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Autumn 2015 Issue 33

Science in School

The European journal for science teachers

In this issue:

Structural colour, peacocks, Romans and Robert Hooke

Also:

Science **under your skin:** activities with **tattoo inks**

Published and funded by EIROforum

Editorial

Welcome to the 33rd issue of *Science in School*

Even though teachers don't go to school during the 'holidays', they are still working. There are the new curricula to read and lessons to plan, and perhaps even exams to mark. During my summer, I've met some of you at conferences and workshops, where we shared advice on how best to teach students. The full report on one of these events is on p 30.

Not only did the enthusiasm and hard work of the people I met take my breath away, but my phone has not stopped buzzing ever since. We are continuing the conversation: sharing links to topics and resources mentioned over dinner, or to news events that have caught our interest. Your passion for your subjects is infectious and it can't help but enthuse and inspire your students as well.

Science in School, of course, aims to support you and continually provide inspiration and new ideas for the classroom. In my conversations with teachers this year, I've found it hugely valuable to hear feedback on the journal and to sign up new subscribers – hello if you are one of those! Don't forget that we couldn't exist without you all as readers and authors. Every teaching activity we publish has already been tried and tested in classrooms and reviewed by your peers to ensure that it is useful. If you would like to share something you've been working on in the classroom, or if you'd like to help with the reviewing process, please get in touch.

And so to the autumn edition, which we hope will help keep your – and your students' – enthusiasm alive! We start by building on your interest in the last issue with the second of two articles on the strange world of transmissible cancers (p 12). We also look at how scientists are trying to understand fear (p 16), and how one scientist made the move from particle physics to the theatre (p 34). Elsewhere we have several articles on colour: from understanding how nature is inspiring us to make colour without pigments (p 20), to an activity on the safety of tattoo inks, something I've personally been interested in for a long time (p 42), and a practical lesson using colour match apps on mobile phones (p 38). There's more, of course, with a biology practical using variegated leaves (p 47), a way to understand physics using craft materials (p 52), and an inspiring tale of a scientific expedition on the world's oceans (p 6). My colleagues and I encourage you to read, share and enjoy this issue. We hope you are as inspired by it as we are by you.

Happy teaching,

Laura Howes
Editor, *Science in School*
editor@scienceinschool.org

About *Science in School*

The European journal for science teachers

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

Brought to you by Europe's top scientific research institutes

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

Inspiring science teachers worldwide

The *Science in School* website offers articles in 30+ languages and is read worldwide. The free quarterly journal is printed in English and distributed across Europe.

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

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- Translate articles for publication online
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See www.scienceinschool.org or contact us.

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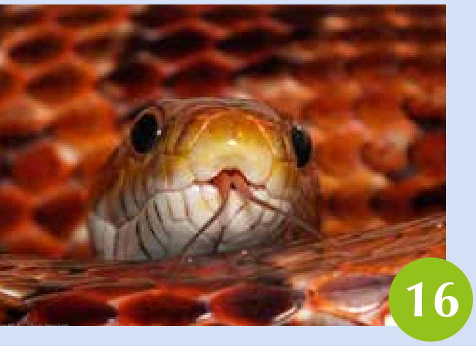
Image courtesy of Eric Roettinger / Kahikai / Tara Oceans

Image courtesy of Dean Thorpe; image source: Flickr



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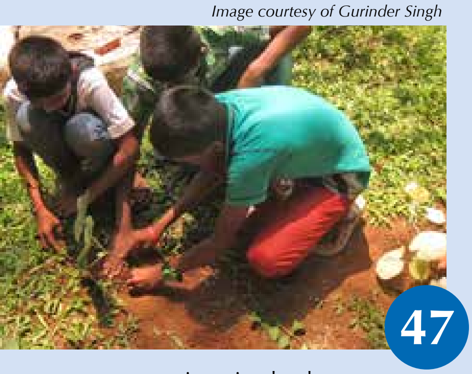
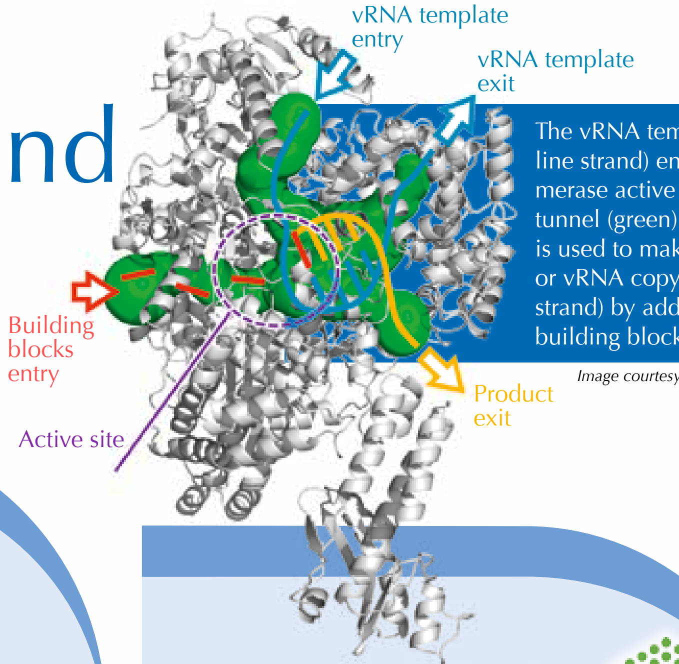


Winners, workshops and illuminating science



The vRNA template (blue line strand) enters the polymerase active site along a tunnel (green). The template is used to make an mRNA or vRNA copy (yellow strand) by adding on RNA building blocks (red).

Image courtesy of Gerlach et al (2015)

CERN

Winners of the 2015 beamline for schools competition announced

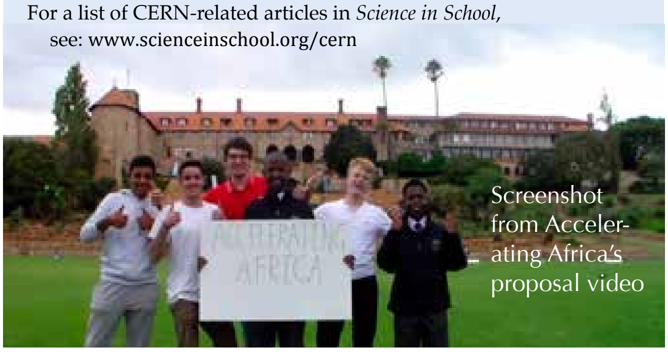
In June, CERN announced the winners of its 2015 beamline for schools competition. Two teams of high-school students will travel to CERN in September to carry out their own experiments using a CERN accelerator beam. The winners, the Leo4G team from Liceo Scientifico Leonardo da Vinci School in Florence, Italy, and the Accelerating Africa team from St John's College and Barnato Park High School in Johannesburg, South Africa, were selected from 119 teams from around the world.

The aim of the competition is to make a fully equipped beamline available for high-school students to run an experiment in the same way that researchers do at the Large Hadron Collider and other CERN facilities. In proposals of fewer than 1000 words, teams had to explain why they wanted to come to CERN, what they hoped to take away from the experience, and how they would use the particle beam for their experiment. They also had to summarise their written proposal in a creative and entertaining video.

You can read more about the two winning teams' proposals and watch their videos on the CERN press website: http://press.web.cern.ch/press-releases/2015/06/cern-announces-winners-its-2015-beamline-schools-competition

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

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



Screenshot from Accelerating Africa's proposal video

(Video: Accelerating Africa)

EMBL

It runs in the family

EMBL researchers have unveiled the first detailed 3D structure of the replication machinery – the polymerase – of the La Crosse orthobunyavirus (LACV). This virus causes human encephalitis but is a member of the same family as the flu virus, and the structure shows that the LACV polymerase has striking similarities to influenza virus polymerase.

These segmented negative-strand RNA viruses have a very specific way of making their mRNA: they 'snatch' a 'cap' of genetic material from the host cell mRNA and insert it into their own. This sets them apart from other groups of viruses, but also suggests that the complex machinery required to do this is likely to be common to them all.

That is exactly what the researchers found: the polymerase of the LACV looks very similar to that of the influenza virus. This level of detail has allowed the team to deduce how the polymerase functions in LACV and also to give new insight into the influenza polymerase. The team hopes that by understanding the structural and functional similarities across the whole group, promising drug compounds could be adapted to other related viruses.

To read more about this story, visit the EMBL website: www.embl.de/press/2015/150521_Grenoble

The full journal reference is:

Gerlach P et al (2015) Structural Insights into Bunyavirus Replication and Its Regulation by the vRNA Promoter. *Cell* **161**: 1267–1279. doi: 10.1016/j.cell.2015.05.006

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

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

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

ESA

More opportunities for teachers in Noordwjik

After a successful and expanded summer school for teachers (see the next issue for a full report), ESA is once again organising a training workshop for science teachers in association with the Galileo Teacher Training Programme.

A diverse workshop programme consisting of practical sessions and lectures from ESA experts will allow participants to explore innovative ways to use space science and astronomy in the classroom to engage students. One of the main topics this year is cosmic light in celebration of the International Year of Light. Participants will also find out more about ESA education activities and resources, as well as the latest from ESA space science and astronomy missions.

The workshop will be held at the European Space Research and Technology Centre (ESTEC) in Noordwijk, the Netherlands, between 23 and 27 November 2015. The deadline for receipt of applications is 09:00 CEST on 21 September 2015. To find out more and apply, visit: http://sci.esa.int/education/56231-esagttp-teacher-training-workshop-2015-apply-now/

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

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

2015 Summer Teachers' Workshop

Image courtesy of ESA/A.Conigli

ESO

Applications for the ESO astronomy camp 2015 are now open

Would your students like to spend a week in the Italian Alps carrying out astronomy activities with other friends of their age and become part of a vibrant international community of alumni and astronomers?

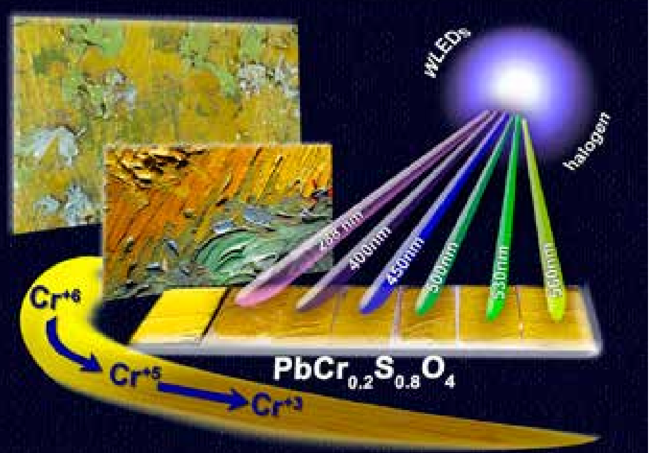
ESO is currently receiving applications for their next Astronomy camp, to take place during the Christmas holidays between Friday 26 December 2015 and Thursday 1 January 2016. The camp will be held at the Astronomical Observatory of the Autonomous Region of the Aosta Valley, Nus, Italy, close to some of Europe highest mountains and under a clear sky. The camp will explore the theme of the Solar System and exoplanets via several astronomical sessions, including lectures, hands-on activities and night-time observations using the Observatory telescopes, alongside various social activities, winter sports and excursions.

To register, applicants should fill in an online form and upload a video (maximum 3 minutes) on the theme 'My favourite astronomical object/phenomenon' by 4 October. Full details, and the form, can be found at: www.sterrenlab.com/camps/eso-astronomy-camp-2015/

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. For more information, see: www.eso.org

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

Image courtesy of ESO



Light-sensitive chrome yellow paints exposed to different wavelengths of monochromatic light.

Image courtesy of ESRF

ESRF

Towards safer illumination of paintings

Experiments at ESRF indicate that art galleries and museums should minimise their paintings' exposure to violet-blue-green as much as possible for the safe display of paintings containing chrome yellows.

Knowledge of the effect of visible light on light-sensitive pigments such as chrome yellows is of great importance for the long-term conservation of unique masterpieces, including those by Vincent van Gogh. A combination of high spatial resolution spectroscopic methods and electron paramagnetic resonance at ESRF allowed a team of scientists from Italy and Belgium to establish that visible light of a blue-green colour is the most effective in stimulating the darkening process of chrome yellows. This occurs via a Cr(VI)→Cr(III) reduction process that also involves Cr(V)-species as intermediates.

For the fuller story, read the ESRF news article at: http://bit.ly/1MCHrKQ

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

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

EUROfusion

JET-Set: experiments with tritium

There is a ripple of excitement in the fusion community, thanks to a batch of tritium that has reached the Culham Centre for Fusion Energy, UK, which houses JET, Europe's largest fusion device. The use of tritium, a heavy, unstable isotope of hydrogen, is crucial to the development of fusion power plants that might provide clean and abundant energy in the future.

Researchers know that the most efficient fuel for a fusion power plant is a mix of tritium and deuterium, another heavy hydrogen isotope that is available from sea water. But what will the exact results be when the mixture is used in the JET vessel? That is what the fusion community wants to test. So far, the JET fusion experiments in the renovated vessel have been fuelled with 'regular' hydrogen and deuterium. Researchers can now test the influence of the tritium–deuterium fuel on plasma performance and on interactions between the plasma and the renovated JET wall.

In many ways, the JET experiments are a test run for ITER, the next generation fusion experiment, which is currently being built in France. ITER will be the first magnetic confinement device to produce a net surplus of fusion energy and to demonstrate the main technologies for a fusion power plant. The deuterium–tritium experiment in JET will provide an important step to gain experience and train a new generation of engineers and scientists.

To learn more, see the story "JET's next tritium experiments materialise" on the EUROfusion website, scan the QR code or visit: www.euro-fusion.org/2015/06/jets-next-tritium-experiments-materialise/

EUROfusion comprises 28 European member states as well as Switzerland and manages fusion research activities on behalf of Euratom. The aim is to realize fusion electricity by 2050. See www.euro-fusion.org

For a list of EUROfusion articles in *Science in School*, see www.scienceinschool.org/EUROfusion.

Image courtesy of EUROfusion

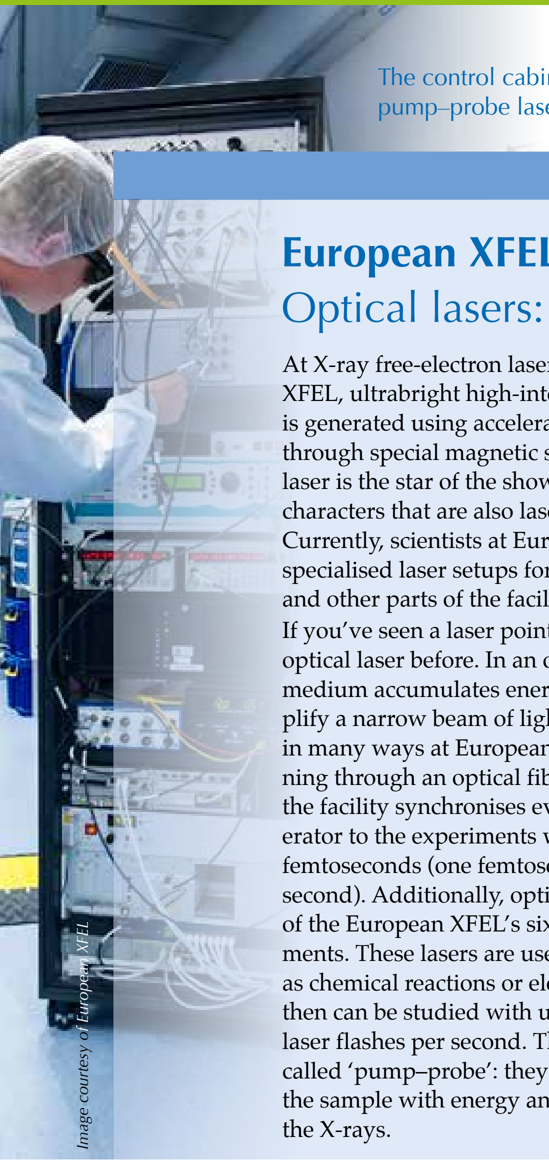

The control cabinet of the pump–probe laser

Image courtesy of European XFEL

European XFEL
Optical lasers: setting the stage for X-ray laser pulses

At X-ray free-electron lasers such as the European XFEL, ultrabright high-intensity laser-like X-ray light is generated using accelerated electrons travelling through special magnetic structures. While the X-ray laser is the star of the show, there are many supporting characters that are also lasers – namely, optical ones. Currently, scientists at European XFEL are preparing specialised laser setups for the scientific instruments and other parts of the facility.

