), the pupils are turned by an external force – the teacher – to face the same direction.

Now looking forwards, pupils can see only the blue parts of the vests – and looking behind, only the red parts (figure 3). (Remind pupils to turn only their heads to see this – not their whole body, as the effect will disappear.)

The pupils now represent a magnetised material – a bar magnet. It has two poles, one red and one blue, shown by the colour of the vests that can be seen from each end of the row. But unlike in a real magnet, we can see its internal structure: the red and blue poles are found all the way through the magnet.

Image courtesy of Katarína Krišková

Figure 3: Modelling the internal structure of a magnet: after 'magnetisation', all the pupils face the same way – like the dipoles in a magnet.



Breaking a magnet in half creates two magnets that are both similar to the original magnet, because of its internal structure.

Activity 3: Breaking the magnet into two pieces

Finally, we will 'break' the magnet into two pieces. This is done simply by dividing each row into two. For example, if you have two parallel rows of eight pupils each, break each row apart after four pupils (keeping the parallel rows together). Ask the pupils to step away from each other at the breaking point so you end up with two separate groups of pupils.

Pupils can then see what happens after breaking a bar magnet: the internal structure remains the same, but the size of the magnet changes. We do not separate the poles of the magnet – we just make two smaller magnets.

It does not matter how we break the magnet – lengthways or widthways. The pupils can explore this aspect by 'breaking' the magnet in different ways – for example, keeping each long row intact but moving the rows apart, rather than breaking them in the middle.

Recording the activity

It is a good idea to take some photos while the activity is underway, to get the best views of the pupil magnets in the different situations. You can use these images after the activity or in another lesson to discuss what is happening inside the magnets.

Acknowledgements

The activity was initiated by Science on Stage Slovakia[w1] and further developed during the University Without Borders summer camp for children aged 10–12 at the Pavol Jozef Safarik University in Košice, Slovakia, in July 2015. The activity also takes place within the magnetism section at the SteelPark science centre in Košice.

Web reference

w1 Science on Stage is the network for European science, technology, engineering and mathematics (STEM) teachers, which was initially launched in 1999 by EIROforum, the publisher of *Science in School*. Science on Stage brings together science teachers from across Europe to exchange teaching ideas and best practice with enthusiastic colleagues from 25 countries.

Resources

For a simple explanation of magnets and how they work, see: http://science.howstuffworks.com/magnet2.htm

Visit the website of the University of Colorado Boulder for a simulation of a magnet and the field around it, with an option to look inside the magnets. See: https://phet.colorado.edu/en/simulation/legacy/magnet-and-compass

Watch a video explaining magnetism at the atomic level in a simple way. See: www.youtube.com/watch?v=Khdi996HL5I

For information on magnetisation of a material in terms of magnetic domains (small areas that contain the atomic dipoles) and how these change when a material is magnetised, see:

The National High Magnetic Field Laboratory website at: https://nationalmaglab.org/education/magnet-academy/watch-play/interactive/magnetic-domains or via the tinyurl: http://tinyurl.com/zh5qhny

The Nondestruction Testing Resource Center website at: www.nde-ed.org/EducationResources/HighSchool/Magnetism/magneticdomain.htm or via the tinyurl: http://tinyurl.com/hssygk5

For two videos about magnetism that are conceptually more advanced than the activity in this article and that may be more suitable for teachers or secondary-school students, see:

A simulation of what happens when a bar magnet is broken, at: https://youtu.be/hK_Yi5nxuKQ

How domains and dipoles interact with each other, at: https://youtu.be/QgwReDkpq6E

Katarína Krišková is a PhD student of the theory of physics education at the Pavol Jozef Šafárik University in Košice, Slovakia. Her thesis focuses on the role of experimentation in developing the skills of lower secondary-school science students. She is also a physics teacher at the grammar school in Košice.

Wind and rain: meteorology in the classroom

Why does it rain? Can we predict it? Give physics students a mass of weather data and some information technology, and they can try working this out for themselves.

By Maria Birba and Theodoros Kondilis

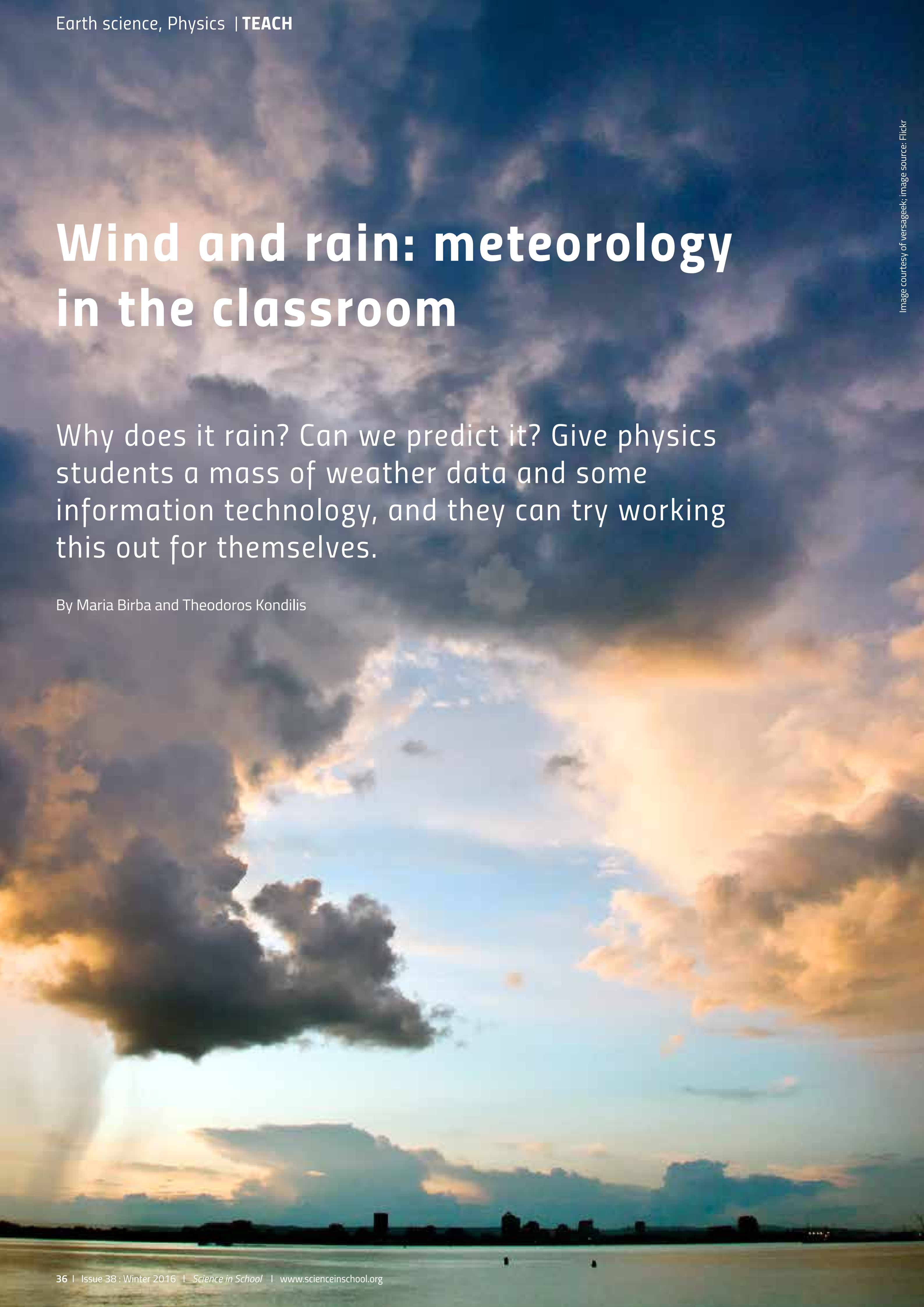


Image courtesy of versageek; image source: Flickr

Thermodynamics is taught in high-school physics – but how many students make the connection with our everyday weather, even though both are governed by the same variables (temperature, pressure and so on)? We decided to try to make this connection clear to students by asking them to explore for themselves how such variables affect each other in the environment, using real scientific data.