If you've seen a laser pointer, then you've seen a weak optical laser before. In an optical laser device, an active medium accumulates energy and concentrates it to amplify a narrow beam of light rays. Such lasers are used in many ways at European XFEL. An optical laser running through an optical fibre along the 3.4 km length of the facility synchronises everything from the accelerator to the experiments with a precision of tens of femtoseconds (one femtosecond is a quadrillionth of a second). Additionally, optical lasers are built into each of the European XFEL's six starting scientific instruments. These lasers are used to initiate processes, such as chemical reactions or electron excitations, which then can be studied with up to 27 000 intense X-ray laser flashes per second. These sorts of experiments are called 'pump–probe': they use an optical laser to pump the sample with energy and then probe the result using the X-rays.

None of these lasers is as simple as a common household laser device – they have a higher intensity, emit femtosecond pulses, and undergo numerous processes to create the special properties required for each experiment. But perhaps the superlative of the optical lasers is that used for the High Energy Density Science (HED) scientific instrument. For example, a recently announced 100 joule laser that has been contributed to the HED instrument by the UK will be able to compress matter to energetic states similar to those found inside Earth-like exoplanets. The 100 joule laser will enable intense pump–probe experiments for research in astrophysics and other fields.

Laser rooms are currently under construction in preparation for the first instruments to go online in 2017. A dedicated optical lasers group, consisting of scientists and engineers, is working on the development, assembly and integration of five large-scale laser systems for the scientific instruments. Read more about the different instruments at: www.xfel.eu/research/instruments/

The European X-ray Free Electron Laser (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. Learn more at: www.xfel.eu

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

ILL Neutrons illuminate neurons

Alzheimer's disease markers could be identified through protein water mobility, suggest ILL scientists. A study of water mobility on the surface of tau protein fibres, one of the pathological hallmarks of Alzheimer's disease, has been conducted by a global team of scientists using neutron scattering experiments at the Institut Laue-Langevin (ILL) in Grenoble, France, and the Jülich Centre for Neutron Science at the Heinz Maier-Leibnitz-Zentrum (MLZ) in Garching, Germany. The team found that water mobility on the surface of tau protein fibres is increased compared to non-aggregated tau proteins. The findings, reported in the journal *Proceedings of the National Academy of Sciences of the United States of America*, suggest that the movement of water molecules could be a marker for the presence of amyloid tau fibres and could contribute to the detection of Alzheimer's disease.

Read more on the ILL news site: http://bit.ly/1PpXbQJ

The Institut Laue-Langevin (ILL) is an international research centre at the leading edge of neutron science and technology. To learn more, see: www.ill.eu

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

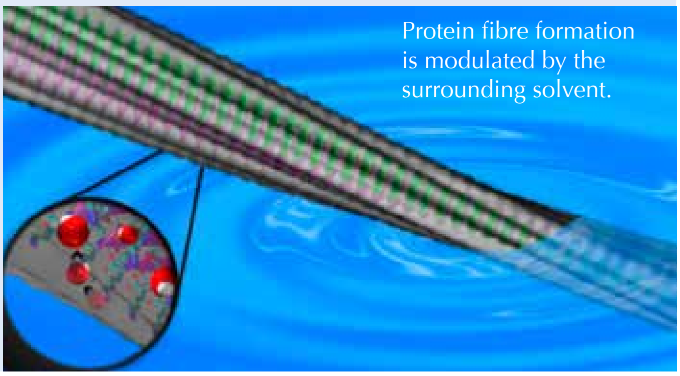

Protein fibre formation is modulated by the surrounding solvent.

Image courtesy of ILL

Tara: an ocean odyssey

After four years travelling around the globe, the schooner Tara has returned with a world's worth of scientific results.

By Andres Peyrot

It's October 2011 and I'm on night duty aboard the schooner *Tara* as it glides across the Pacific Ocean's dark and seemingly infinite waters. Tomorrow seems far off, but two things keep me awake: the smell of salt hanging in the air and specks of light scintillating in the wake of our boat. These 'stars of the sea' are in fact bioluminescent plankton – drifting micro-organisms so strange-looking that some of them inspired the design of creatures in the 1979 film *Alien*. Yet as tiny and bizarre as they may seem, plankton represent nine tenths of the living mass in the oceans and form the base of the global food web. Through photosynthesis, they generate half of the oxygen we breathe, draw carbon from the atmosphere into the deep sea, and

REVIEW

- **Biology**
- **Ecology**
- **Chemistry**
- **Ages 11+**

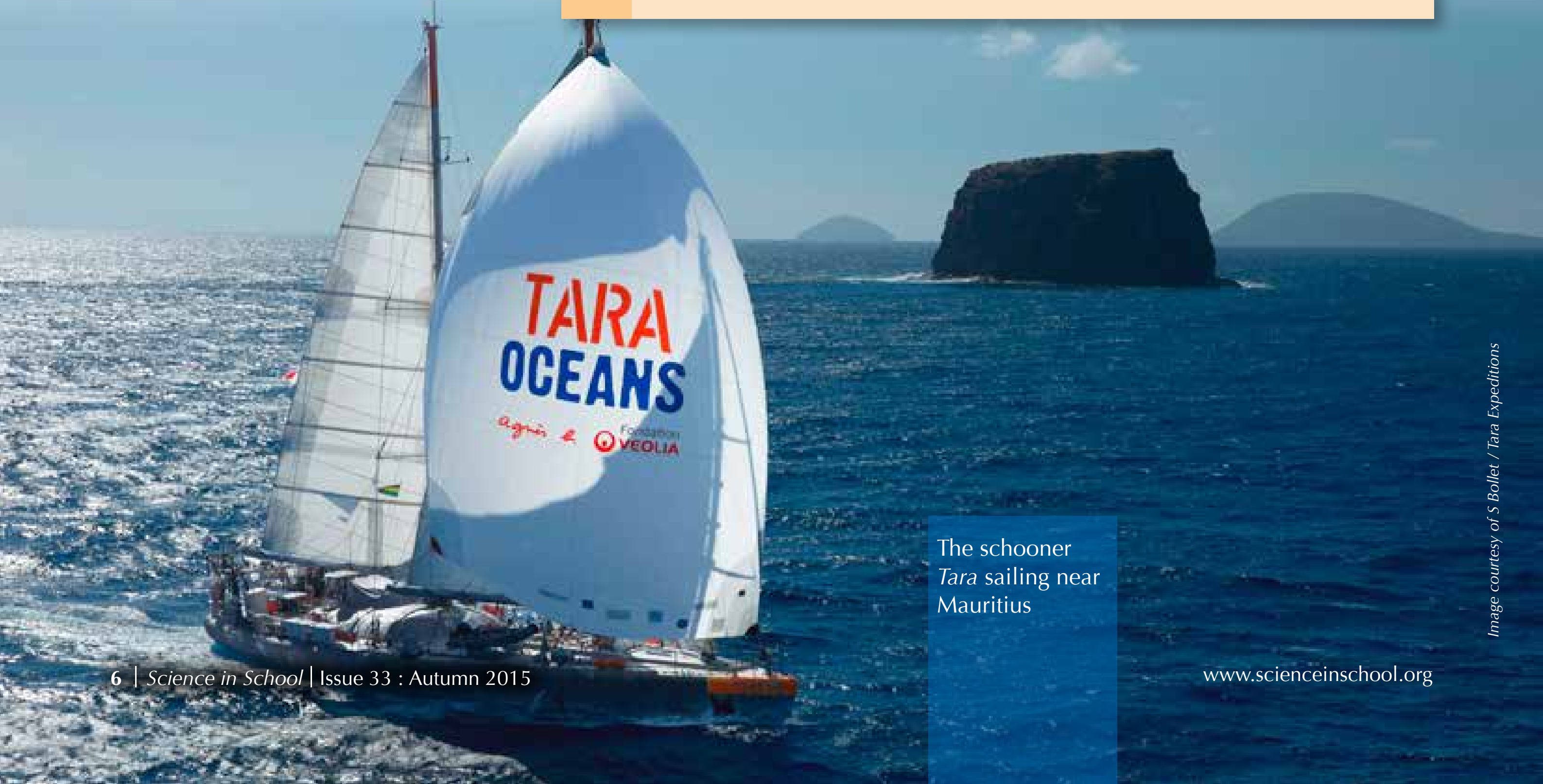
The Tara Oceans project brought together many fields of research that together produced the impressive Ocean Microbial Gene Catalogue, which will be used to monitor the health of our oceans.

The article offers the possibility to understand how scientists can characterise micro-organism populations and how environmental conditions shape ecological communities.

It can be used to study questions such as:

- what is the ecological role of plankton?
- why are specimens frozen?
- what is DNA barcoding?
- what is the main environmental factor influencing ocean ecosystems?
- why is the Oceanic Interactome compared to Facebook?
- what is the importance of viruses in ocean ecosystems?

Monica Menesini, Liceo Scientifico Vallisneri Lucca, Italy



The schooner *Tara* sailing near Mauritius

Image courtesy of S Bollet / Tara Expeditions play a crucial role in the global nitrogen cycle.

At dawn, the deck is abuzz with scientists who comb the upper ocean in search of plankton with thin nets, water pumps and a 'rosette', an instrument that traps water at different depths and measures its properties (mainly temperature, pressure and salinity). They catch all kinds of plankton, from tiny viruses 0.02 micrometres in diameter, to animals as 'large' as two millimetres across. This is roughly the ratio of the size of a golf ball to ten Olympic-sized swimming pools! Marine biologists funnel the specimens caught in the nets into test tubes, label them and freeze them to avoid chemical and enzyme degradation.

Down in the 'dry lab', a cabin filled with microscopes and computer screens, the imaging expert, Jérémie, places a drop of sampled water under a microscope. Suddenly, the boat is caught in waves that turn the entire lab into a swinging pendulum. I look for the edge of a table, anything, to keep my balance, while Jérémie, seemingly unaware of the complete havoc around us, sways in time with his microscope. He's captivated by what he sees beneath the lens – this single droplet is teeming with improbable life forms…

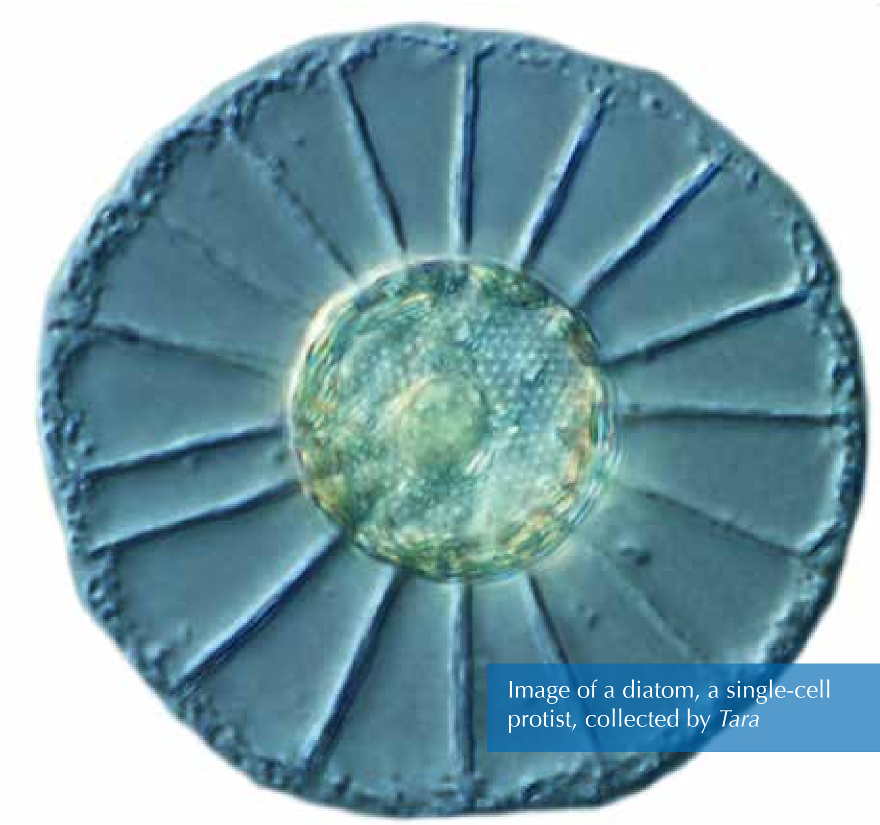


Image of a diatom, a single-cell protist, collected by *Tara*

Image courtesy of John Dolan

Image courtesy of H Bourmaud / Tara Expeditions

Tara sailing past the Cape of Good Hope

An explosion of data

Over the course of *Tara*'s oceanic odyssey (2009–2013), more than two tonnes of frozen genetic material from plankton were shipped across the world to different laboratories for analysis. In the labs, researchers used chemicals to break open the specimens and extract their DNA molecules. They scanned the strands

Image courtesy of F Aurat / Tara Expeditions

Eric Karsenti (left), director of the Tara Oceans project, together with Etienne Bourgois (right), who funded a large part of the project, on board *Tara*

More about EMBL

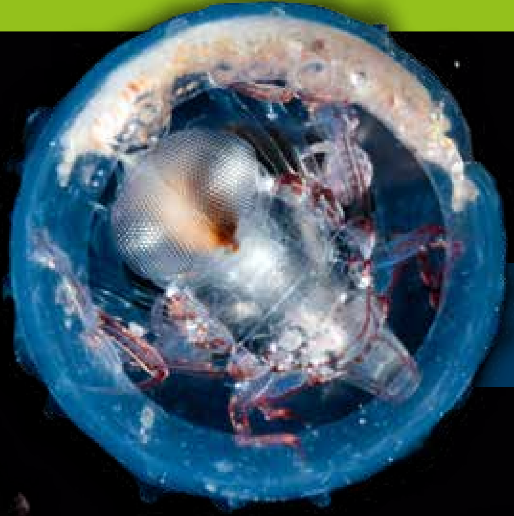
EIROforum

EMBL

The European Molecular Biology Laboratory (EMBL[w1]) is one of the world's top research institutions, dedicated to basic research in the life sciences. EMBL is international, innovative and interdisciplinary. Its employees from 60 nations have backgrounds including biology, physics, chemistry and computer science, and collaborate on research that covers the full spectrum of molecular biology. See: www.embl.org

EMBL is a member of EIROforum[w2], the publisher of *Science in School*. See the list of all EMBL-related articles in *Science in School*: www.scienceinschool.org/embl

Image courtesy of Eric Roettinger / Kahikai / Tara Oceans



Planktonic marine organisms

An amphipod, *Phronima sp.*, sampled by *Tara* in the north Pacific

Image courtesy of Luis Gutierrez Herredia / UCD / Tara Oceans

Image courtesy of Eric Roettinger / Kahikai / Tara Oceans

at an extremely high rate (a method known as shotgun sequencing) to generate a staggering list of 7.2 trillion pairs of nucleotides – the famous building blocks of DNA (adenine, thymine, guanine and cytosine) – and then used specific genes as 'barcodes' to identify different sorts of plankton, such as bacteria, Archaea and eukaryotes. Viruses, however, do not have a universal molecular identifier to be used as a barcode. Instead, researchers used protein clusters – groups of similar genetic sequences – to identify different viral populations.

Eric Karsenti, scientific director of the Tara Oceans project, explains the significance of this massive census. "The data we collected enable researchers to look in unprecedented detail at the populations, environments and dynamics of the oceans' vital life support system." He adds, "This is the first global description of the complete plankton ecosystem."

Image courtesy of Tara Expeditions

Scientists bringing back the rosette that allowed them to sample the oceanic plankton at different depths.