By the end of the activity, the students were impressed by the logical way in which these natural phenomena are related – and got a thrill from working with a top scientific institution, the National Observatory of Athens, Greece.

Aims

Our aim was to extend the high-school study of thermodynamics to Earth's most important gaseous mixture: the atmosphere. So we devised an activity where students used real data from a weather station to investigate how temperature and pressure interact in Earth's atmosphere, and how these variables are correlated with other important physical quantities (relative humidity, dew point and wind direction).

In this article, we provide details of our activity and show our own results as an example. We hope you will be inspired to repeat this activity using local data from your own region.

The activity itself takes about 6 hours, although you may need to allow up to 4 more hours to ensure that students have all the background knowledge they need before they start.

Preparation

Before starting the activity, students should have classroom knowledge and skills in the following areas:

- Gas laws and the variables involved
- Other thermodynamic variables (relative humidity, dew point) and theories of how they are related to temperature and pressure
- Basic meteorology (allow 2 hours to teach this, if needed). This should include: high and low pressure systems and the weather conditions they cause; air masses and fronts; global winds and jet streams; and how to read a weather map. Students should also be able to draw logical conclusions about everyday weather phenomena, such as 'When the wind comes from the sea, the relative humidity increases'. (The resources section at the end of this article contains links to useful videos for teaching these topics.)
- Ability to plot graphs using computer programs. Microsoft Excel is ideal for this, as it is easy to extract data from tables and represent them graphically. Allow 2 hours to teach this if needed (this can be done in a science or information technology lesson).

There are two options for finding a suitable source of data: either contact a weather organisation that may be willing to provide data from a previous or current year (our source was the National Observatory of Athens), or install your own school meteorological station. Either way, you will need data for all the variables you wish to study. We suggest the following variables:

- Atmospheric pressure
- Air temperature
- Relative humidity
- Dew point
- Wind direction

The amount of data you need will depend on what you wish to study. For example, if you wish to study changes in air temperature in a one-month period, you will need 1-2 readings per day for 30 days. Alternatively, if you wish to study changes in air temperature from day to night, you will need readings taken every 30 minutes for a few days.

We used data from winter, because in the Mediterranean region, winter is the most interesting season meteorologically, as it shows the greatest changes in the values of the physical variables we studied.

Procedure

1. Divide the students into groups so that each group can work on a different set of data. Initially, we suggest that different groups work on the data for different variables in the same period, as shown in the graphs below. As an extension, data from different periods can also be used.
2. Provide the students with their group's data, and instruct each group to create one or more graphs from the data. They should plot the variables either against each other or against time (*t*) for the whole period covered by the data.

REVIEW

✓ Physics

✓ Thermodynamics

✓ Ages 16–19

This article describes an enjoyable way to use various detailed weather data sets to consider thermodynamics in everyday actions and to predict the weather if the data sets are local enough to the school using them. Usually this topic is treated at a very basic level, without any particular attempt at extrapolation or prediction, which makes this activity novel in its depth, detail and approach.

Eric Deeson, UK

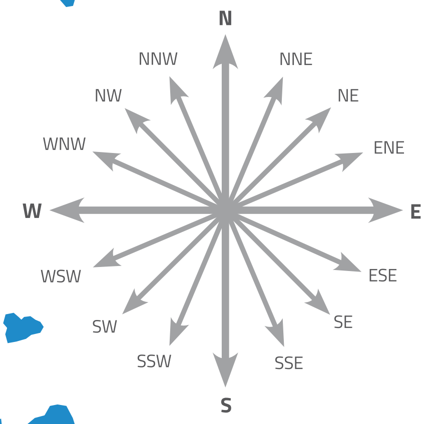


Figure 2: The 16 compass points

Figure 1: Map of Greece, with the position of the weather station indicated by an orange circle

3. Ask students to decide what correlations they can find between the variables and to express these as clearly as possible. Using their knowledge of meteorology, can they suggest what might cause these correlations?
4. As a final task, students can try to predict the weather in their own region or another area, using current data and the principles they have learned about in this activity.

Example results

To explain how to use the data, we present some examples of the graphs produced in our classroom for December 2014, together with explanations of what they revealed.

The National Observatory of Athens provided us with data from a weather station between the Ionian Sea (part of the Mediterranean) on the south-west side of the station, and a mountain located in an east-south-easterly direction from the station (figure 1). This was ideal, as it meant that wind blowing from different directions had a direct influence on the weather.

To show the wind direction on the graphs, the 16 different compass points (S, SSW, SW, WSW, etc.) were each allocated a different colour, as shown in figure 2 and table 1. (Note: The wind direction is where the wind blows from, not towards.)

Wind direction and air temperature

From figure 3, we can see the following correlations:

- **When southerly and east-south-easterly winds prevail, there is an increase in air temperature.** This is seen at the region of the graph labelled A. Such winds are known as descending winds because they come largely from the direction of the mountain and are naturally warm and dry. This is because air warms as it descends the mountain, and it is also dry, having lost much of its moisture on the windward side of the mountain.
- **The temperature fluctuates between night and day.** It is cooler at night and warmer during the day. This can be seen at points B and C on the graph.
- **Land and sea breezes produce mild weather.** When there are humid winds during the day and dry winds during the night, it means daytime *sea breezes* (here from the west or south-west, as at point D) and evening *land breezes* (here from the east), which produces mild weather.