Experts from different fields analysed the sequenced data using advanced imaging, bioinformatics and the latest physical modelling technologies – techniques that are rarely used together. "This is the emergence of a new type of research in life sciences," says Eric. "Five years ago, this was science fiction!" And together, the teams of researchers have begun to tackle questions that explorers of the past could not have even dreamed of addressing: What types of plankton populate our oceans? How do they interact with one another and their environment? How will they react to climate change and how will this affect us?

Back on dry land

The labs of the European Molecular Biology Laboratory in Heidelberg, Germany, might seem an unlikely

Images courtesy of Eric Roettinger / Kahikai / Tara Oceans

A *Platynereis dumereii* worm sampled by *Tara* in the north Pacific

place for ocean studies – they are a six-hour drive from the nearest coastline. But it's here that Shinichi Sunagawa, a researcher in computational biology, helped create an ocean microbial gene catalogue of 40 million genes from microbial plankton, 80% of which are are new to science, indicating a huge biodiversity of unknown plankton in our oceans. Scientists found a strong correlation between the species that were found and the temperature of the habitat, identifying water temperature as the main environmental factor in shaping oceanic microbial communities. Further studies will determine how changes in water temperature could impact our oceans' ecosystems and, consequently, our planet's environment.

Most of the genes from Shinichi's catalogue belong to eukaryotes – organisms (like us) whose DNA is coiled within a nucleus. This complex and

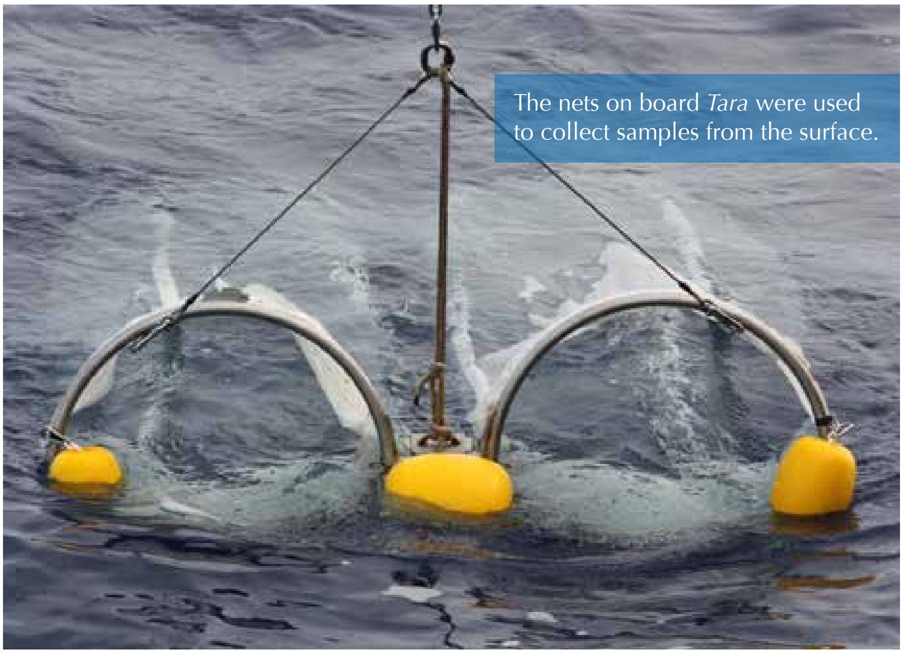
Image courtesy of J Girardot / Tara Expeditions

The schooner *Tara* was very popular all along its route and many people, including Ban Ki-Moon, secretary of the United Nations, visited it during its stopovers.

stable cell structure was a milestone in evolution, enabling multicellular beings to form, and some eukaryotes have astounding properties as a result. Diatoms, for example, are single-celled organisms that synthesise a protective layer of glass at low temperatures, something we can only do using heat! Colomban de Vargas, a marine biologist who participated in both the expedition and the analyses, identified a total of 150 000 genetic types of eukaryotes – one hundred times more diversity than previously known. The key to this hyper-diversification lies in the species' interactions.

An oceanic social network

On board *Tara*, scientists nicknamed the specimens they 'met' under the microscope: there was Hubert the protist and Dana the diatom. Later, Gipsi Lima-Mendez, a postdoc at the Uni-



The nets on board *Tara* were used to collect samples from the surface.

Image courtesy of V Hillaire / Tara Expeditions

versity of Leuven, Belgium, revealed the 'social' interactions between Hubert, Dana and their friends by helping create the oceanic interactome: a sort of planktonic Facebook that tells us which plankton are 'friends" – always found together – and which are not. Then, she used computer-generated models to predict specific interactions between species, such as the symbiotic relationship between a flatworm and a photosynthetic microalgae: the microalgae lives inside the flatworm, safe from predators, and in exchange synthesises nutrients to feed its host. This predicted interaction was later observed using advanced microscopy of samples from the *Tara* expedition.

Ocean interaction is far from 'survival of the fittest'. According to Eric, "80% of interactions between organisms in the ocean are positive," meaning that most organisms help one another to thrive. "This changes the way we look at evolution. Collaboration also makes life evolve and become more complex on Earth."

The most abundant type of plankton is also the most elusive: viruses – so tiny that we could not see them with the microscopes on board the vessel. Ten million of them can squeeze into a single drop of seawater, and their impact is huge: they shape the populations they infect, drive evolution by transferring genes to different species, and "have global influences on the cycling of nutrients, organic matter and atmospheric gases", says Jennifer Brum, a postdoc at the University of Arizona, USA, who took part in identifying more than 5000 viral populations, 99% of which were new. It's like discovering a new underwater planet of alien life! The next step is to determine which viruses infect which organisms.

Collectively, these studies give us a benchmark against which to monitor the health of our oceans in the future. The 11.5 terabytes of data from the expedition – more data than Wikipedia – is stored at the European Nucleotide Archive, where it will remain in the public domain, available to current and future scientists. After all, scientists are still working with samples that Charles Darwin collected during his 1823 expedition on board the *HMS Beagle*. Who knows how long the *Tara* data will be answering questions that we haven't even imagined yet.

Image courtesy of F Benzoni / Tara Oceans

Coral reefs

Tara sailing past New York City

Image courtesy of VHillaire / Tara Expeditions

Web references

w1 – To learn more about EMBL, visit: www.embl.org

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

Resources

The non-profit organisation Tara Expeditions owns the schooner *Tara* and provides a lot of interesting and accessible resources on its scientific achievements on its website. See: www.oceans.taraexpeditions.org

More specifically, their pedagogical team has also set up projects and activities for schools. See: www.oceans.taraexpeditions.org/m/education

Read all the details and the most recent developments about the Tara Oceans project on the website of the European Molecular Biology Laboratory. See: www.embl.de/tara-oceans

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Andres Peyrot is a Swiss-Panamanian documentary film director and journalist, and a graduate of New York University's Tisch School of the Arts. He has collaborated on numerous TV documentaries about art, history, culture and sciences. In autumn 2011, he embarked on a journey on *Tara* from Hawaii to San Diego, through the infamous Great Pacific Garbage Patch. During the voyage, Andres documented, photographed and filmed this unique expedition.

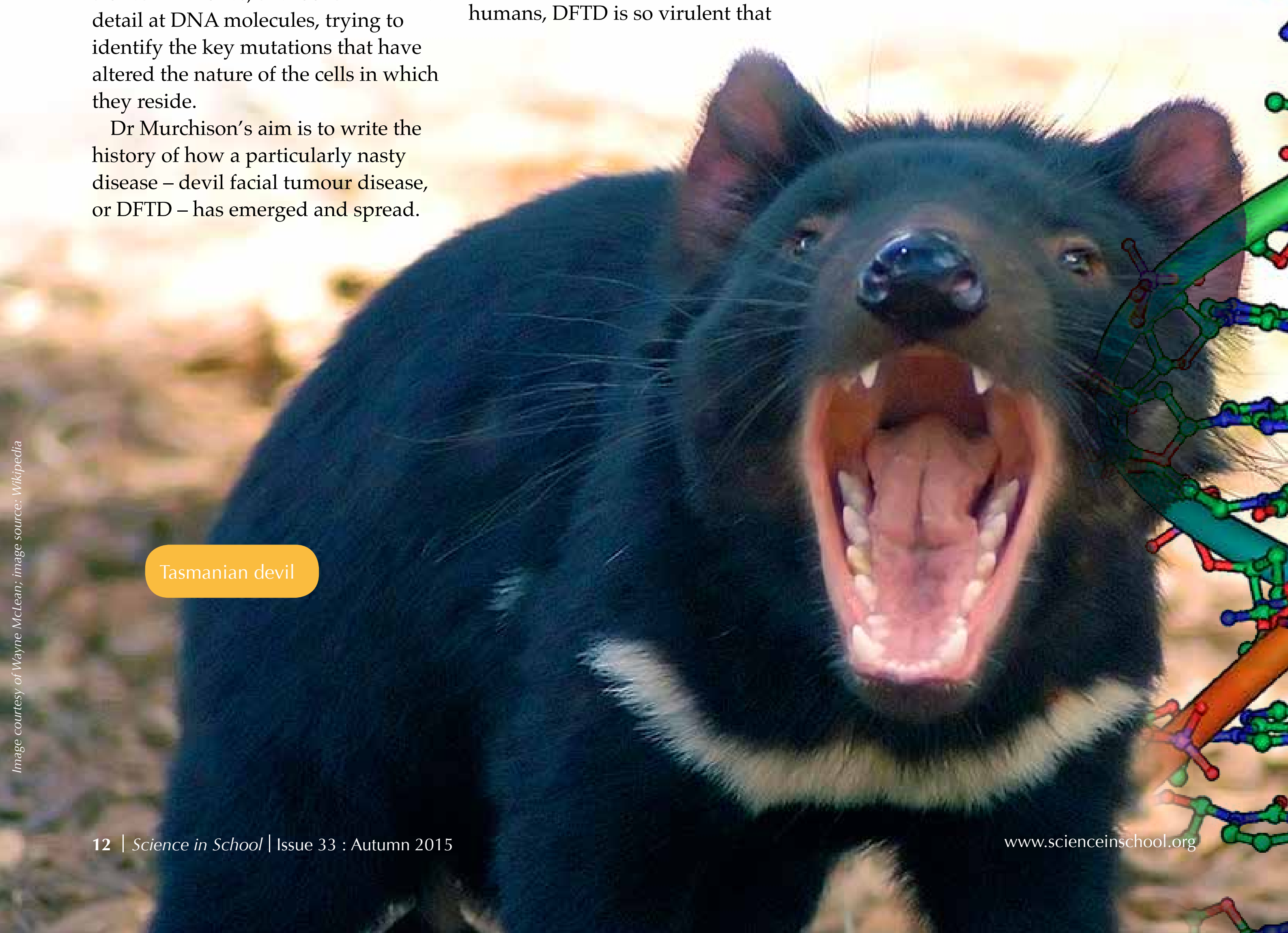
Infectious cancers: the DNA story

What makes a cell turn cancerous – and how does a cancer become infectious? In the second of two articles on transmissible cancers, Elizabeth Murchison explains what the genetic details tell us.

By Susan Watt

Dr Elizabeth Murchison describes her work as 'molecular archaeology': instead of examining old stones and bones, she looks in minute detail at DNA molecules, trying to identify the key mutations that have altered the nature of the cells in which they reside.

Dr Murchison's aim is to write the history of how a particularly nasty disease – devil facial tumour disease, or DFTD – has emerged and spread. This infectious disease is not caused by viruses or bacteria, but by tumour cells that have gained the ability to transfer from one individual to another, producing fatal tumours in each new host. Although it does not infect humans, DFTD is so virulent that



Tasmanian devil

Image courtesy of Wayne McLean; image source: Wikipedia

REVIEW

- Evolution
- Biology
- Ages 15–17

The second part of the DFTD story is focused on the genetics of transmissible cancers. DFTD is a terrible disease that is reducing the Tasmanian devil population.

The article can be used to explore some interesting topics, such as 'molecular archaeology', DNA/genome sequencing, and the immunological aspects of normal and transmissible cancers. Perhaps an even more interesting idea is raised by the last paragraph of the text, which describes a conservation strategy for the Tasmanian devil. This could be used to develop a debate about the ethical concerns and boundaries of conservation efforts:

a) Should humans interfere in a natural selection process?

Alternatively, should humans try to save a species that is threatened by natural causes?

b) Thinking about the discoveries made by Charles Darwin about the Galapagos finches, do we have the right to select and separate a group of individuals from the main population? What consequences for a species are posed by the reproductive isolation of its populations?

Like the first article on this subject, this article stimulates biology teachers to deepen their knowledge of these topics.

Luis M. Aires, Antonio Gedeao Secondary School, Portugal

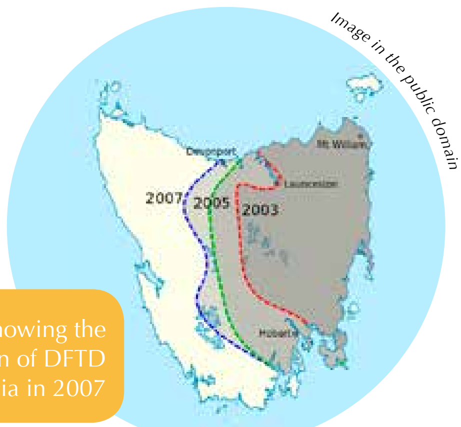


Image in the public domain

Map showing the progression of DFTD in Tasmania in 2007

Image source: Wikipedia

although it emerged only in the past few decades, it is now threatening the species it affects – Tasmanian devils – with extinction.

Archaeological cancer

The nucleotide sequence of the DFTD tumour today is, in effect, an archaeological record made up of the genome of the original DFTD tumour from some 30 years ago plus the mutations that have accumulated since then. "As molecular archaeologists, we piece together the genome variation we find today, and try to work out which occurred in the original devil tumour, and which occurred after that," says Dr Murchison.

All cancers – not just transmissible ones – arise when a cell accumulates mutations. Every time a cell divides and its DNA is copied, there is a chance that the process will produce a new mutation. Other mutations occur as a result of carcinogens – for example, cigarette smoke or infection with the human papilloma virus (HPV). Some mutations that increase the risk of cancer can also be inherited, such as the BRCA1 gene, which is associated with breast cancer.

Typically, cells in human cancer tumours have undergone between 1000 and 5000 mutations in their DNA, although this number can increase to 100 000 or more when an individual has been exposed to carcinogens over a long period.

Surprisingly few mutations

Initially, Dr Murchison's team expected the number of mutations in the DFTD cancer to be much higher than in human cancers, because of the exceptional properties and rarity of transmissible cancers – but this is not the case. "We've estimated that DFTD has about 20 000 mutations, which is less than some human cancers," she says. "This suggests that, to be transmissible, you don't need enormous numbers of mutations – just the key mutations that allow the cancer to spread and survive in a new host."

The team is now trying to pinpoint the identity of these key mutations. The first task was to work out the genetic information in normal Tasmanian devil cells, to act as a comparison with tumour DNA. "We had to start by sequencing the genome of Tasmanian devils, as there was no reference genome," Dr Murchison says. "If we were to just sequence the genes from a

BACKGROUND

Genetics of the canine transmissible venereal tumour

Genetic analysis has revealed that the canine transmissible tumours we observe today all have a common ancestor – which emerged 11 000 years ago! It also provides details of what the dog that had the first CTVT looked like, as shown in this sketch.

Gene name	Associated physical characteristic
ASIP	'Agouti' (mixed) coat colour
CBD103	Possible black coat colour
KRT71	Straight or wavy hair
FGF5	Short hair
IGF1	Medium or large size
BMP3	Probably pointy snout
MGAM	Adapted to starch and meat diet

Sketch of the dog in which CTVT first appeared, 11 000 years ago, according to genetic analysis

Artist: Emma Werner

DFTD cancer, we would have no way of knowing which genes were mutated and which were normal." This was a challenge in itself, similar in scale to establishing the human reference genome[w1].