S
SSW
SW
WSW
W
WNW
NW
NNW
N
NNE
NE
ENE
E
ESE
SE
SSE

Table 1: Wind directions and their corresponding colours

Image courtesy of Maria Birba and Theodoros Kondilis

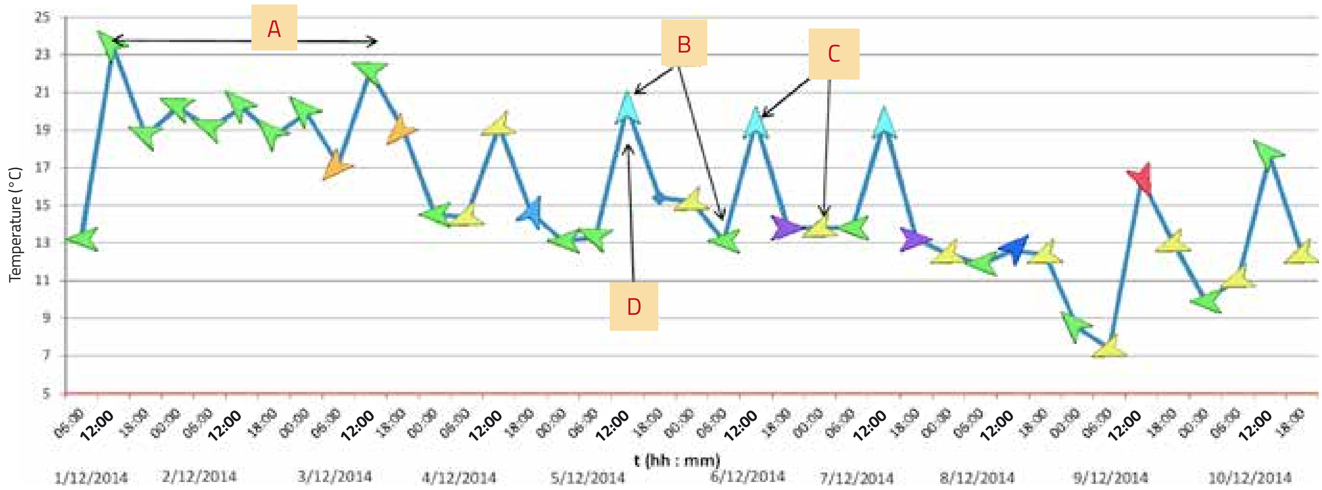


Figure 3: Wind direction and air temperature

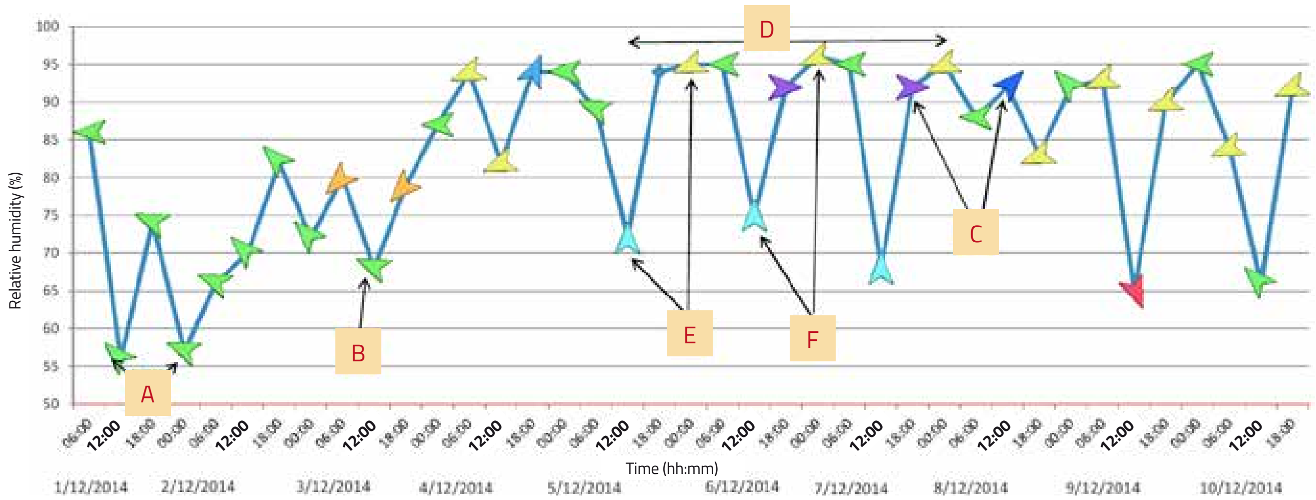


Figure 4: Wind direction and relative humidity

Another phenomenon, which is not apparent from the graphs but which we often notice, is that **when there is a wind from the north, air temperature falls.** The northerly wind causes a drop in air temperature because it comes from regions closer to the North Pole, which are colder than ours.

Wind direction and relative humidity

Wind carries a different amount of humidity depending on where it has come from (for example, over land or sea). From figure 4, we can see the following correlations between wind direction and relative humidity for our location:

- **When easterly (descending) winds prevail, relative humidity decreases.** This (seen at A and B on the graph) is because the winds from the mountains are warm and dry.
- **When the winds are southerly or south-westerly, relative humidity increases significantly.** This (as at C) is because these winds come from the sea.
- **Slight fluctuations in humidity are linked to winds shifting direction.** These winds (seen at interval D) are also likely to be weak.
- **Relative humidity varies with time of day.** Relative humidity is normally high at night (so we see condensation) due to cooler temperatures (see point E on the graph), and low during the warmer daytime hours (revealed by evaporation; see point F). When clouds are absent during the night, more heat is lost from Earth's surface through radiation, producing cooler temperatures and increased humidity.

Relative humidity, air temperature, dew point and rainfall

From figure 5, we can see the following correlations:

- **Changes in air temperature are linked to changes in relative humidity.** This is because for the same amount of moisture in the air, a higher air temperature means a lower relative humidity. So when temperature rises, relative humidity falls.
- **The dew point varies less than the temperature.** The dew point reflects the concentration of water vapour in

Images courtesy of Maria Birba and Theodoros Kondilis

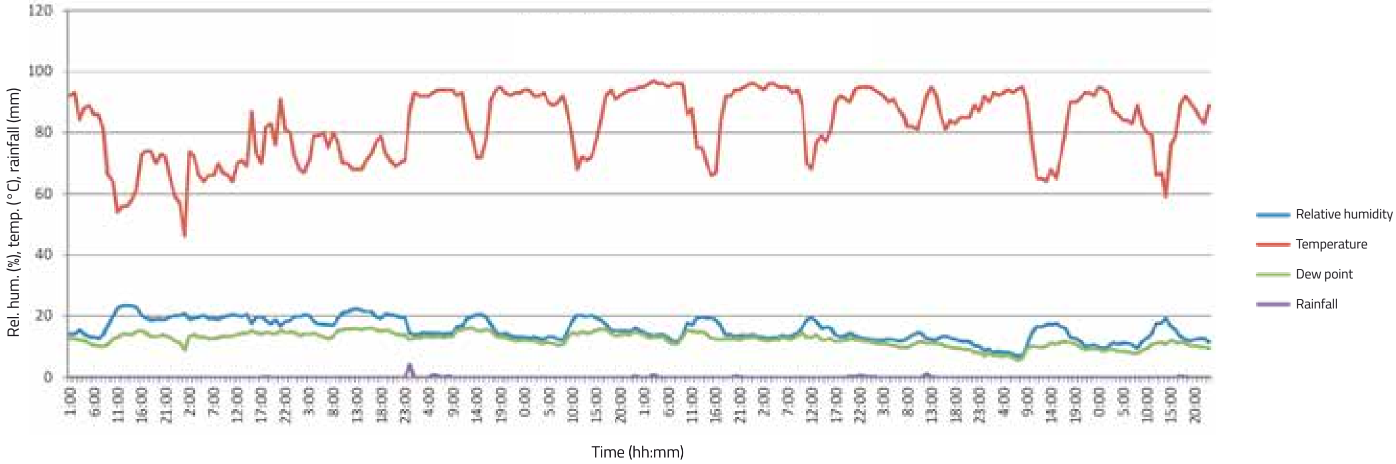


Figure 5: Relative humidity, air temperature, dew point and rainfall

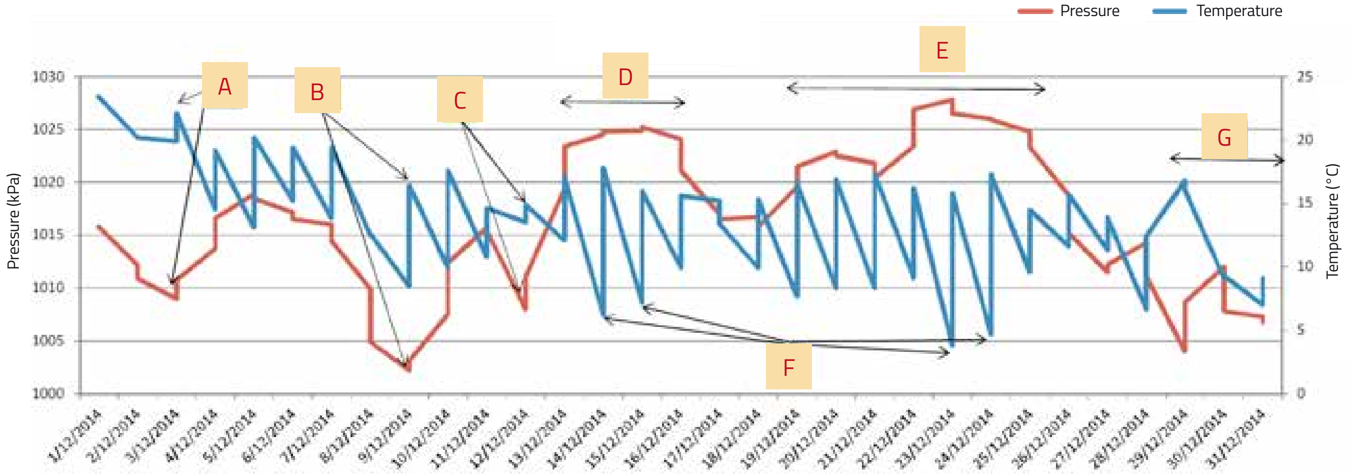


Figure 6: Atmospheric pressure and air temperature

the atmosphere. This was less variable than temperature in the location and period that we studied.

- **When the air temperature becomes the same as the dew point, rain is likely to fall.** This is because, at the dew point, relative humidity reaches 100%, leading to condensation.

Atmospheric pressure and air temperature

From figure 6, we can see the following correlations between temperature and atmospheric pressure in high- and low-pressure conditions:

- **Low pressures alter the temperature.** When a low barometric pressure approaches a region, intense winds are drawn in towards the centre of this system because the pressure is lower inside the system than outside it. If the prevailing winds are from warmer regions, then the temperature increases. This phenomenon is called *thermal intrusion*. It occurs frequently at our weather station, where low-pressure systems from a south-south-westerly direction (the Mediterranean) arrive and increase the temperature (as at A, B and C on the graph). If the prevailing winds are from colder regions, this is called a *cold intrusion* and the temperature normally decreases – as seen at G, where a very low-pressure system caused a rapid decrease in temperature on the last two days of the month.
- **High pressures bring fine weather.** The opposite phenomena are observed when a high barometric pressure approaches a region: winds are very weak or completely absent and the sky is cloudless, meaning fine weather. This is seen here at intervals D and E.
- **High-pressure systems cause *temperature inversion*.** The absence of clouds increases heat loss by radiation from Earth's surface, thus cooling both the surface and the lower levels of the atmosphere (seen at the points indicated by arrows at F). This leads to cooling of the lowest levels of the atmosphere relative to those just above, hence the idea of 'inversion'.

Atmospheric pressure and rainfall

From figure 7, we can see the following correlations between atmospheric pressure and rainfall:

- **When the atmospheric pressure falls, rainfall occurs.** When a low barometric pressure approaches, it is accompanied by intense winds. These winds move anti-clockwise, converging at the centre of the system and then rising, as they have nowhere else to go. The air mass-

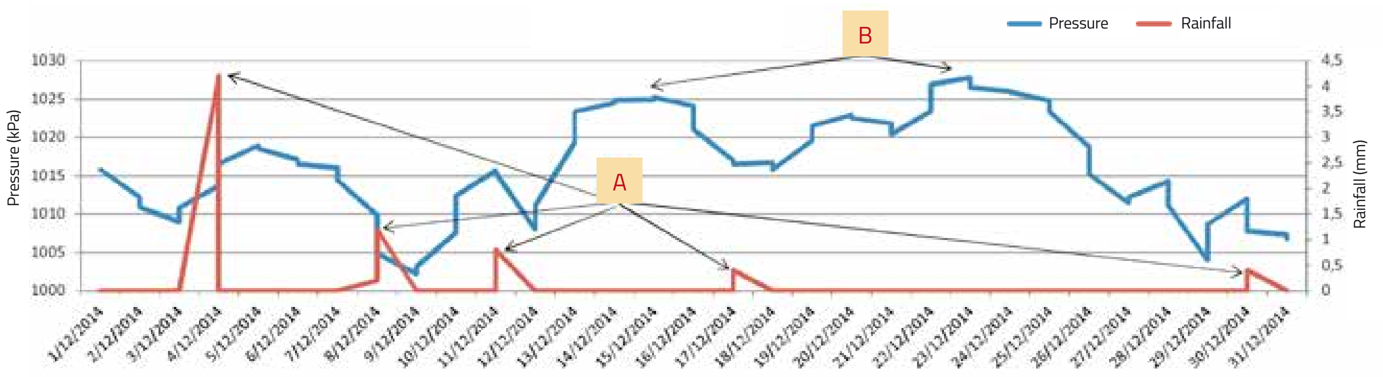


Figure 7: Atmospheric pressure and rainfall

es cool as they move upwards, so condensation takes place, clouds are formed and precipitation occurs. We can see this on the graph at the points indicated by arrows at A.

- **When the atmospheric pressure is high, rainfall is unlikely.** When a high-pressure system approaches, winds are either absent or weak. The air masses converge high up and descend, moving to the centre of the system. They become warmer as they fall, so water droplets evaporate rather than condense. The result is that there are no clouds, so no precipitation and the weather is fine. This can be seen at B on the graph.

End note

During their investigations, the students worked with great zeal as they became thoroughly involved in doing something rather unusual for a science lesson. The teachers encouraged students to make connections between their everyday experiences and their existing scientific knowledge – so by increasing their understanding of common weather phenomena, the students also extended and deepened their knowledge of thermodynamics.

Impressively, the students were able to use their new knowledge to make some valid short-term weather predictions. As a simple example, from noticing an increase in atmospheric pressure and temperature, they predicted 1–2 days of fine weather without rain – quite correctly.

Acknowledgements

The authors would like to thank Nickolaos Zounis and Susan Watt for their help in preparing this article and in creating the graphs.

Resources

For explanatory videos on the following meteorological topics, see the web links:

Why high pressure is associated with fair, clear skies and low pressure with dark clouds and rain: www.youtube.com/watch?v=aiYyCurh_SU

High- and low-pressure systems: www.youtube.com/watch?v=_NeFCO_Dww4

Global winds and jet streams: www.youtube.com/watch?v=j5x6y3a1eRs

Air masses and fronts: www.youtube.com/watch?v=OBz3fwXX64A

Understanding maps, isobars and isotherms: www.youtube.com/watch?v=N5rJ1yWk4lU

Air masses, fronts and low pressure: www.youtube.com/watch?v=9xFz2kDNKSQ

Planetary and periodic winds: www.youtube.com/watch?v=fNFX7AINLMU

For videos about using information technology to create graphs, see these web links:

Office tutorials: an introduction to graphing (Microsoft Excel 2010): www.youtube.com/watch?v=DM52xjSLGqs

How to plot multiple data sets on the same chart in Excel 2010: www.youtube.com/watch?v=MHNpG__dNnc

How to make a line graph in Excel (scientific data): www.youtube.com/watch?v=Xn7Sd5Uu42A

How to make and add custom markers in Excel dashboard charts: www.youtube.com/watch?v=38MvR8yLUWs
For an associated online tutorial, see: www.exceldashboardtemplates.com/how-to-make-and-add-custom-markers-in-excel-dashboard-charts/

Ahrens CD (2013) *Meteorology Today, an Introduction to Weather, Climate, and the Environment* 10th edition. Belmont, Canada: Cengage Learning. ISBN: 978-1285114163

Glickman S (2000) *Glossary of Meteorology* 2nd edition. Boston, USA: American Meteorological Society. ISBN: 978-1878220349

Schaefer VJ (1998) *Peterson First Guide to Clouds and Weather* 2nd edition. Boston, USA: Houghton Mifflin Harcourt. ISBN: 978-0395906637

Wallace JM, Hobbs PV (2006) *Atmospheric Science: An Introductory Survey* 2nd edition. Burlington, MA, USA: Elsevier Academic. ISBN: 978-0127329512

Maria Birba is a physicist and teacher with a PhD in atmospheric physics. Since 2003, she has taught at various high schools and technological institutions in Greece, including the Technological Institution of the Ionian Islands. Her professional interests include nuclear physics as well as meteorology, and in 2014 she led her school in an international competition organised by CERN. She has also co-ordinated multilateral school projects (Comenius and Erasmus).

Theodoros Kondilis is an engineer at the Thessaly Larissa Institution, Greece. Since 2007, he has been responsible for the meteorological stations of the National Observatory of Athens. He is also a weather forecaster for the news portal www.iliatora.gr and through www.metar.gr on public television.