The next step – comparing DNA from DFTD tumours to the reference genome – was also not as simple as it sounds. The disease first evolved in the 1980s, so when genetic variation is found between the reference genome and a particular DFTD tumour, it's not clear whether the variation is derived from the original tumour or was picked up as a mutation over the past 30 years. To separate the original mutations that helped spawn the disease from the variations that occurred later, the team is now carrying out a 'big screen', sequencing DNA from hundreds of normal Tasmanian devils and comparing it to DNA from hundreds of DFTD tumours.

So far, the results have shown that the original transmissible tumour occurred in a female Tasmanian devil, because the tumour genome contains two distinct X chromosomes. The genetic basis for one key change has also been identified: the tumour's ability to hide from its new host's immune system by suppressing a gene that produces the 'friend or foe' molecular signal in normal cells. This finding, along with the fact that Tasmanian devils are genetically rather similar across the whole population, explains why cells from one individual are able to proliferate in another without triggering an immune response. The discovery is already being exploited in the search for a vaccine against DFTD. The research has also shed light on how the DFTD tumour cell line has evolved during its spread across Tasmania, revealing that there are several genetic subtypes of tumour.

Dr Murchison's research is also looking at the only other known transmissible cancer – canine transmissible venereal tumour (CTVT), which occurs in dogs. Here, as with DFTD, her aim is to piece together genetic profiles of the animals in which the original tumours emerged and to trace their evolutionary path since then (see box).

Fighting for survival

Back in Tasmania, people fighting for the conservation of Tasmanian devils are not relying solely on research efforts to deal with the

Images courtesy of H.Neves/EMBL

DNA analysis in the lab

threat of DFTD. A wildlife conservation project has started to establish a new population of healthy, uninfected Tasmanian devils on their own small island, separated from the main population. So while the scientific work to understand this devastating disease continues, the future for these fierce little animals may already be looking a little brighter. "We all have a strong common goal in trying to do something to help the devil," says Dr Murchison.

Web reference

w1 - The human reference genome was determined by the Human Genome Project. For more information, visit the project website: www.genome.gov/10001772

Resources

For an introduction to DFTD, see the first of the two *Science in School* articles on the topic:

Watt S (2015) Infectious cancers. *Science in School* **32**: 6–9. www.scienceinschool.org/2015/issue32/taz

For more about DFTD and efforts to save the Tasmanian devil, see: www.yourgenome.org/interactives/saving-the-devil

For a short lecture by Elizabeth Murchison explaining her work to a general audience, see: www.ted.com/talks/elizabeth_murchison

For an article on transmissible cancers, see:

Giles C (2010) Sympathy for the devil. *Wellcome News* **62**: 8–9

This issue of *Wellcome News* can be downloaded from the Wellcome Trust website: http://bit.ly/1Fpxe0b

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Susan Watt is a freelance science writer and editor. She studied natural sciences at the University of Cambridge, UK, and has worked for several UK publishers and research councils. Her special interests are in psychology and science education.

An almost fearless brain

Wouldn't it be great to live without fear? Or would it? Research is showing just how important fear can be.

By Jose Viosca

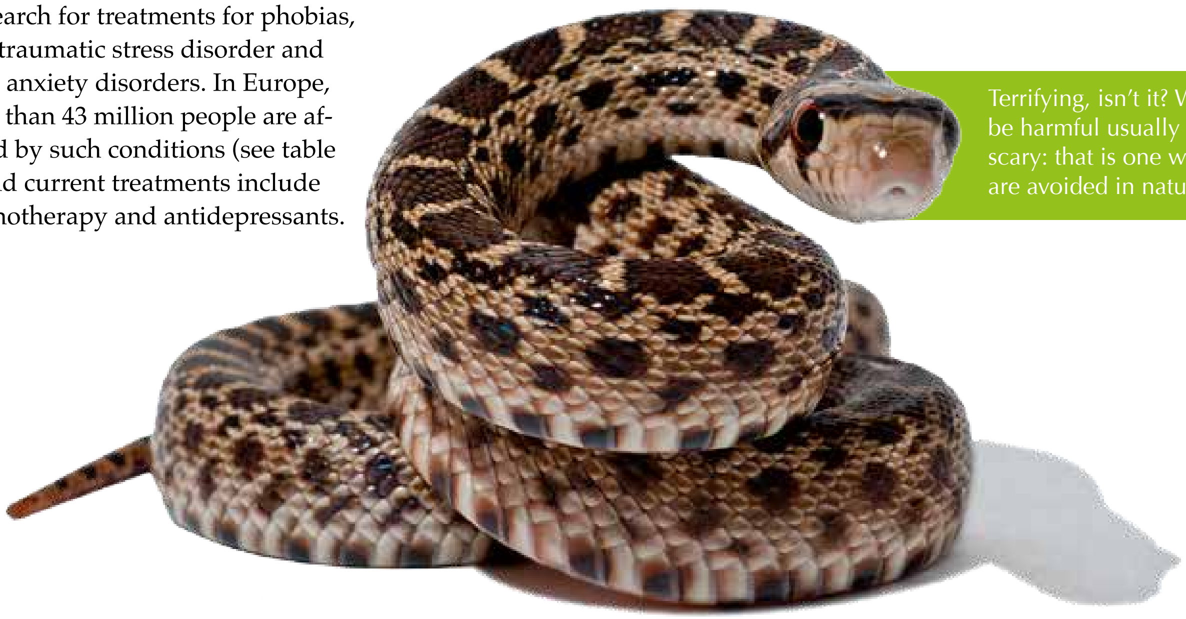
Living a fearless life is one of the favourite topics of fiction novels and films. In the 1932 novel *Brave New World*, happiness is easy: just take a pill and your problems will disappear, together with any fear. For me, a neuroscientist and science-fiction lover, it is amazing to see some of Aldous Huxley's fiction becoming reality in laboratories that investigate the neural basis of fear.

Despite its varied causes, fear results in remarkably similar symptoms: your heart races, you start to sweat, you are suffocating, dizzy and nauseous. You are terrified of losing control or of dying.

The selective removal of specific fears is a key goal in neuroscience, as we search for treatments for phobias, post-traumatic stress disorder and other anxiety disorders. In Europe, more than 43 million people are affected by such conditions (see table 1), and current treatments include psychotherapy and antidepressants. These are helpful approaches, but in some cases they do not work or they have unpleasant side effects. To provide more effective treatments, we need to understand how the brain processes fear.

Brave New World is one of the most read novels of the 20th century

Image courtesy of Chris Goldberg; image source: Flickr



Terrifying, isn't it? What can be harmful usually also looks scary: that is one way dangers are avoided in nature

Image courtesy of nick ta; image source: Flickr

Neurons (green) in the brain connect with thousands of other neurons, creating millions of neuronal circuits.

Image courtesy of Penn State; image source: Flickr.

Condition	Number affected (millions)
Panic disorder	5.3
Agoraphobia	4.0
Social phobia	6.7
Generalised anxiety disorder	5.9
Specific phobias	18.5
Obsessive compulsive disorder	2.7

Table 1: Europeans incidences of the most common fear and anxiety disorders
Data source: Wittchen & Jacobi (2005)

REVIEW

- **Health**
- **Biology**
- **Ages 14+**

This interesting article introduces readers to the innovative method of optogenetics for exploring brain functions. One function is to process fear, an emotion produced by different brain regions such as the hypothalamus and the amygdala.

Fears of authority or failure are feelings that the majority of children experience in school. As the author points out, these kinds of stress should be carefully managed by teachers and students, to set the equilibrium point where valid objectives aren't seen as "refutable" or a "threat". But does fear have the potential to enhance learning? Cognitive neuroscientists believe so.

Several investigations have shown that, when processing emotionally charged information, the hypothalamus and amygdala trigger a profuse secretion of the hormone adrenaline. Among the effects of the so-called 'fight or flight' mechanism is the improvement of cortical memory; an emotional event is always recorded with extra vivacity, for better processing and knowledge.

Recently, I observed a curious pedagogic 'experiment' conducted by a secondary science teacher. In one class, the students learned about anatomical features of predator dinosaurs (*Tyrannosauraus rex* and others) through an expository lesson supported by direct instruction, reading and watching a BBC documentary segment. In a different class the teacher made a brief introduction and then showed the *Jurassic Park* movie! Can the reader guess which class achieved better results in retrieving the information?

Luis M. Aires, Antonio Gedeao Secondary School, Portugal

To this end, researchers are now exploring one region of the brain: the hypothalamus. Located deep within the brain, the hypothalamus is a kind of ancient brain centre for motivations and internal drives such as hunger. Although human impulses such as the desire for happiness or love are not limited to the hypothalamus, they relate to basic motivations that have their roots in the need to survive and reproduce. If the energy levels in your body run low, for example, certain neurons in the hypothalamus will scream out, triggering the sensation of hunger. Similarly, a chain of neurobiological reactions underlies the sensation of thirst when your body is short of water; anger if someone invades your territory; and fear if you encounter a fierce dog.

How does this work? We know that the hypothalamus consists of more than 15 groups of nerve cells – neurons – which all use a variety of chemical messengers and receptors to communicate with each other. We know very little, however, about which of these types of neuron are involved in each survival motivation. Nor do we yet understand how the hypothalamus co-ordinates such

The hypothalamus is like an air traffic controller, co-ordinating many responses to ensure a safe outcome.

Image courtesy of Joseph Gruber; image source: Flickr

an array of diverse functions. Are the same neurons involved? Or do distinct but neighbouring cells rapidly communicate to determine which response to trigger?

To answer these questions, scientists need to systematically deconstruct the hypothalamus into its component parts, like thousands of pieces of a large jigsaw puzzle. This can be done by switching specific neurons on or off using nothing but a flash of light.

Does this sound like the stuff of science fiction? In fact, it is one of the techniques used in the research group that I worked in at the European Molecular Biology Laboratory (EMBL) [w1]. A photoactive protein, like those present in our eyes, is introduced into a specific type of neuron in the brain. The protein can then trigger or silence the activity of the neuron in response to a flash of laser light. When researchers in our group used light to switch off certain neurons in the hypothalamus of mice, the mice lost all sense of fear. Instead of avoiding a rat – a natural predator of mice – they approached it, forcing us to stop that particular experiment to protect the mice.

Intriguingly, a similar behaviour has been observed in humans – which first suggested to neuroscientists that fear is controlled by different areas of the brain. Before we knew the hypothalamus was involved in fear, we thought perhaps the only area of the brain involved was another small region known as the amygdala. A woman known in the scientific literature only as 'SM' had a genetic condition that destroyed neurons in the amygdala, which is known as the centre of emotions and an essential component in processing fear. Over the years, scientists exposed SM to all kinds of terrible stimuli including horror movies, poisonous snakes and spiders, but she showed no fear. One day, however, they asked her to breathe in air with a high concentration of carbon dioxide. This raises the carbon dioxide levels in the blood and would normally be associated with suffocation. This, finally, caused SM to panic – she screamed for help while pulling the mask away. Scientists observing her concluded that other brain regions besides the amygdala must be able to trigger and process fear.

For the first time, SM had experienced fear. What a wonderful idea, you might think. This is what scientists are searching for, to help treat anxiety disorders and other conditions. SM's life, however, demonstrates the importance of fear. Over the years, her lack of fear had led her into many dangerous situations – including many assaults – because she did not recognise the early signs of danger, just like the mouse that carelessly approached the rat. Fear is not only unpleasant and disturbing but is also there to warn us of dangers.

This research illustrates the importance of striking a balance, which scientists continue to investigate. Basic emotions can be vital but become harmful in the extreme. In *Brave New World*, for example, people paid a very high price for happiness and fearlessness: they lost their freedom. Perhaps the purpose of fear is also to point out the need to constantly evaluate and react, to make appropriate choices, and to seek answers about our emotions and behaviours at home, work or school.

Reference

Wittchen HU, Jacobi F (2005) Size and burden of mental disorders in Europe—a critical review and appraisal of 27 studies. *European Neuropsychopharmacology* **15**: 357–376. doi: 10.1016/j.euroneuro.2005.04.012

Web reference

w1 – To learn more about the European Molecular Biology Laboratory (EMBL), see: www.embl.org

Resources

The fearless mouse approaching a rat was first observed in this research:

Silva BA et al (2013) Independent hypothalamic circuits for social and predator fear. *Nature Neuroscience* **16**: 1731–1733. doi: 10.1038/nn.3573

To learn more about the case of SM, see:

Feltman R (2015) Meet the woman who can't feel fear. *Washington Post* Jan 20. www.washingtonpost.com or use the direct link: http://tinyurl.com/oudglh8

Costandi M (2013) Researchers scare 'fearless' patients. *Nature News* Feb 2013. www.nature.com/news or use the direct link: http://tinyurl.com/bnokv2s

Image courtesy of Dean Thorpe; image source: Flickr

To find an explanation of optogenetics, the technique to control neuronal activity with light, see:

Rutherford A (2015) Cell control in a flash. *EMBLetc* Jan 26. http://news.embl.de or use the direct link: http://tinyurl.com/pog6yk5

To learn how optogenetics can be used to investigate brain circuits, see:

Gross C (2014) Fight or Flight. EMBL Insight Lecture, Feb 16. http://news.embl.de or use the direct link: http://tinyurl.com/nuplrr8

To learn about previous EMBL research into the role of the amygdala in fear, see:

Stanley (2011) A neural switch for fear. *Science in School* **18**: 32-35. www.scienceinschool.org/2011/issue18/fear

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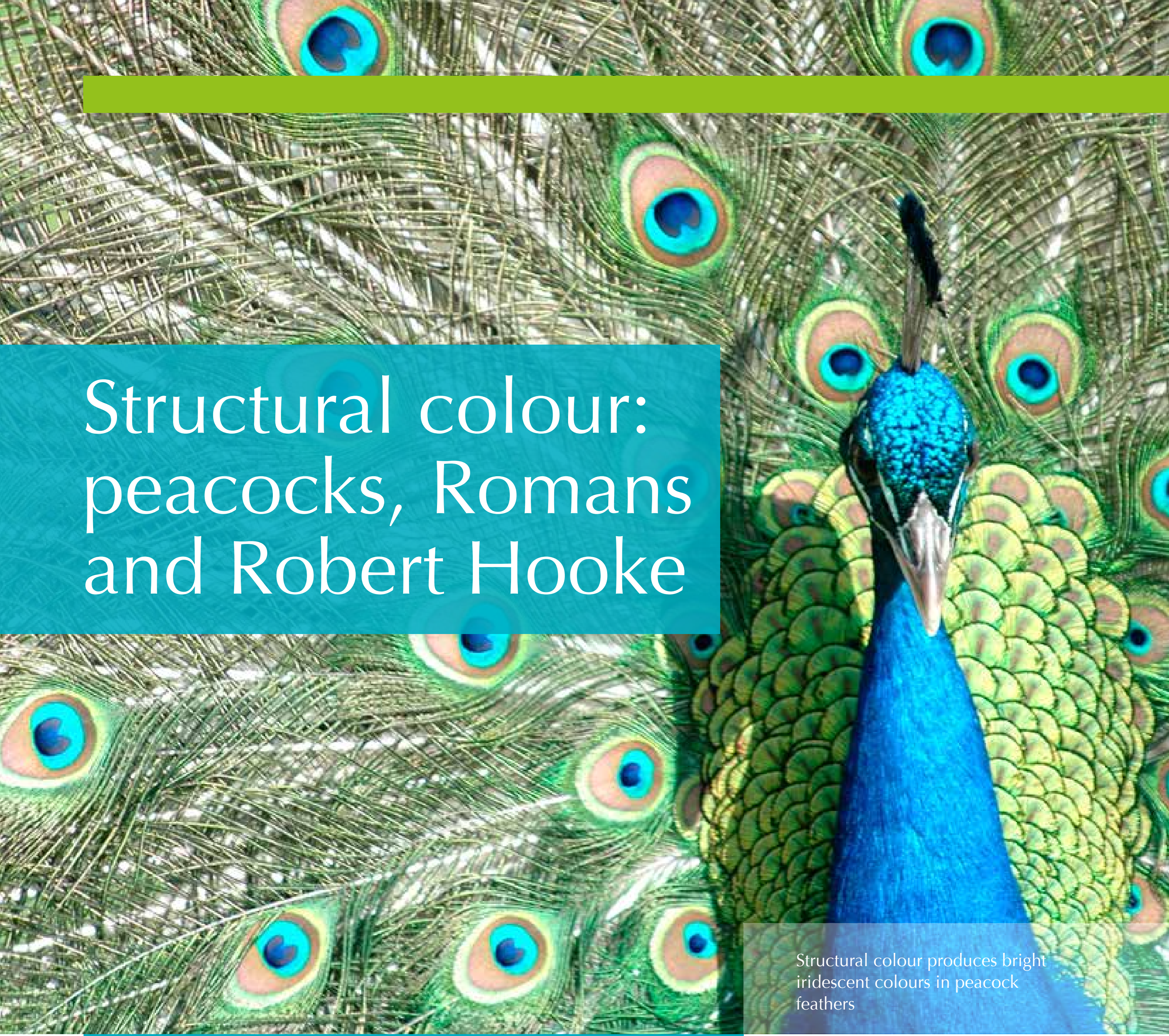
Jose Viosca is a neuroscientist turned science communicator. He investigated the neural circuits of fear as a postdoctoral researcher at the European Molecular Biology Laboratory. Now he is an editorial intern for *Science in School*.