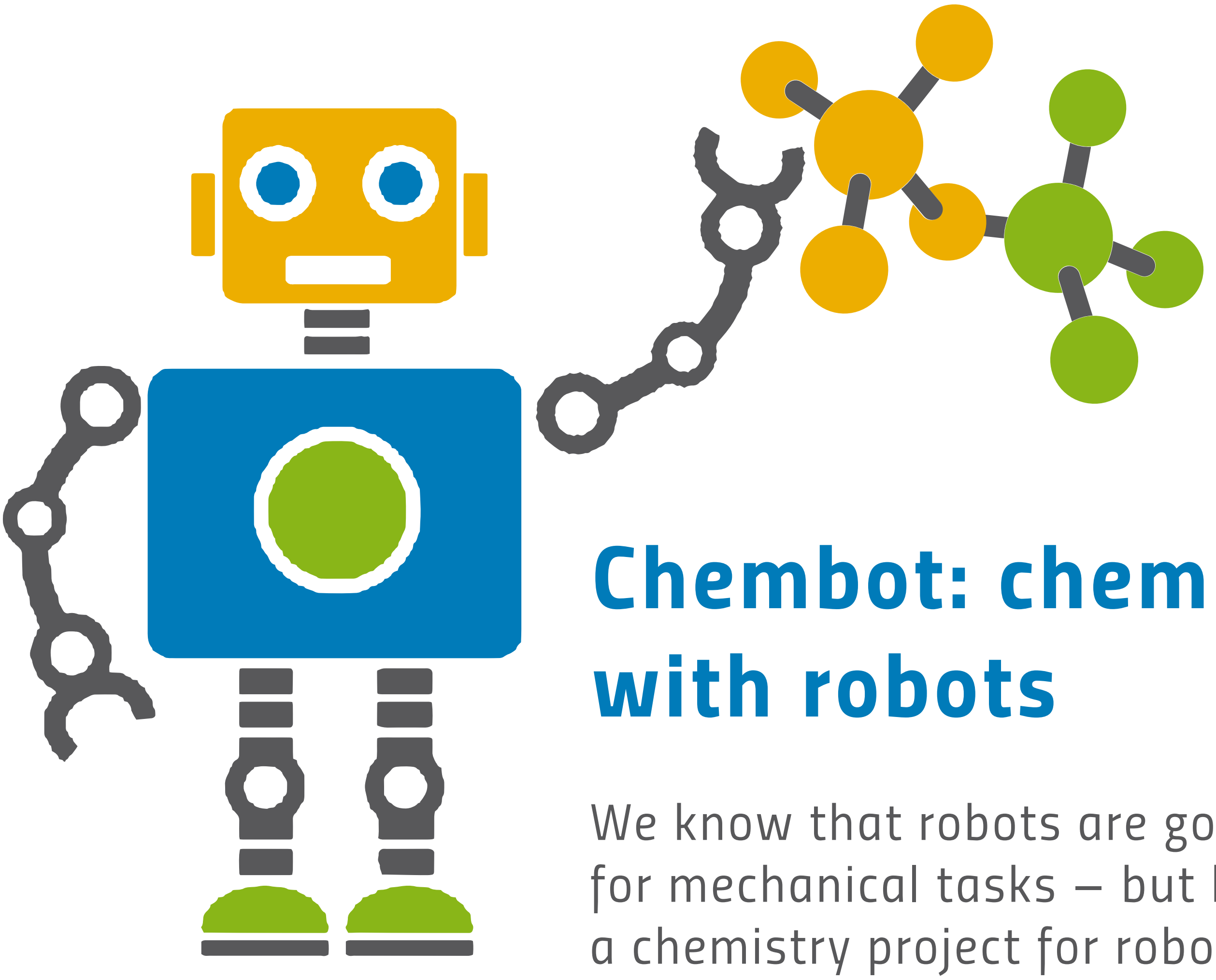


Image courtesy of Nicola Graf

Chembot: chemistry with robots

We know that robots are good for mechanical tasks – but here's a chemistry project for robots that don't mind getting their sensors wet.

By Eleftheria Karagiorgou and Vasileios Spahos

What's the best way to make a connection between robotics and the school science curriculum? This is the challenge we set ourselves in developing Chembot – a robot that does simple chemistry experiments.

We were inspired to develop this activity because, as computer science teachers, we wanted to make a link to other branches of science – in this case, chemistry. So we set students the challenge of building a robot to answer this question: does the pH of a liquid change with temperature, or does it stay the same?

In this article, we describe the practical details of the Chembot activity, which needs around six teaching hours to complete and is suitable for senior high-school science students (age 16–19) with a basic knowledge of programming. Chembot also works well as an extracurricular activity, perhaps with the school's robotics club.

Setting up the challenge

This project is all about thinking and working collaboratively. The students build the robots themselves using Lego Mindstorms robotics kits, and then equip them with suitable sensors to measure the temperature and pH of a liquid.

To help students develop and refine their initial ideas about how to approach the challenge, you can use a three-step, increasingly collaborative process:

1. Think: Students think independently about how to proceed, forming ideas of their own.
2. Pair: Students discuss their thoughts in pairs. This step allows students to articulate their ideas and to consider those of another person.
3. Share: Student groups share their ideas with a larger group, such as the whole class. Often students are more

comfortable presenting ideas to a group with the support of a partner (from step 2).

To succeed in the challenge, the students also need to solve three problems in sequence:

1. How should the sensor and robot electronics be integrated to work together?
2. How will the robot manage to immerse the sensors into the liquid to take a measurement?
3. What do the results say about the relationship (if any) between the temperature of a liquid and its pH?

Materials

For each small group (e.g. four students), you will need:

- Lego Mindstorms EV3 kit
- Lego Mindstorms EV3 software (free to download if you have a Lego account)
- pH meter and adaptor, e.g. those made by Vernier
- One Lego EV3 temperature sensor
- Computer, to write the code for the programmable robots
- Liquids at room temperature: water, plus (optional) vinegar or Coca-Cola
- Large bowl
- Ice cubes or water heater (use both for a larger range of data)

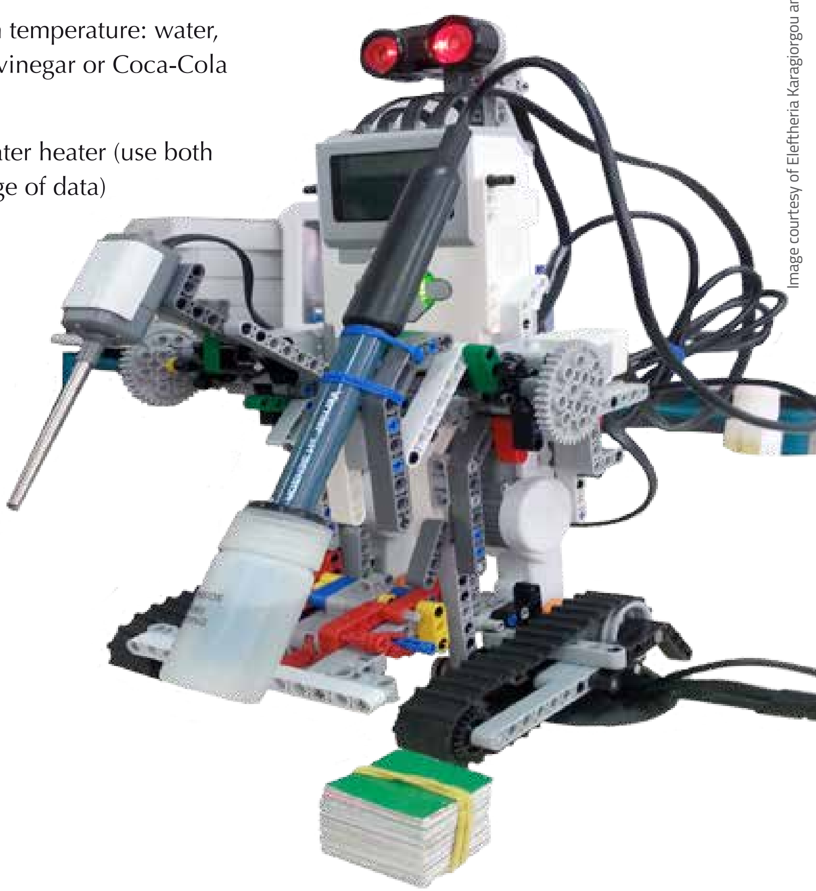


Image courtesy of Eleftheria Karagiorgou and Vasileios Spahos

REVIEW

✓ Chemistry
✓ Mathematics
✓ Computer science
✓ Design and technology
✓ Careers
✓ Programming
✓ Ages 14–19

Teaching any science using only standard manual equipment gives students a false impression of what doing science in today's technological world really means. Chembot empowers learners to investigate a scientific question and simultaneously build the robotics needed to collect data. It takes an abstract concept such as pH and encourages learners to find out its meaning by investigating how it varies with another factor, in this case, temperature.

This project serves to show learners that doing science requires perseverance and imagination. Students follow the scientific method to reach conclusions of a valid research question. At the same time, the learning activity takes an inquiry-based and constructivist approach to investigating a scientific concept. Furthermore, students use critical thinking skills to develop the best design for the Chembot and troubleshoot along the way by sharing solutions with their peers and supervisors.

Chembot, which was shortlisted for the Inspiring Scientists competition, also aims to encourage creativity, a characteristic that is much needed in scientific jobs. It shows learners that knowing, understanding and applying scientific knowledge is not enough in today's world. Innovation and entrepreneurship are key to success in this field, and computer science is an area of expertise which sustains these skills.

This competition entry demonstrates that the more cross-curricular links are made with other sciences, including computer science, and to problem-solving scenarios, the more effective our role as educators is in preparing our students to work in a scientific or technical field.

Angela Charles, Malta

Procedure

The activity consists of five phases.

Phase 1: Introduction

Duration: 30 min

First, discuss the following chemistry topics as a class:

- The theory of acidity and the definition of pH as a measure of the concentration of hydrogen ions in a liquid
- pH meters and the pH scale (the lower the pH, the greater the acidity)
- The challenge: to build a robot that can measure pH and temperature
- The experiment: what data to collect and how to analyse the results

Then divide the students into small groups so they can start thinking critically about their construction plans and the elements needed.

Image courtesy of Eleftheria Karagiorgou and Vasileios Spahos

A finished Chembot, complete with sensors

Phase 2: Constructing the robots

Duration: 2 hours 30 min

This phase is carried out with the students in their groups of four.

The students build the basic robots using the Lego EV3 kits, then add the pH meters and temperature sensors to create the Chembots.

To make a Chembot, students need to make decisions about:

- Robot morphology – what materials to use, what the robot will look like
- Robot parts – which items from the EV3 kits to use

Phase 3: Programming and testing the robot

Duration: 1 hour 30 min

Working in groups, the students then programme their robots to carry out the temperature and pH measurements using the programming environment of Lego EV3, which is user-friendly and based on blocks. Each block represents a specific function. For example, one of the basic functions is the movement of the gears on the motors to control the sensors.

Once students think they have a working robot, they test it to resolve any remaining problems and challenges. This means ensuring that the sensors are working, the gears on the motors function well, the programming of the robot is correct, the construction of the robot is robust, and so on.

This is the most important and challenging phase – not only for the students but also for the teachers, who need to check that all the students understand what the aim of the project is and to help them with any problems they encounter.

Phase 4: Performance and adjustments

Duration: 1 hour

Each group takes a turn using their Chembot to take measurements. You can set up a testing desk in the laboratory with bowls containing the different liquids. To obtain water at different temperatures, put water at about room temperature (25 ˚C) into a bowl. Cool it gradually by adding ice cubes or heat it using the water heater, repeating the process for each group.

The students then use their Chembots to measure temperature and pH, reading the results from the EV3 screen of the robot and recording them.

Students should analyse their results and try to answer the initial question: what (if any) is the relationship between the temperature of water and its pH? Each group should produce a graph showing their results (this can be done using Excel), as well as their answer to the main question, and any information gathered about the pH of the other liquids.

Phase 5: Results and discussion

Duration: 30 min

Finally, the results are discussed as a class. Can the students use their understanding of acids and pH to explain their results?

They should have found that there is a relationship between the temperature of water and its pH: the higher the temperature, the lower the pH. So why is this?

Image courtesy of Eleftheria Karagiorgou and Vasileios Spahos

Chembot embedding its sensors into cold water to take measurements of temperature and pH

The pH scale represents the concentration of hydrogen (H^+) ions in a liquid. But it is the inverse logarithm (to base 10) of the concentration – so the more hydrogen ions there are, the lower the pH.

For example, at 25 °C, the concentration of H^+ ions in pure water is 10^{-7}, so its inverse log is 7, and thus the pH is 7. As the temperature of water rises, the number of molecules that are dissociated into H^+ and OH^- ions increases.

$$H_2O \rightleftharpoons H^+ + OH^-$$

The dissociation process happens to more molecules at higher temperatures, so there will be a higher number of H^+ ions – and the pH will fall. For example, at around 50 °C, the concentration of H^+ ions is about 10^{-6} (which is ten times larger than 10^{-7}), so its inverse log is 6 and its pH is 6. If the temperature of the water falls, the opposite happens: the concentration of hydrogen ions falls, so the pH increases.

You might like to challenge the students with this question: does the decrease in pH mean that the acidity of water increases with temperature? In fact, this is not the case: for each H^+ ion there is still an OH^- ion, so the water is still neutral. For a liquid to be acidic, it must have an excess of H^+ ions.

End note

At the end of the project, we asked students to complete a short questionnaire about the project. All of our students appreciated this attempt to create an interdisciplinary hands-on activity in the classroom – in fact, they would like this to happen more often in STEM curriculum subjects.

The students also gained an important insight from this project, beyond the details of robotics and chemistry: every field of science is not autonomous, but is connected to other sciences "like links in a chain", as one student aptly commented.

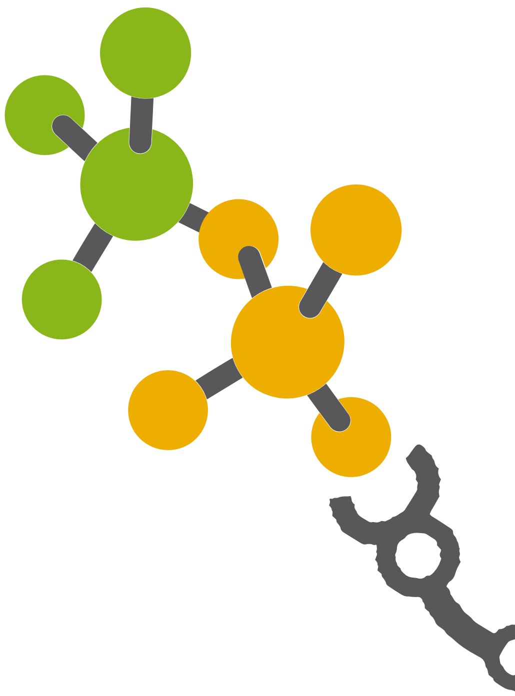
Acknowledgements

This project was one of the seven finalists in the Inspiring Science Education Scenario Competition 2015–2016, and was presented in the Inspiring Science Conference 2016 in Athens, Greece.

Resource

For information on the full educational context of this project (Programming with Robots), visit the Inspiring Science Education (ISE) repository. See: www.opendiscoveryspace.eu

Eleftheria Karagiorgou and Vasileios Spahos are computer science teachers, each with 15 years of experience. They teach at the 7th Senior High School of Trikala, Greece, and their main research interest is educational robotics and its application to STEM. They regularly participate in robotics contests, including the World Robot Olympiad. With sponsorship from the Stavros Niarchos Foundation, they have established an educational robotics laboratory at their school.