The brain is a large puzzle. Neuroscientists try to understand each piece to grasp the whole.

Image courtesy of University of Bristol; image source: Flickr

Structural colour: peacocks, Romans and Robert Hooke



Structural colour produces bright iridescent colours in peacock feathers

Image courtesy of Paul Friel; image source: Flickr

For thousands of years, nature has produced brilliant visual effects. What is the physical principle behind it and how can we use it?

By Jordi Gomis-Bresco and Jose Viosca

Colour is how we visualise different wavelengths of light. The colours we see depend on the light that is reflected or transmitted from objects into our eyes. The most common source of colour is pigmentation: almost everything we see, including our clothes and ourselves, is coloured by pigment molecules.

But there is another way to make colour – one that fruits, beetles, butterflies and peacocks, for example, all use: structural colour. Their colours change depending on your viewpoint, due to microscopic structures on their surfaces that interfere with the reflection of light. Humans have been using structural colour long before knowing its cause, and today scientists are taking inspiration from nature to develop structural colour further. "We try to create materials that manipulate light using the same physical principles as those found in nature," says Pete Vukusic, a professor of biophotonics at the University of Exeter, UK. "The aim is not to mask or hide things, but to give materials and objects interesting and functional optical properties such as brightness, directionality or iridescence."

A brief history of wave interference

One sunny afternoon in the 17th century, Robert Hooke discovered something that has gone down in history. Wondering why the colour of peacock feathers changed if viewed from different angles (called iridescence), he plunged a feather into water and made an astonishing discovery: the colour disappeared. "Fantastical", he wrote. Using a microscope, Hooke saw that the peacock feather was covered in tiny ridges. He concluded that this was evidence that light reflection and refraction were behind colour.

We know now that the colours of many birds and insects arise from

REVIEW

- **Physics**
- **History**
- **Material science**
- **Optics**
- **Biology**
- **Ages 14–19**

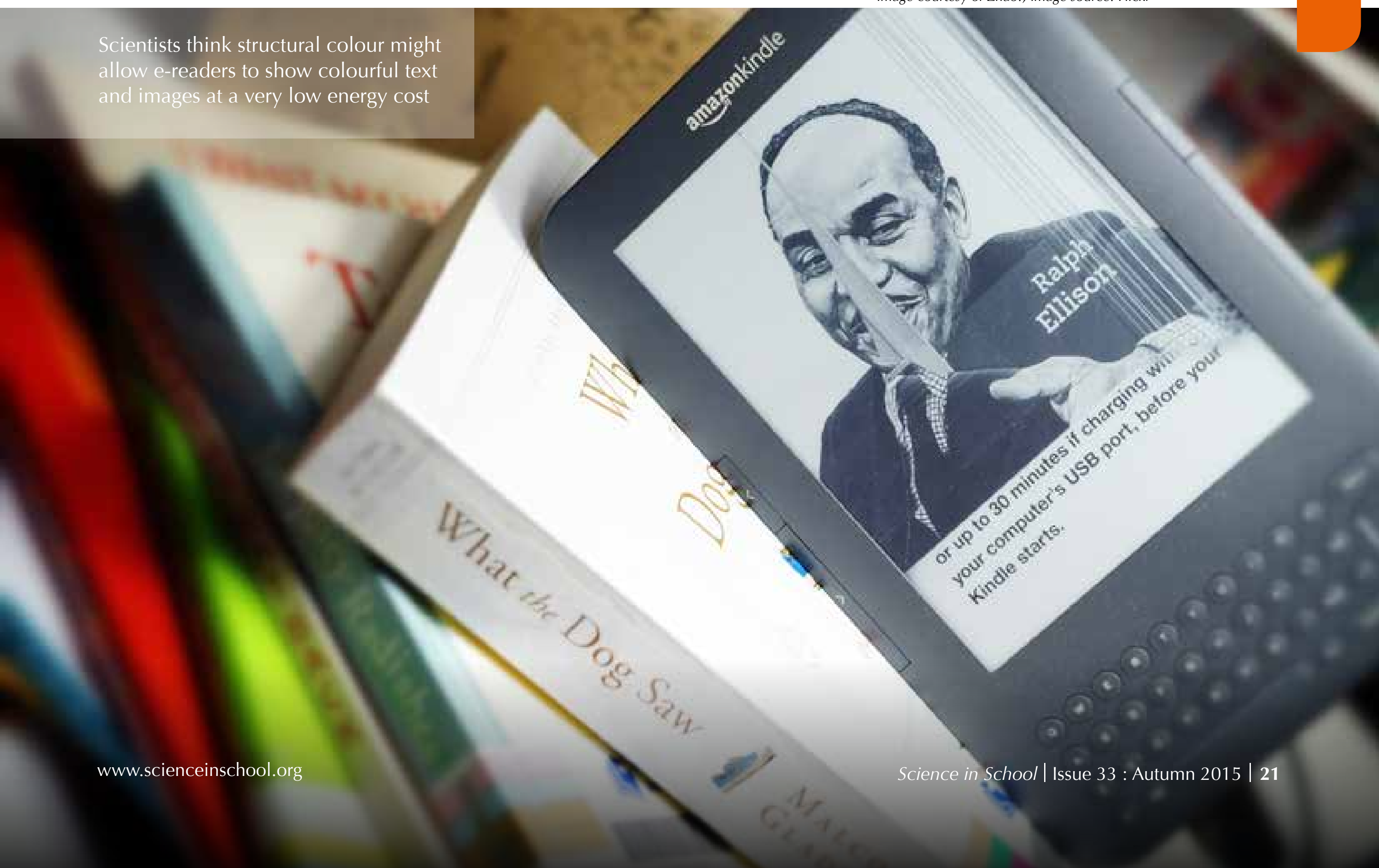
Structural colour and its scientific application are likely to be of great interest to pupils. This article is very interesting and gives a good overview of optical effects and how colour is 'produced'.

The article tries to stimulate questions like:

- How is our eye able to see colours physically?
- What is colour? Give a physical explanation.
- How can we create colours?
- Explain the dual nature of light.
- How are colours used in nature and in technology?
- What is structural colour?
- Give some examples of the use of structural colour. How do these items create colour?
- Explain some technical applications of structural colour.

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

Image courtesy of Zhao!; image source: Flickr



Scientists think structural colour might allow e-readers to show colourful text and images at a very low energy cost

BACKGROUND

The dual nature of light

Hooke's explanation of light was soon rejected by Isaac Newton, who thought that light was made of particles (he called them "corpuscles"). Decades later Thomas Young showed that light behaves as a wave by using interference, the phenomenon by which two waves superimpose to result in a wave of bigger or smaller amplitude. In Young's famous double-slit experiment, light coming from a single source passed through two slits in a solid screen and was observed on a wall behind the screen. The light that came out of these two slits began to show a pattern of light and dark areas, much as ripples propagate in a pond, and if these patterns overlapped the patches became stronger as the waves interfered. This is behaviour that could be explained only if two waves had emerged, one per slit, and then interfered with each other to combine or to cancel out at certain positions.

Later research, however, seemed to contradict Young. The gold leaf experiment showed that electrons are ejected from a metal surface when exposed to electromagnetic radiation, but only if the light has a high enough frequency, and hence energy, while the intensity of the source does not determine whether the plate discharges or not. This was evidence that the beams of light are made up of individual units called photons.

Today we say both that light travels as a wave, but that it also consists of energy packets called photons. Light has a dual nature.

Image courtesy of Following Hadrian; image source: Flickr

The striking structural colours of the Lycurgus cup: reflected light appears green while transmitted light shines red

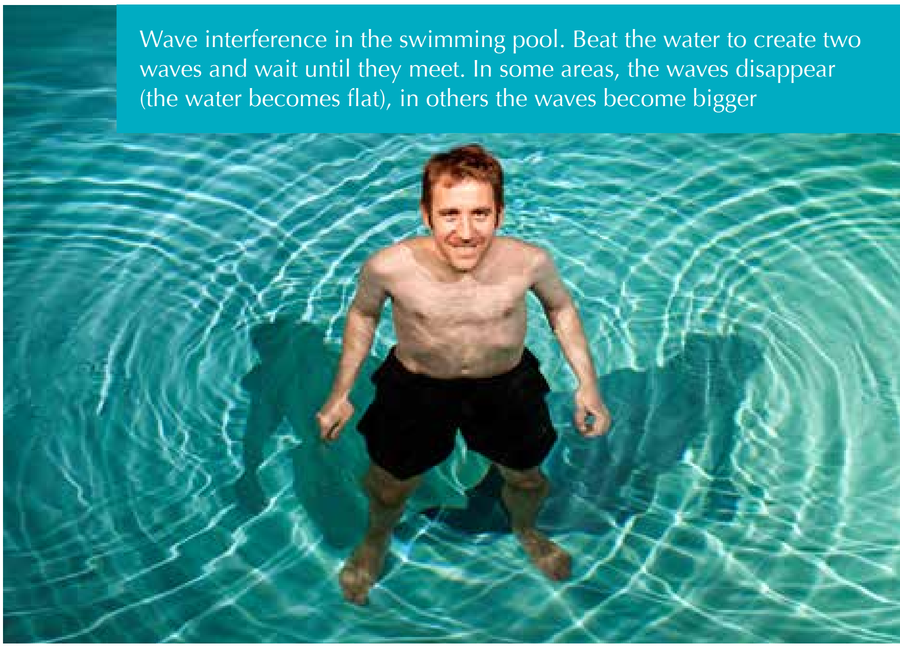


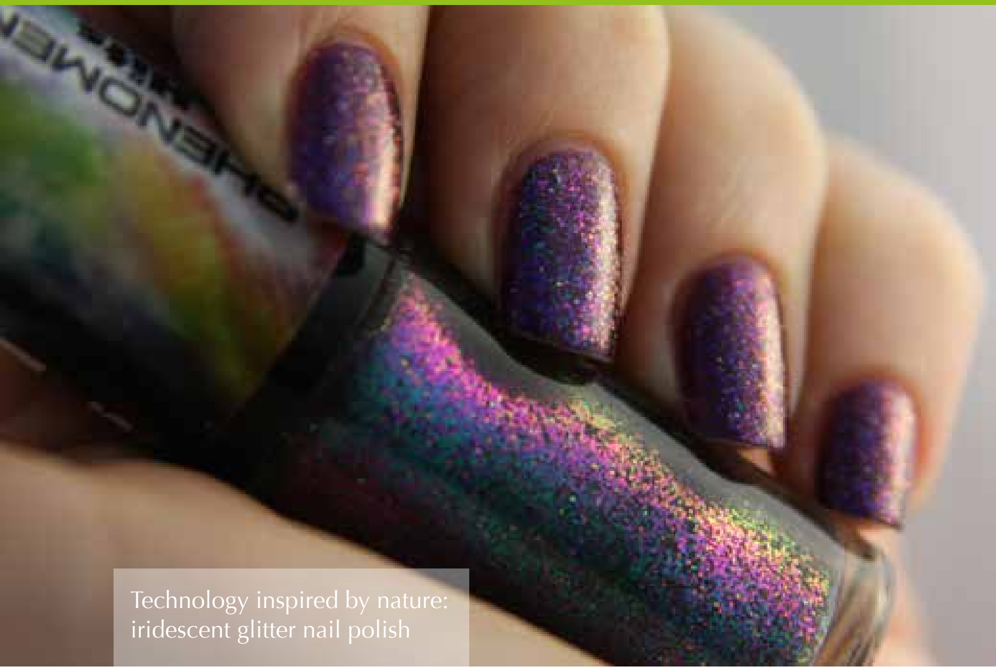
Image courtesy of ESO/M. Alexander; image source: Wikipedia

Wave interference in the swimming pool. Beat the water to create two waves and wait until they meet. In some areas, the waves disappear (the water becomes flat), in others the waves become bigger

structural colour, produced by light interacting with regular structures just a few hundred nanometres in size. These structures break down incident light into several reflected waves that interfere with each other, destroying or reinforcing different wavelengths in different directions and appearing to our eyes as brightly coloured or iridescent. In pigmentary systems the physics is completely different, which explains why structural colour can be much brighter. "Pigments both reflect and absorb light. These absorptive processes, which are intrinsic to the production of pigmentary colour, are the very things which can limit the colour brightness," says Vukusic.

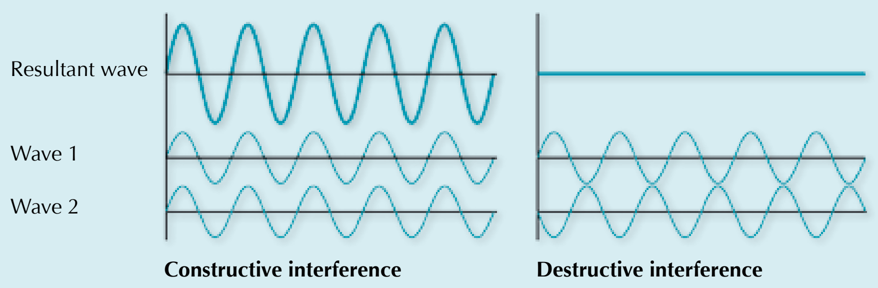
Structural colour – past, present and future

Over thousands of years of evolution, living organisms have mastered how to manipulate and channel light using delicate, periodically arranged nanostructures. Peacocks, for example, use the brilliant structural colours of their feathers as part of their courtships. Today these biological designs inspire engineers seeking to control



Technology inspired by nature: iridescent glitter nail polish

Image courtesy of Romina Campos (Hits phenomena – Moonbow); image source: Flickr



In some conditions, two waves can superimpose and result in a wave with bigger amplitude when they align in phase (left), but they can also destroy each other if out of phase (right). In structural colour, visible light is decomposed when reflected by particular nanostructures: certain wavelengths are reinforced and others destroyed, giving brightly coloured or iridescent materials

Modified from "Interference of two waves" by Haade (Wikimedia Commons)

light in optical technologies. Scientists are working to produce colour-reflective screens, for e-books or electronic paper, that don't need their own light to be readable. These displays would use much less power than backlit versions in computers, smartphones and TVs[w1]. Humans have also used structural colour without even being aware of it.

The Lycurgus cup is a Roman artefact stored in the British Museum in London, UK. Made of glass, it changes its colour from green to red depending on whether the incident light is reflected by the glass or passes through from behind (Freestone, 2007). Like peacock feathers, the striking colour of the Lycurgus cup is due to structural colour, but caused by much smaller structures only several nanometres across – gold nanoparticles dispersed inside the glass. When the surfaces of the metal nanoparticles interact with light, they retain and direct specific colours of light. The Roman glassmakers found by chance that precious metals added to glass gave impressive colour effects, but they could not reproduce it, and the few similar pieces that remain today were all made around the fourth century BC.

Today, at last, humans can use the science of structural colour to make many objects, even the lipstick in your handbag. By using particles that are made of many thin layers and immersing thousands of them in the formulation we get an iridescent lipstick. "The regular nanostructures contained in these particles strongly reflect colours, giving different dramatic and selective appearances in different directions," says Vukusic, who has also worked with cosmetics firm L'Oreal.