Practical pyrotechnics

Hot, luminous and destructive: fire is a force of nature. Here we look at how to use and control it safely with water and carbon dioxide.

Image courtesy of Thomas's Pics; image source: Flickr

By Małgorzata Krzeczkowska, Emilia Grygo-Szymanko and Paweł Świt

Fire has a place in prehistory, culture, and technology. Early humans would have encountered fires of natural origin – from forest fires and lightning to perhaps volcanic eruptions. Later, humans learned how to create and sustain fire at will and to use it for light and heat. Much later, we came to understand its chemistry and how to adapt it for use in the most exquisitely controlled way – as in, for example, the internal combustion engine.

Today, as well as being an essential part of technology, fire is a hazard: in Europe, several thousand people lose their lives each year due to fire, with economic losses estimated at one per cent of GDP[w1]. Fire is thus an important topic, for both its power and its risks.

Inspired by this idea, we have developed a set of activities for students aged 11–14 to safely explore the nature of fire. In the first activity, we show how to 'burn money', while the second activity demonstrates the fire-extinguishing properties of carbon dioxide. Finally, we give students a chance to discuss how to stay safe from fire. The activities require a total of around 35 minutes (the first activity about 15 minutes, and the second and third are 10 minutes each).

As a prelude to the practical activities, we asked the students to name five ideas they associate with the word 'fire'. The most frequent associations are presented in figure 1.

Activity 1: Money to burn?

This activity is a bit like a magic trick – a demonstration of how you can burn your money and still keep it!

Materials

- Fake bank note
- Metal tongs
- Two crystallising dishes
- Approximately 25 g sodium chloride (table salt)
- Water
- Methylated spirits or another version of denatured alcohol (ethanol)
- Fireproof surface, e.g. covered with metal, tiles or silver foil
- Fire-extinguishing equipment (a fire extinguisher or a wet cotton towel) – as a precaution.

REVIEW

✓ Chemistry

✓ Ages 11–14

This article is a great opportunity for teachers to connect lessons with the children's everyday experiences. It combines exciting activities with a final discussion about safety; I like the fact that the article is based on learning about fire safely. Furthermore, the final activity makes the article suitable for discussions relating to the limits and dangers of chemistry and science, and their application in real life.

Christiana Nicolaou, Archangelos Elementary School, Nicosia, Cyprus

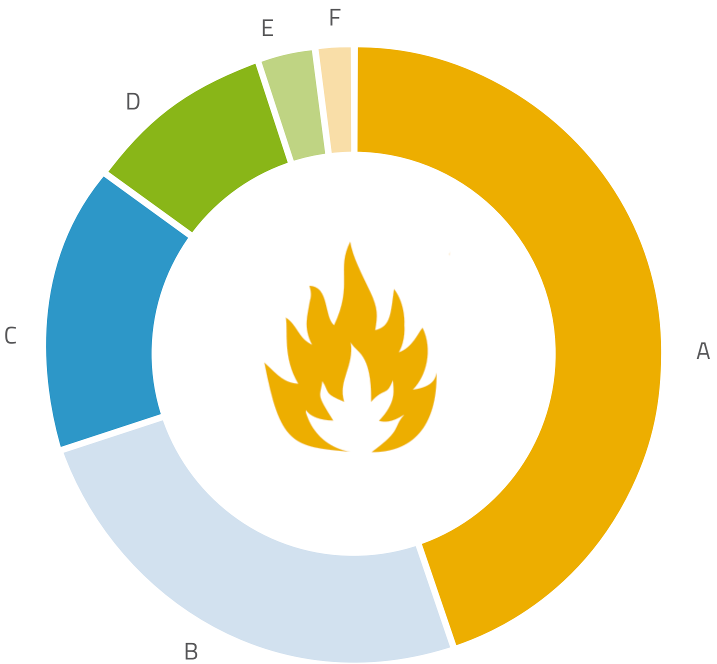


Figure 1: Students' associations with the word 'fire'. A: Heat; B: Burning; C: Campfire; D: Flames; E: Part of our environment; F: Matches

Images courtesy of Emilia Grygo-Szymanko

Figure 2: Materials for activity 1

Figure 3: The bank note is first dipped into water.

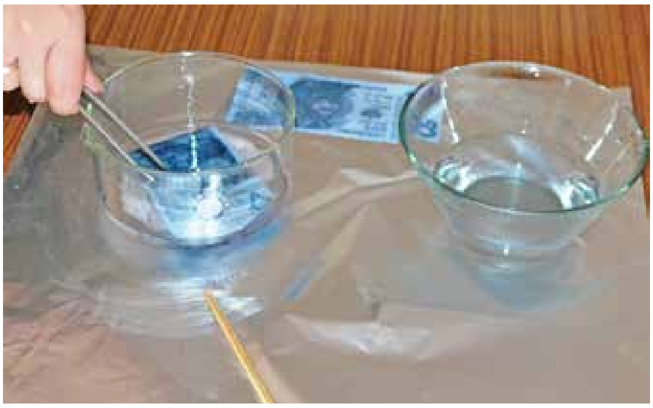


Figure 4: The bank note is then dipped into the methylated spirits.

Figure 5: A burning match is held to the edge of the bank note.

Procedure

This activity should be carried out by the teacher as a demonstration.

Safety note: Safety glasses, a lab coat and gloves should be worn. Special care should be taken with the open flames and when handling the methylated spirits to avoid causing a fire.

1. Place two crystallising dishes on the fireproof surface. Fill one with about 50 ml of water and the other with 50 ml of methylated spirits (figure 2).
2. Add the salt to the dish containing the methylated spirits and stir until the mixture is clear.
3. Pick up the bank note with metal tongs. Dip it first into water so that it is fully immersed for a few seconds (figure 3).
4. Shake off any excess water, and then dip the note into the methylated spirits (figure 4). Move away from the dish containing the methylated spirits to avoid the risk of igniting the alcohol vapour in the next stage.
5. Still holding the note with tongs, quickly (and very carefully) put the burning match to the corner of the bank note and let it burn (figure 5).
6. Once it stops burning, ask the students to check the note. Did it burn away? Was it damaged at all?

Discussion

After the experiment, ask the students to discuss among themselves in groups what happened. Encourage them to come up with their own ideas, using a worksheet[w2] or the following questions:

- Did the note burn?
- If not, why not? (Water moistened the bank note, preventing it from burning. Alcohol is more volatile than water; the methylated spirit vapour burns just above the surface of the paper.)
- What colour were the flames – and why? (The yellow flame indicates the presence of sodium from the salt.)

Then discuss the students' ideas as a class, guiding them if needed to the correct explanations.

Activity 2: Making a chemical fire extinguisher

This activity is carried out by the students under teacher supervision. There are two variations: in the simpler one (version 1), we produce carbon dioxide

in a beaker and then find that it will extinguish a lighted match or candle placed in the beaker. In version 2, we tip the carbon dioxide over the flame – an action similar to that of using a fire extinguisher to put out a fire.

Safety note: Safety glasses, a lab coat and gloves should be worn, and the activity should be carried out in a well-ventilated area. Special care should be taken with the open flames and when handling the methylated spirits to avoid causing a fire. Students should be reminded how to work safety with flames, and what to do with the hot remains after the experiment.

Materials

- One beaker (version 1) or three beakers (version 2)
- Candle
- Matches
- 20–50 g baking soda (sodium hydrogen carbonate, $NaHCO_3$)
- 25 ml of 10% white vinegar

Procedure

1. Place the baking soda in a beaker.
2. Pour about 25 ml vinegar onto the baking soda (figure 6) – a vigorous reaction should take place.

Version 1

3. After the reaction has continued for a few seconds, carefully light a match or candle and hold the burning item in the beaker, above the liquid (figure 7). What happens?