Researchers are also trying to use the physics of light channelling and structural colour in the plastics industry. This is the idea behind Plast4Future[w2], a research project led by Anders Kristensen of the Technical University of Denmark, which is focused on making more environmentally friendly coloured plastics. "With structural colour, you can make plastics using fewer materials and it also facilitates recycling according to a cradle-to-cradle production philosophy," says Kristensen, referring to the approach that models human industry on nature's processes, ensuring that energy and material resources flow between compartments without running out or accumulating waste.

The same physical properties that coloured the Lycurgus glass may someday colour commercially available plastics. Professor Kristensen developed a way to do this just last year. First, his team made a silicon mould with an array of thousands of nanoholes. Then they moulded the plastic and deposited a thin film of aluminium on top. The result was a coloured plastic without pigments, and the colour could be tuned by changing the diameter of the nanoholes (Clausen, 2014). "For recycling, the aluminium can be removed from the plastic, which can then be melted and remoulded, generating a plastic with the same or another colour," explains Kristensen. "With the traditional system, however, pigments cannot be

Image courtesy of Matthew Kirkland; image source: Flickr

Nanostructures in beetle's shells are responsible of their bright iridescent colours

removed so the recycled plastic will have the same colour," which means that plastic recycling at the moment is more wasteful and complex.

The Plast4Future project also explores how to give plastics other features such as antifogging or even hydrophobicity (repelling water). All these innovations are of interest to companies that make things from cars to toys: Fiat and LEGO are both active partners in this project.

Far from a curiosity, structural colour is a tool to achieve a cleaner, less polluted world. Such a scenario could hardly be imagined by the major historical figures in this story, but they all helped us to understand what we know today about this extraordinary source of visual effects.

References

Clausen JS et al (2014) Plasmonic Metasurfaces for Coloration of Plastic Consumer Products. *Nano Letters* **14**: 4499–4504. doi: 10.1021/nl5014986

Freestone I et al (2007) The Lycurgus Cup: A Roman nanotechnology. *Gold Bulletin* **40**: 270–277. doi: 10.1007/BF03215599

Web references

w1 – Read more about how next-generation e-readers can use structural colour to improve their high-resolution colour displays: www.ns.umich.edu/new/releases/21171-next-gen-e-readers-improved-peacock-technology-could-lock-in-color-for-high-res-displays

w2 – Visit the Plast4Future website at www.plast4future.eu

More about XFEL

The European XFEL is a facility that is under construction in the Hamburg area of Germany that will be able to study basic properties of matter for various disciplines, including nanotechnology, using ultrabright flashes of X-ray laser light. Since the X-ray laser can make visible structures at the atomic scale and at timescales near a quadrillionth of a second, it will be able to study the details of interactions of nanoparticles with other matter and with light. This could open the door for a better understanding of how nanoparticles are structured, how they behave in terms of reactivity and atomic motion, and why they function in certain ways in different environments such as in solution or as aerosols.

Jordi Gomis-Bresco is a research fellow at the Institute of Photonic Science, in Castelldefels, Barcelona, Spain. He investigates how to manipulate light, confine it to the interface of materials, and exploit it to develop new concepts for telecommunication and sensing devices. In his spare time, he conducts all sorts of kinematic experiments in the park near his house with his two children.

Jose Viosca is a neuroscientist turned science communicator, interested in people, science education, and everything that catches his attention. Find him on Twitter: @jviosca

Towards a better lithium-ion battery

Watching what happens to the electrodes in a lithium-ion battery with neutron science.

Chemistry

Physics

By Matteo Bianchini and Emmanuelle Suard

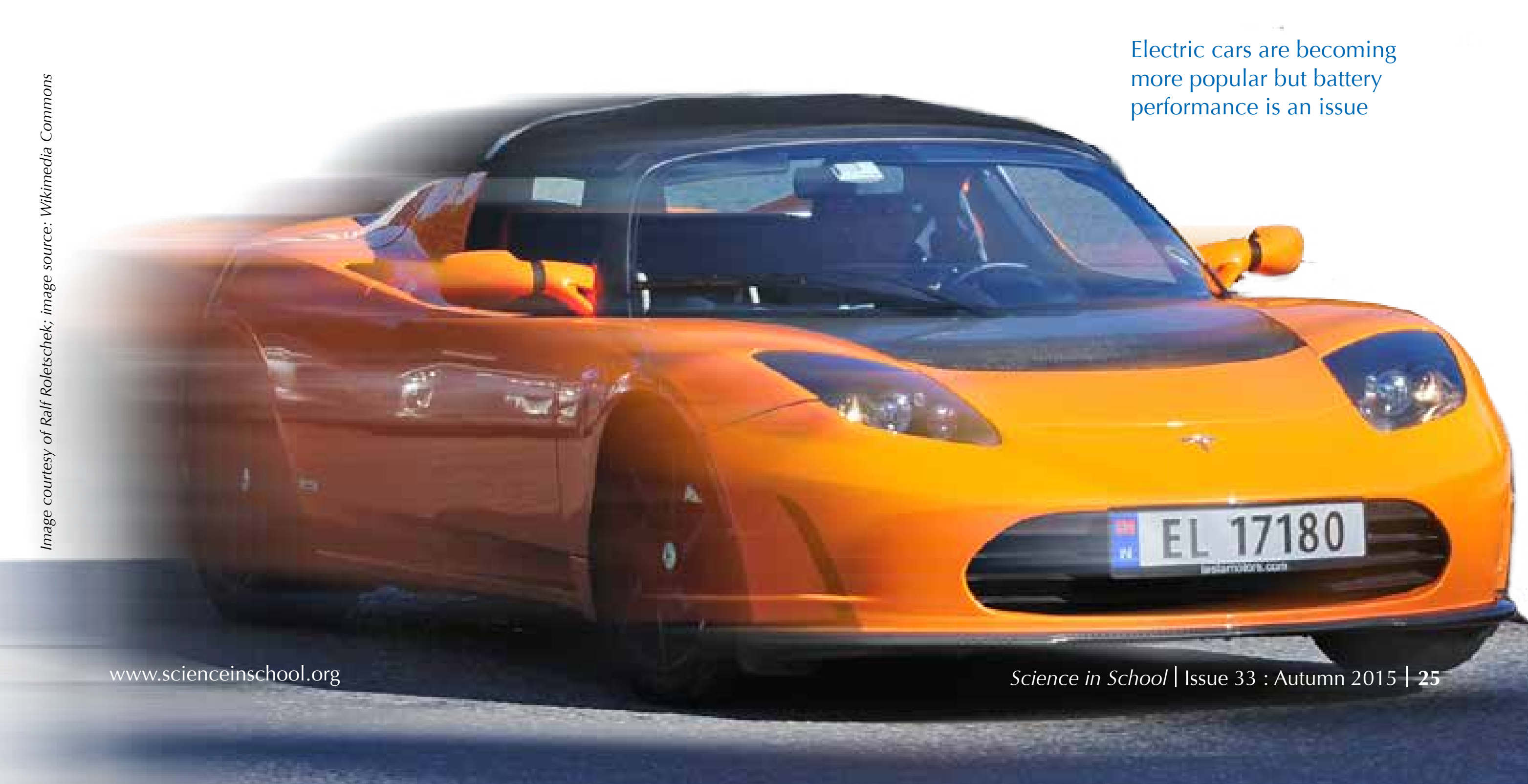
Lithium-ion batteries power our phones and laptops. They are even starting to power our cars, but the development of electric cars has been hindered by slow progress in battery technology. To help speed up this process and improve lithium-ion battery technology even more, my colleagues and I at Institut Laue-Langevin (ILL)[w1] recently made a supersized battery so that they could see what happens inside while it is operating. The resulting 'movie' helped the scientists to see how they could improve the electrodes in the battery.

The power of lithium

We know lithium as the reactive group-one metal in the top left-hand corner of the periodic table. One of only three elements created in the Big Bang, lithium doesn't just power your laptop – it is also burned up as star fuel.

Back on Earth, we get our lithium from the ground, where huge underground lakes containing lithium salts are tapped to generate about 25 000 tonnes of lithium metal every year. Much of this is used to make lightweight, rechargeable lithium-ion batteries.

Like all batteries, lithium-ion batteries store electrical energy using chemical potentials. Unlike other batteries, lithium-ion batteries are rechargeable so its reactants can be generated again just by passing electricity through the



Electric cars are becoming more popular but battery performance is an issue

Image courtesy of Ralf Roletschek; image source: Wikimedia Commons products. Once the battery has gone flat, it can be connected to a recharger which uses electrical energy to reverse the chemical reactions that took place in the battery while it was in use.

Unsurprisingly, lithium-ion batteries work by using positively charged lithium ions to transfer charge. Like all batteries, the battery is made up of two electrodes: one positive and made from a compound containing lithium (often with a transition metal oxide, for example manganese); and one negative, often carbon. These two electrodes are connected by an electrolyte that allows the charge carriers (lithium ions) to move between the two electrodes. The two half reactions are, for example:

$$LiMn_2O_4 \rightleftharpoons Li_{1-x}Mn_2O_4 + xLi^+ + xe^-$$

$$xLi^+ + xe^- + xC_6 \rightleftharpoons xLiC_6$$

When the battery is discharging (i.e. when it is supplying power), the lithium ions move from the carbon electrode back to the lithium-containing electrode and then back in the opposite direction when the battery is recharged. Unfortunately, this backwards and forwards process can't go on forever. Over time, lithium ions passing in and out of the electrodes cause them to swell and shrink repeatedly, thereby degrading them slowly. Much like how your favourite clothes lose their fit and fray around the edges as you repeatedly wear and wash them. Eventually your favourite jeans don't fit you as well as they used to, and in a similar way, the lithium ions can't fit into the lattice of the electrodes so well. The battery loses capacity.

To improve batteries, therefore, you need to improve the electrode materials – which means you need to understand how these materials change with repeated charge and discharge cycles. This is where ILL and its neutron source come in, allowing us to 'visualise' the changes

REVIEW

- Chemistry
- Physics
- Electrochemistry
- Materials
- Electricity
- Ages 15–18

Lithium-ion batteries are one of the most important electrochemical applications present in the daily lives of students. However, their low capacity and durability are factors that have delayed implementation, for example in electric vehicles.

Scientists at the Institut Laue-Langevin (ILL) explain in this article some of their work to improve characteristics of lithium-ion batteries. Teachers can use the article not only to give examples of cutting-edge research, but also to explain in class the basic concepts of electrochemistry which underlie the operation of batteries in general.

Several comprehension questions could be devised, regarding for instance the direction of the electrical current, or the electron flow; the function of the electrolyte; or even the stoichiometry of ionic compounds. The article can be used to discuss the difficulties that arise during the development of a technological product using the example of the durability of batteries vs capacity. It allows a connection between materials science and electrochemistry. Environmental issues may also arise with respect to the disposal of batteries.

Duarte Nuno Januário, Portugal

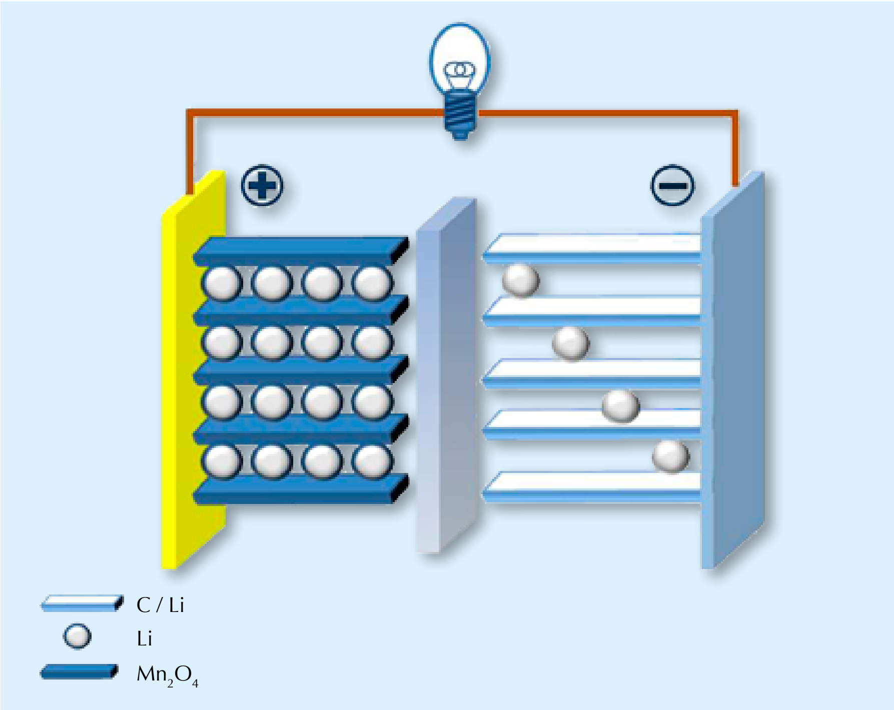
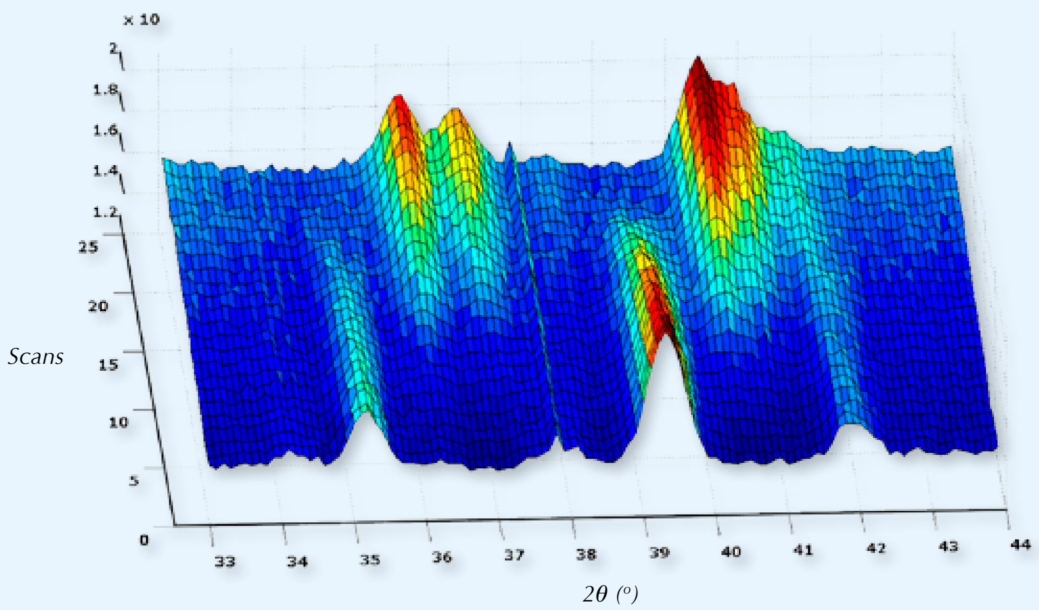


Image in the public domain by Chem51grpThinLiBat via Wikimedia Commons

A basic lithium-ion battery uses lithium ions as the charge character. Over time these deform the electrodes, causing them to degrade.

Image courtesy of the author



The $LiFePO_4$ electrode changes as it cycles through charges; red areas show degradation

in the crystal structure of the electrodes. Neutron diffraction is an excellent technique for seeing lithium ions moving through the electrodes because neutrons are readily scattered by light elements such as lithium.

Real-time movies

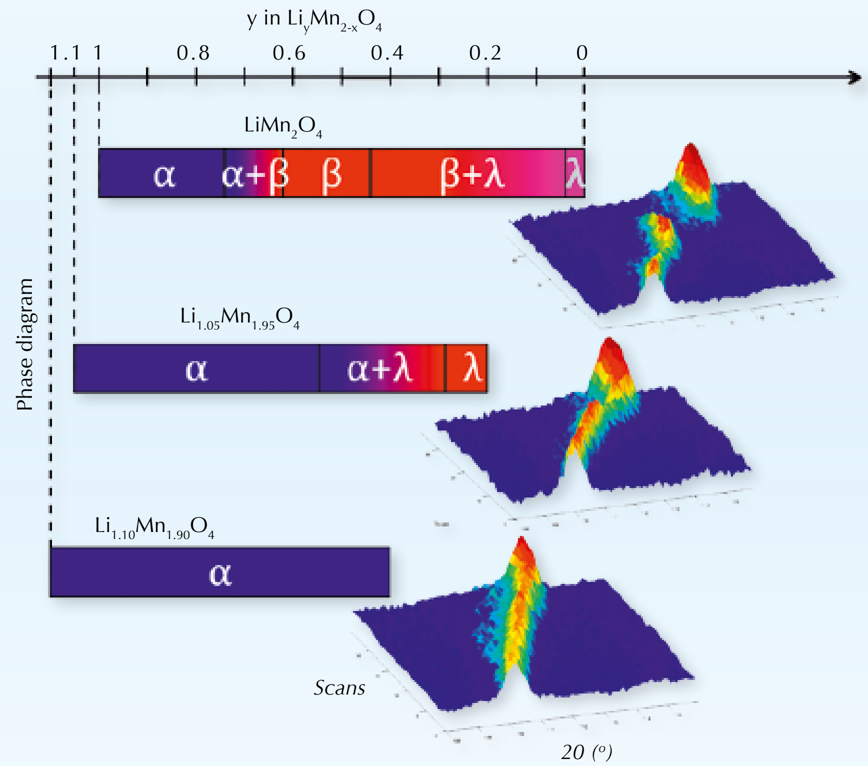
For this reason, we developed a novel battery to study what happens in the electrode materials while it is actually operating (Bianchini M et al 2013; 2014). The aim was to obtain a high-quality, real-time movie of the entire process. To make the movie we created many neutron diffraction images by scattering neutrons through the electrode material as the battery charged and discharged. We then used neutron diffraction patterns as frames for the movie; much like stop-motion animation or making a flip book, playing the images one after the other allows us to see what's really happening to the electrode.

We first tested and optimised the function of a single battery cell, the methodology and the quality of the diffraction patterns using relatively well understood electrode materials such as lithium iron phosphate ($LiFePO_4$). $LiFePO_4$ is already available as a safe, cheap and long-lasting electrode. Once satisfied with the experiment, we then studied some newer electrode materials based on lithium manganese oxide ($LiMn_2O_4$) to see how their behaviour differed. $LiMn_2O_4$ is an interesting positive-electrode material with a high capacity and charge/discharge rate, although its capacity quickly fades upon cycling, thwarting commercial application. By tweaking the molecular formula of the material, we found that adding more lithium to the structure, at the expense of manganese, can overcome this challenge.

Basing our work on the molecular formula of $LiMn_2O_4$, we made three compounds with the formula $Li_{1+x}Mn_{2-x}O_4$, where x is the amount of extra lithium. The three compounds had x values of 0, 0.05 and 0.10. By watching how the materials changes during charging, we found that the extra lithium reduces the usable capacity of the battery but eliminates the problem of fading capacity. The battery doesn't hold as much charge to start with but it lasts longer at that same level.

We found that this is because:

1. The volume change induced by the loss of lithium ions is reduced as the amount of lithium in the electrode material is increased,



The different manganese electrodes undergo different changes as they are charged and discharged

and the physical mechanism by which this happens is modified.

2. When the amount of lithium is increased, the amount of Mn^{3+} is reduced by an equivalent amount, and we know that this species hinders the long life of batteries.

As a result, the material with the highest amount of lithium is a much better battery material.

We have not only shown that neutron diffraction can help us to understand the behaviour of lithium ions and lithium-ion batteries, but also found a real example of how to improve these batteries. Given our promising results, the study of this type of material is expanding to different compositions such as those containing additional nickel ($LiMn_{1.6}Ni_{0.4}O_4$), operating at higher voltages and thus having more energy. Maybe one day our work will help your electric car run faster and last longer.

References

Bianchini M et al (2013) A New Null Matrix Electrochemical Cell for Rietveld Refinements of In-Situ or Operando Neutron Powder Diffraction Data. *Journal of the Electrochemical Society* **160**: A2176–A2183. doi: 10.1149/2.076311jes

Bianchini M et al (2014) Li-Rich $Li_{1+x}Mn_{2-x}O_4$ Spinel Electrode

BACKGROUND

The transparent battery

The special battery cell that we used for this experiment has larger than normal electrodes so we could obtain the highest quality neutron diffraction patterns for analysis. The most important feature in this special battery is the use of a titanium–zirconium alloy, which is known for being neutron-transparent – it doesn't scatter neutrons and instead they pass straight through. In this way, only the signal from the electrode of interest was collected, avoiding other unwanted contributions from the cell. We also used a deuterated version of the electrolyte, with hydrogen atoms replaced by the heavier deuterium, to further reduce scattering and improve the signal obtained.

Despite the larger than average size of the battery, the samples we had to study were still small (≈200 mg) in terms of what is normally required for neutron diffraction experiments (≈1 g). But thanks to the high power of the ILL neutron source and the state-of-the-art diffractometers available, we could get the images we were hoping for.

Materials: An *Operando* Neutron Diffraction Study during Li^+ Extraction / Insertion. *Journal of Physical Chemistry C* **118**: 25947–25955. doi: 10.1021/jp509027g

Web references

w1 –To learn more about ILL, visit: www.ill.eu

See the list of all ILL-related articles in *Science in School* at: www.scienceinschool.org/ill

w2 – EIRO forum 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*. Learn more at: www.eiroforum.org.

Resources

Scientists at the European Synchrotron Radiation Facility (ESRF) in Grenoble, France, also work on lithium-ion batteries and there is an interesting article on their work on pages 16 and 17 of the July 2015 issue of *ESRF news*. See: http://mag.digitalpc.co.uk/fvx/iop/esrf/1507/

More about ILL

EIROforum

NEUTRONS FOR SCIENCE

The Institut Laue-Langevin (ILL)[w1] is an international research centre based in Grenoble, France. It has led the world in neutron-scattering science and technology for more than 40 years, since experiments began in 1972. ILL operates one of the most intense neutron sources in the world, feeding beams of neutrons to a suite of 40 high-performance instruments that are constantly upgraded. Each year 1200 researchers from more than 40 countries visit ILL to conduct research into condensed matter physics, chemistry, biology, nuclear physics and materials science. ILL is a member of EIROforum[w2], the publisher of *Science in School*.

The ILL with the Alps in the background.

Image by Wurzeller [Public domain]; image source: Wikimedia Commons

Chemistry

Physics

Science teaching in the spotlight

A packed schedule brought teachers from across Europe and Canada to share ideas, best practice and a lot of fun.

By Laura Howes

The East London campus of Queen Mary, University of London, UK, saw explosions, laughter and a buzzing atmosphere in June 2015 as 350 science teachers from across Europe and Canada gathered to share classroom ideas and projects at the 2015 Science on Stage festival. For some countries the summer holidays had already begun, which meant that many teachers at the festival had given up their free time to come to London. Teachers whose school year hadn't yet finished had taken valuable time off from teaching. This alone shows just how important the teachers – and their schools – thought it was to attend.

"This is a unique opportunity for teachers from all over the world to get some fantastic ideas about science teaching," said Charlotte Thorley, Chair of the UK national steering committee, and festival director. "We want them to leave with a hundred plans to help improve their teaching rather than just a bag full of leaflets that they'll never look at again."

The ninth Science on Stage festival was subtitled 'Illuminating science education', a suitable theme given that 2015 is the International Year of Light. Because of the theme, many of the attendees focused on different aspects of light, but that didn't mean that physics was the only feature: the festival also had a lot of chemistry, biology and mathematics on display.

At the launch event, attendees were treated to insights into computer vi-

Image courtesy of QMUL/Gary Schwartz

Image courtesy of QMUL/Gary Schwartz

sion (known as image salience) from the vice-principle for public engagement and student enterprise at Queen Mary, Peter McOwan. But the message that will probably stay with most attendees is how easily our vision can be tricked as we focus on the 'important' parts of an image.

The magic tricks that McOwan performed on stage could have been a metaphor for the whole festival – with so much to see, it was difficult to ensure that things weren't overlooked. Several attendees felt that the festival could have run even longer than four days. "It really could have been a whole week," said UK chemistry teacher Kristy Turner.

As at previous festivals, the attendees had been selected in a series of national events and competitions to represent some of the best teachers and projects in their countries. All the representatives set up stalls at which they held demonstrations – on radical new ways of teaching science to children with disabilities, the science of Harry Potter, teaching fractals through Islamic tiling, and ways to involve pupils in research and development that has real industrial applications.

Many delegates loved discovering how their colleagues in other countries used simple techniques to demonstrate more complicated concepts. For example, Spanish teacher Jose and Linda from Italy bonded over their love of different geometric forms. Linda explained how she used 3D pens, which extrude a small amount of plastic, to get her students used to manipulating surfaces in three dimensions in a very tactile and visual way – an approach that Jose described as "fascinating". Throughout the festival, the words of Stephanie Schlunk from the opening ceremony were being demonstrated: "Science on Stage is by teachers, for teachers."

Some of the attendees were also selected to give demonstrations and lectures or to hold workshops for smaller groups, including one tasty workshop from a Swiss representative who used molecular gastronomy to create an eggless chocolate mousse that used just melted chocolate, ice and a lot of whisking. And, of course, the festival feeling was enhanced by the national foods that everyone brought along and shared.

After a busy Friday that saw celebrations continue into the night, including biology-themed ceilidh dancing, the slightly tired participants gathered for the final day. All the participants at the international Science on Stage festival were already winners: they had been selected from among thousands of teachers across Europe and Canada for their innovative ideas. But there were additional prizes for some lucky participants (see box overleaf), before the details of the next festival were announced in a cloud of golden glitter. The 2017 Science on Stage festival will take place from 29 June to 2 July in Debrecen, Hungary.

Originally, Science on Stage was the brainchild of EIROforum[w1], the

General science

Primary

Image courtesy of Dirk Laessig

publisher of *Science in School*. The organisation is now funded mainly by Think Ing, an initiative of the German Association of the Metal and Electrical Industry Employers (*Gesamtmetall*), which aims to improve science teaching in Germany and Europe. If you would like to take part in your national event – and maybe even be selected to attend the next international festival – contact your national organisers via the Science on Stage website[w2]. The national calls will start from autumn this year. And if you want to see what was shared in London, take a look through the virtual poster fair from the event[w3].

Web references

w1 – 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*. For more information, see: www.eiroforum.org

BACKGROUND

The winning projects

All projects at the 2015 Science on Stage festival represented inquiry-based learning approaches and were judged based on how well they:

- promote students' interest in science;
- refer to everyday life;
- have a sustainable effect;
- are feasible in everyday school life and can be financed with reasonable expenses;
- promote inquiry-based learning.

The winners were:

- Diane-Marie Campeau from Canada, whose project 'The land is the teacher' used indigenous pedagogy, the land and its resources as a framework to do interdisciplinary science.
- Renata Rydvalová from the Czech Republic, whose project 'Honey kingdom' allowed primary-school and kindergarten children to explore the world of bees and so learn biology, maths, physics and chemistry.
- Gregor von Borstel, Andreas Böhm, Manfred Eusterholz and Andy Bindl from Germany, who developed their 'Bodyheater, heater meals and active O_2' experiments to integrate the teaching of various chemical concepts using real-world examples. An earlier version of the project was published in *Science in School* (www.scienceinschool.org/2011/issue18/lncu).
- Hans Mulder from the Netherlands, whose low-budget sea aquarium used inexpensive materials and allowed students to study the feeding habits of shellfish and *Nereis virens* (a harmless bristle worm) directly, instead of relying on dissection.
- Thierry Dias and Jimmy Serment from Switzerland, whose project 'Learning by doing in mathematics' offered several innovative, aesthetic and playful learning scenarios in mathematics, using origami, puzzles and large geometric structures to understand how different shapes fit together.
- And finally, Colin Inglis from the UK, whose project 'Natural alternatives to antibiotics: scientifically sound or muddled myth?' involved school children and suggested plants that are traditionally thought to have antimicrobial properties. The students then tested the essential oils to establish if they could be used as natural alternatives to antibiotics, before likely candidates were passed to the University of York, UK, for further analysis.

Image courtesy of QMUL/Gary Schwartz

w2 – To find out more about Science on Stage Europe and how you can get involved, see: www.science-on-stage.eu

w3 – The Science on Stage UK website hosts a searchable virtual fair for the 2015 festival where you can view the delegate posters, including all of the winning projects. See: www.scienceonstage.org.uk/exhibition2015/index.html

Laura Howes is an 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 to join *Science in School*.

General science

Primary

From smashing science to smashing stories

From a scientific career to the theatre: how Ben Lillie tells the stories behind the science.

By Jose Viosca and Laura Howes

Theatre image: courtesy of Mohammad Jangda (Humanities Theatre at the University of Waterloo); image source: Flickr
Hubble image: courtesy of NASA/JPL-Caltech; image source: Wikipedia

Two physicists walk into a bar and decide to put on a show. That might sound like the beginning of a joke, but describes the start of *Story Collider*, a series of shows in which scientists tell the stories behind their research. The project began after Ben Lillie and Brian Wecht, two particle physicists, performed a mix of comedy and personal science stories for audiences in New York, USA.

There is, it seems, a thirst for the stories that Ben and Brian began telling five years ago. *Story Collider* is still popular, with regular shows for the general public both in the USA and around the world, plus podcasts and videos on the website[w1]. At its core, you can see the founders' interest in exploring how science shapes people. "We live in a scientific world and this is exciting on its own, but it is also changing how we see ourselves and how we live in the world," he says. "One of the missions of our shows is to reveal the human side of science."

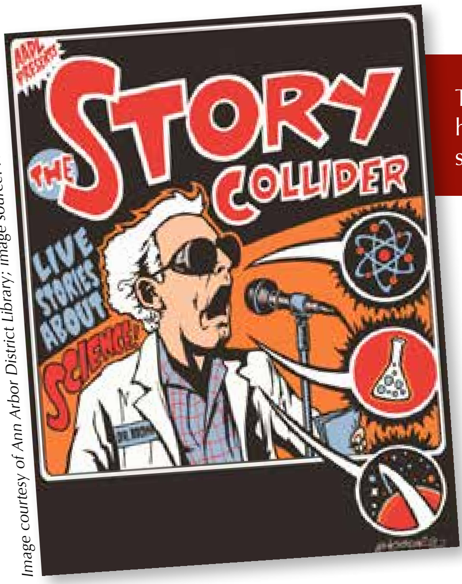


Image courtesy of Ann Arbor District Library; image source: Flickr

The *Story Collider*: human stories about science

An uncommon path

Over the past five years, Ben and the *Story Collider* team have collected incredible stories from researchers and other people who work in science. Among them are fascinating – and very varied – tales of how researchers became scientists.

"One of my favourite people is Stuart Firestein," says Ben[w2]. A professor of neuroscience, Firestein spent his 20s working as a theatre manager, focusing on Brechtian theatre, which focuses on analysing what is going on and involving the audience as part of the play. At the age of 30, Firestein realised that he was a terrible theatre manager, went back to college and began studying neuroscience, which Ben describes as "the same as Brechtian theatre but doing experiments".

When Firestein, who has recently retired from the biology department at Columbia University, USA, began teaching entry-level university classes on neuroscience, he realised that he was continually telling stories about things that are already known, whereas in research you focus on what you don't know. "So he said, 'Let's teach that'," explains Ben. Firestein started a weekly three-hour seminar class called 'ignorance', in which he invited colleagues to explain everything that they did not know in their field. Their contributions became a book called *Ignorance*, about how ignorance drives science; for Ben, this exemplifies how Firestein's theatre background brought a very different perspective to research.

Bridges between sciences and humanities

Firestein's career is an interesting mirror of Ben's own. After originally studying theatre in college, Ben quickly changed course, gaining a bachelor's degree in physics from Reed College and a PhD in theoretical physics from Stanford University, both in the USA. But today, Ben isn't in the lab analysing data. Instead, he works in the theatre district of New York City and around the world. "I realised that I really wanted to talk about people," says Ben. So he traded particle colliders for the *Story Collider*.