Version 2

3. As soon as the reaction starts, place another beaker on top of the first and hold it in place, so that the gas produced in the reaction is trapped (figure 8).
4. When gas production in the bottom beaker stops, turn the top beaker upright and place it on a table. (The carbon dioxide will stay inside because it is heavier than air.)
5. Light a candle and place the burning candle in the third beaker. Then tip up the seemingly empty second beaker, which contains the gas, so that the invisible gas flows into the beaker with the burning candle (figure 9). What happens?

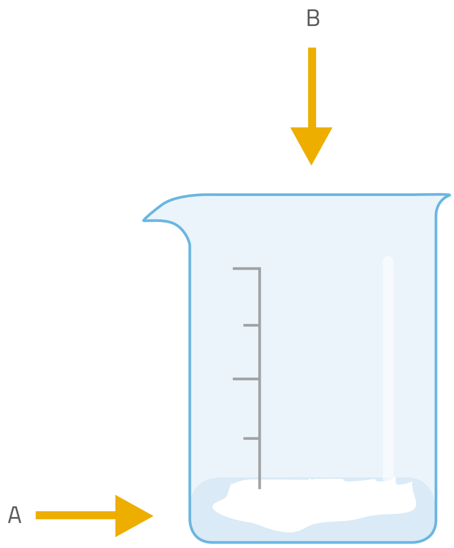


Figure 6: Baking soda (A) is placed in a beaker, followed by vinegar (B).

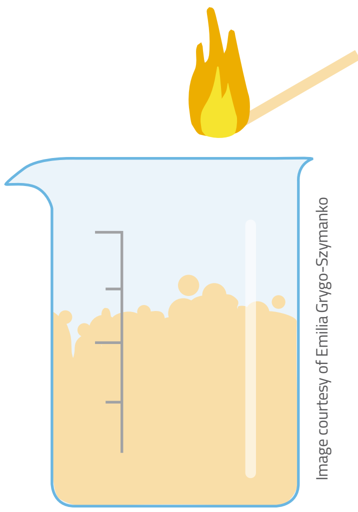


Figure 7: A match is placed over the beaker.

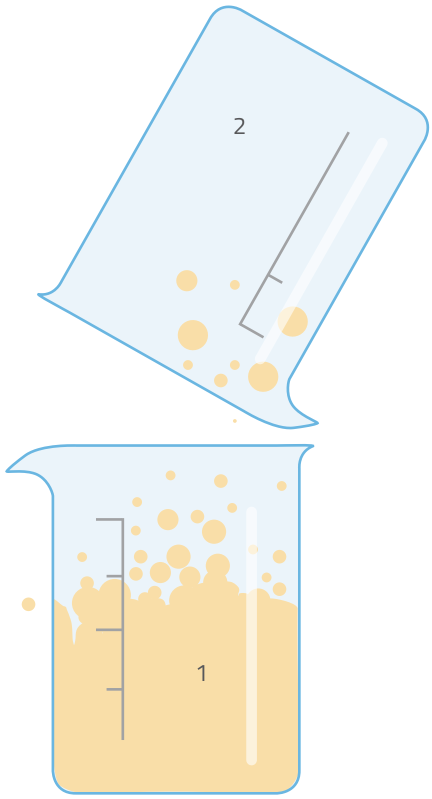


Figure 8: Holding a second beaker on top traps the gas produced.

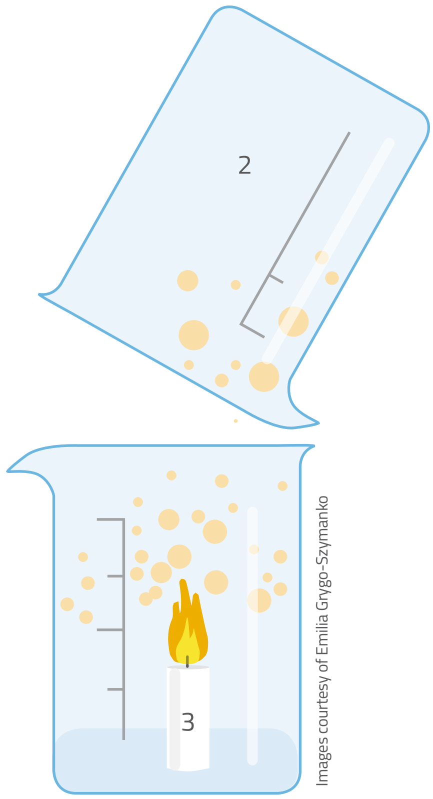


Figure 9: Pour the invisible gas onto the burning candle.

Discussion

Ask the students to discuss among themselves in groups what happened (in either version of the experiment). Prompt them with questions such as:

- What happened to the candle or match flame – and why?
- What gas is produced in the reaction?
- Why does the gas stay in the beaker and not escape?

Use a worksheet[w2] to provide a structured approach to these questions, guiding students to the correct explanation.

The gas produced in the reaction of baking soda with vinegar is carbon dioxide (CO_2):

$$NaHCO_3 + CH_3COOH \rightarrow CH_3COONa + H_2O + CO_2$$

Carbon dioxide is heavier than air, so it stays in the beaker. It also does not support combustion – in fact, it prevents oxygen from reaching the flame, which is needed to sustain burning, so the flame goes out. The fact that carbon dioxide is heavier than air also means it can be 'poured' from beaker to beaker.

Carbon dioxide can also be dangerous for humans and other animals, when it occurs in higher concentrations or in an enclosed space (which is why it is necessary to carry out this experiment in a well-ventilated area). This is not simply because we need oxygen to breathe, but also because our bodies sense carbon dioxide levels and use this to regulate breathing – so an atmosphere containing just one per cent carbon dioxide can interfere with this mechanism. But carbon dioxide is also useful: plants use carbon dioxide, water and light for photosynthesis, which produces oxygen and enables plants to grow.

Activity 3: How to stay safe

The aim of this final activity is to raise students' awareness of the risks associated with fire. Topics to cover include:

- Everyday items or activities that cause the main fire risks
- How to prevent fires at home and outdoors
- How to put out a fire (types of fire extinguishers and how to use them)
- What to do in the event of a fire (important fire-fighting dos and don'ts)
- What to do if someone gets burned (important first-aid dos and don'ts)

We suggest starting with an initial teacher-led discussion, followed by students carrying out Internet research in groups. Each group can tackle one of the questions above (or similar questions), creating a poster or a presentation to show the rest of the class.

It is also worth considering inviting a guest speaker – ideally a fire-fighter or a first-aid provider trained in dealing with burns. As well as providing information, this will underline the fact that fires really do happen – and while we rely on trained experts when things go wrong, it's up to all of us to help prevent fires from happening in the first place.

Web references

w1 To see the world fire statistics from The Geneva Association, visit: www.genevaassociation.org/media/874729/ga2014-wfs29.pdf

w2 The worksheets for activity 1 and two are available to download from the *Science in School* website. See: www.scienceinschool.org/2016/issue38/fire

Resources

For an explanation of how fire extinguishers work and how to use them, see: http://home.howstuffworks.com/home-improvement/household-safety/fire/question346.htm

For ideas for some CO_2-related activities, see: Rau M (2011) Fizzy fun: CO_2 in primary school science. *Science in School* **20**: 24-29. www.scienceinschool.org/2011/issue20/co2

Małgorzata Krzeczkowska is a senior lecturer in chemistry at the Jagiellonian University in Krakow, Poland. She trains secondary-school chemistry teachers

and is the author of many educational materials for teachers and students. She is also involved in science workshops for primary and upper secondary-school students and is an enthusiast for home education.

Emilia Grygo-Szymanko is a PhD student at the Jagiellonian University, where her subject is new methods in inorganic analytical chemistry. She holds a master's degree in chemistry and is interested in developing teaching methods for school chemistry.

Paweł Świt is a PhD student at the Jagiellonian University, where he studies the development of new analytical calibration strategies and the use of flow techniques. He holds a degree in engineering and chemical technology and a master's degree in chemistry. He is also interested in education, especially in relation to chemistry.

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