"Science and arts have a lot of similarities," says Ben Lillie. "But I'm equally fascinated about the differ-

General science

REVIEW

✔ **General science**
✔ **Ages 14–18**

Contrary to popular opinion, science, like art, is a creative subject. Scientists have to use known information to create novel investigative processes to determine the unknown. This interview with Ben Lillie explains how he is trying to bring science to the public by engaging them with stories told by scientists. Science is everywhere and should not be separated from daily life. The *Story Collider* website contains a wealth of inspirational, tragic and hilarious podcasts from more than 150 scientists about how personal events have shaped their careers. These short stories would be ideal to show students that not all scientists follow conventional routes and that life events can influence careers and research. It is well worth dipping into these podcasts and they would make an ideal start to a discussion on science and careers.

Shelley Goodman, UK

Image courtesy of EMBL Photolab/Hugo Neves

Ben Lillie

ences. People will say, 'in sciences and arts you need to be creative,' which is a true statement, but you are not entirely using the same definition of creative. The kind of creativity you need is different."

Ben is sure that science can benefit from the arts and vice versa. "The best scientists tend to have a broad range of interests. There is a fun statistic about the fraction of Nobel laureates who also play musical instruments being much higher than in the science population at large." There are also fields in which visual representations are very powerful, such as astronomy and biology.

For Ben, the mix of science and culture isn't limited to explicit links, as he explains by describing a recent visit to an art gallery. "I walked into a visual exhibit about music and nostalgia, and in the back of the gallery there was a giant image of the Hubble Ultra Deep Field. What is that doing there? So I walked up and I realised it was not the Hubble Ultra Deep Field; the artist had taken stage lights from the final performances of dead musicians and arranged them to look like galaxies seen by the Hubble Space Telescope. What was striking was that it was not an explicit science–art thing; the artist had just needed an image and the image he had reached for happened to be an astronomical one. That to me is a sign of success in getting science out into the culture, when science shows up in places you wouldn't expect it."

Keeping audiences engaged

"Our goal is to tell stories you don't typically hear," says Ben, and while he acknowledges that performing on a stage and teaching are not identical, there are some tricks that can be useful in both. "Start in the middle of an action," he advises. "Start with a question, start with some mystery and then slowly explore that."

Second, he adds, put the crucial bit of information right where it is needed. If you need to explain what 'dilithium' is, introduce it early on or create a mystery about it – but make sure you explain what it is before it becomes important.

Finally, Ben says, putting as much distance as possible between the mystery and the solution is key to keeping the audience engaged. "Whether this is a good thing to do for teaching, I don't know, really," Ben cautions, "but it is a great thing to do in a movie or in a entertainment setting. If you have a mystery that you can keep on adding bits of information to, that keeps the audience engaged."

Web references

w1 – Explore the *Story Collider* website at http://storycollider.org/

w2 – A podcast with Stuart Firestein's talk can be found on the *Story Collider* website[w1] at http://storycollider.org/podcast/2013-03-31

Resources

There are many videos of Ben's talks online, including this talk on the impact of personal stories: www.youtube.com/watch?v=iuX4I2KsZuw

Eva Amsen, the Outreach Director for *F1000Research*, is particularly interested in the link between music and science and has been describing her research as she works on a documentary about people who are both musicians and scientists. You can follow along on her blog at http://easternblot.net/category/musicians-and-scientists/

Jose Viosca is a neuroscientist turned science communicator who is interested in people, science education and everything that catches his attention. Find him on Twitter: @jviosca

Laura Howes is one of the editors 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 to join *Science in School*.

Image courtesy of Lestat (Jan Mehlich); image source: Wikimedia Commons

Smartphones in the lab: how deep is your blue?

Exploring coloured chemistry using smartphones

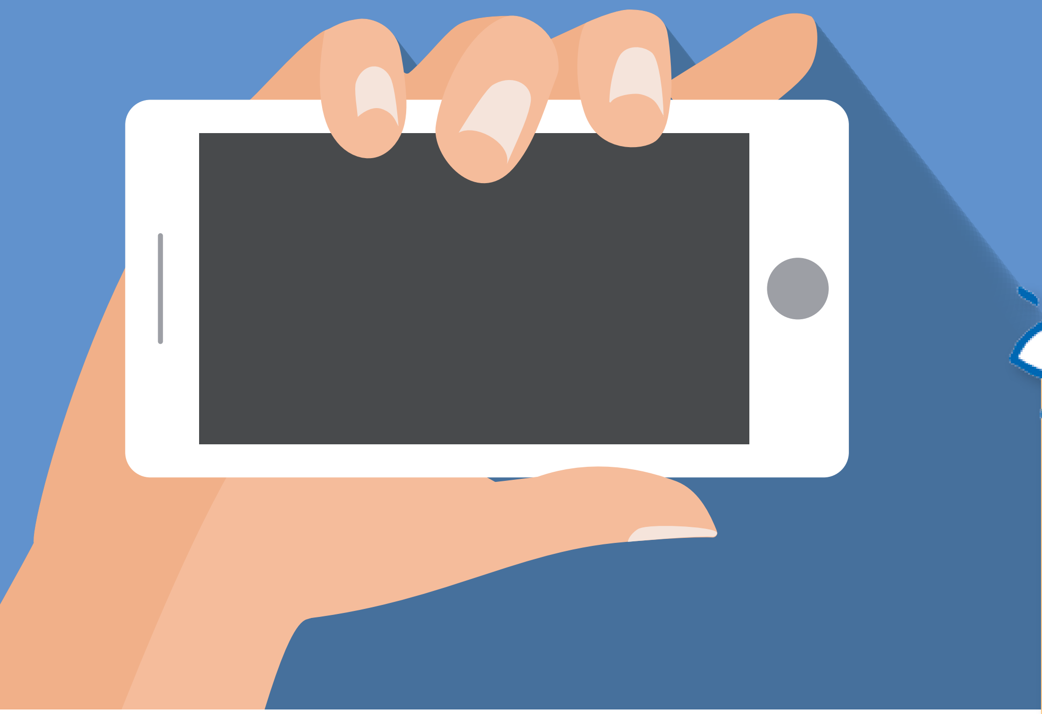


Image courtesy of OlgaLebedeva / iStockphoto

By Marc Montangero, Daniel Bengtsson, Márta Gajdosné Szabó, Miroslaw Los and Lilla Jónás

When copper is dissolved in an aqueous solution of nitric acid, the solution turns blue. The more copper is added, the more intense the colour becomes. But how can you work out exactly how much copper was used by only looking at the colour?

People know that when you dilute a coloured syrup, it turns lighter. This is because the absorption of light, which produces the colour, is proportional to the concentration of the dissolved colorant (according to the Beer–Lambert law). In this activity, students aged 13–18 test this law using free colour match apps on their smartphones.

This activity is intended for a chemistry lesson, but can be modified for a mathematics class. This activity gives students an opportunity to practice the scientific method. They have a question to answer – how much copper did my teacher dissolve? They must then choose what method to use before taking the measurements, collecting data, organising the data in a table, and making a graph to

REVIEW

✔ Chemistry

✔ Age 15+

I have seen this demonstration in my school from one of the authors, Marc Montangero. The article is a new approach to teaching the Beer–Lambert law without a spectrophotometer – a smartphone is used instead and so the necessary equipment is very simple. However, a special program has to be installed on any given smartphone.

This activity could be used to begin discussions when teaching molar and mass concentration; the relationship between colour and wavelength; the Beer–Lambert law; and the visible spectrum.

Maurice Cosandey, Ecole Polytechnique Fédérale de Lausanne, Switzerland estimate the amount of dissolved copper.

Here we suggest four different protocols:

- A classic cookbook protocol, which provides all of the details on how to carry it out.
- A protocol for a mathematics class, in which all the solutions have been prepared in advance; the students only make the measurements and carry out the analysis.
- An open protocol, in which the students receive a small amount of information and a question to answer.
- A co-operative protocol, which suggests collaboration between schools.

Chemistry cookbook protocol

The teacher or technician needs to prepare a copper solution of unknown concentration at least one day in advance (see box). After this preparation, the students do the work during the activity, which should take around 1.5 hours.

Make the reference scale

Materials

- 30 g copper nitrate hydrate ($Cu(NO_3)_2 \cdot 3H_2O$)
- Distilled water
- Three 100 cm^3 flasks

Procedure

1. Label the flasks 1, 2 and 3.
2. Take each flask and add 5, 10 or 15 g of $Cu(NO_3)_2 \cdot 3H_2O$. Calculate the exact masses m_1, m_2 and m_3 of pure copper in each flask.
3. Add water until the total volume is 100 cm^3; close the flasks and shake well. This makes the scale with numbers 1, 2 and 3.

Note: You can also replace $Cu(NO_3)_2 \cdot 3H_2O$, which is moisture sensitive, with hydrated copper sulfate ($CuSO_4 \cdot 5H_2O$ – do not change the quantities) or anhydrous $CuSO_4$ (use about 3.3 g, 6.6 g and 10 g in this case).

BACKGROUND

Making the copper solution of unknown concentration

Safety note: Nitric acid (HNO_3) is corrosive, so use gloves, glasses and a fume hood. The reaction of copper produces such large amounts of toxic gases that this must be done in the hood at least one day in advance.

Materials

- 1.5–3.5 g pure copper
- 7.5–17.5 cm^3 65% HNO_3
- Distilled water
- 50 cm^3 beaker
- 100 cm^3 flask

Procedure

1. Take between 1.5 g and 3.5 g of pure copper (note the exact mass, $m_{(Cu)}$).
2. Pour $5m_{(Cu)}$ cm^3 of 65% HNO_3 into a 50 cm^3 beaker (e.g. if you took 2 g of copper, use 5 x 2 = 10 cm^3 of nitric acid).
3. Add the copper (little by little if it is in powder form), close the fume hood and wait until all the copper has been dissolved.
4. After the copper is completely dissolved, add dropwise to 30cm^3 of water, then transfer the solution to a 100 cm^3 flask, dilute with water to 100 cm^3 and close the flask. Stir well.

Measure the H-values with a smartphone

Materials

- Flasks 1–3 (from the 'Make the reference scale' procedure above)
- Smartphone with Color Grab (android) or ColorAssist Free Edition (iOS) app installed[w1]
- Large sheet of white paper
- Pencil

Procedure

1. Put flask 1 on a piece of white paper (the paper should rest against a vertical support so that it forms

Image courtesy of Science on Stage

Making the unknown copper solution

both a white base and background) and use the pencil to mark the exact position of the flask on the paper.

2. Fix your smartphone on the table so that the centre of the camera points at the largest part of the flask (the viewing angle should be horizontal).
   The distance between the background and the flask should be about 4 cm, and between the smartphone and the flask should be about 14 cm.
3. Use the app on your phone to read the H-value (of the HSV or HSL colour model, explained further down in the article) and note it.
4. Repeat this with flasks 2 and 3 using the same geometry.

Identification of the unknown solution

1. Use the values for m_1, m_2, and m_3 calculated earlier to plot a graph of the H-value as a function of the mass of copper. The H-value is proportional to the concentration of the solute and so this graph should be a straight line.
2. Using the protocol as above, measure the H-value of the unknown solution.

Image courtesy of Science on Stage

Students measuring the H-value with the smartphone

3. Use your graph to determine the mass of copper in the unknown copper solution.

Mathematics class protocol

The teacher makes the four solutions in advance as above and labels the reference scale flasks with the equivalent mass of pure copper on the flasks. The equipment that the students will probably need or ask for to carry out a fair test should be prepared. This experiment should easily be completed in around 45 minutes.

Procedure

1. Install one of the colour apps on your phone and work out the best way to measure the colour. Try to learn how to pause the measurement and how to use the smartphone's flash to assist with the measurement.
2. Measure the H-values of the solutions in the three flasks, which are labelled with the mass of copper that they contain.
3. Draw a graph of the relationship between the H-value and the mass of copper. The more copper the solution contains, the darker it is.
4. A fourth flask contains an unknown mass of copper. Measure the H-value of this solution and use the graph to determine the mass of the copper in this flask.

Open protocol

Ask your students to install the app and tell them how to use it. Give them the three flasks with the masses of copper written on them and ask

Image courtesy of Science on Stage

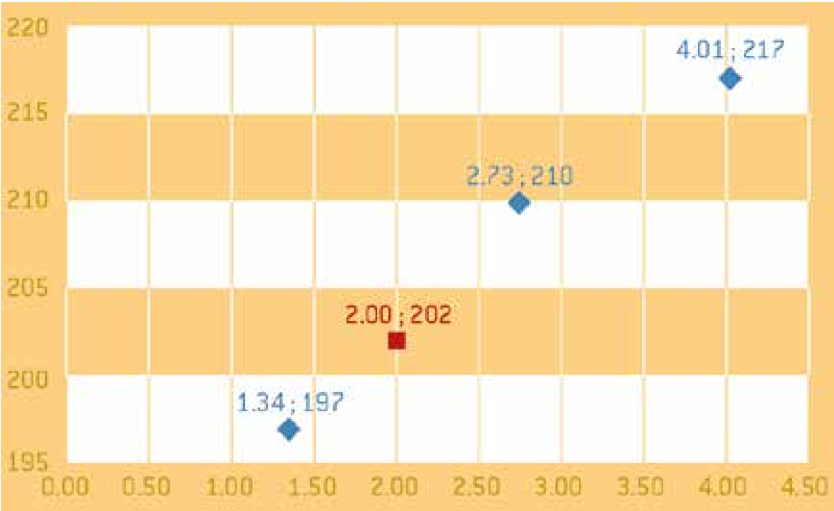


Image courtesy of Science on Stage

Plotting the relationship between H-value (*y*-axis) and the mass of copper (*x*-axis)

them to devise a fair test to determine the mass of copper in the fourth flask using the H-value.

Co-operation option

The students carry out the experiment and also use their smartphones to make a video that explains how to do the experiment. This video is sent to another class (in the same school or internationally), who should then follow the same protocol.

How the apps work

The colour match apps measure colour using the phone camera and express its values in terms of a colour model (RGB, HSV, LAB, etc.). This can be useful when you want to buy paint of a particular colour: you can measure the colour with your smartphone and ask the paint shop for the same colour.

The RGB system is the most commonly used colour model (it's how colours are expressed on your computer screen, for example), but these values are not related to the wavelength of the colour. Instead the RGB system uses only one wavelength of each primary colour. The hue value (H) of the HSV or HSL colour model distinguishes between different blues (navy blue, denim blue, cornflower blue, etc.). This value can be used instead of absorption in a certain range of concentrations.

Although we did not try it, we think the same procedure could be used with other coloured solutions (e.g. potassium permanganate or food colouring solution). You would have to identify the range of concentrations for which the H-value is proportional to the concentration of the solution.

We have tried to use this procedure with the well-known red cabbage colour experiment but it did not work because the wavelengths of the different colours of red cabbage do not vary linearly with pH. The app was not even able to differentiate the hues between pH 3 and 10, and could therefore only give us the basic colour of red cabbage (pink, purple, green or yellow) from which we could deduce a range of possible pH values. As we usually do that by eye, it makes no sense to use the smartphone for this purpose.

Acknowledgement

This activity was first developed by Science on Stage and published in their collection of articles on using smartphones in science teaching, iStage 2[w1]. At a workshop in Vienna, Austria – and later over e-mail and the open-source learning platform, moodle – 20 teachers from 14 European countries worked together to develop 11 teaching units that show how smartphones and apps can be used in maths, physics, chemistry or biology classes.

iStage 2 provides a unique summary of practical examples from all over Europe of how to integrate smartphones in daily classes. The brochure is the second publication of the iStage series that deals with new digital media in STEM classes. It is available online, and in print in English and German, funded by SAP. As well as the print and online versions, the brochure can be downloaded as an ibook.

Web reference

w1 – All of the materials and apps can be found on the Science on Stage website. See: www.scienceonstage.de or use the direct link: http://tinyurl.com/q65zxuc

Marc Montangero, Daniel Bengtsson, Márta Gajdosné Szabó, Miroslaw Los and Lilla Jónás are secondary-school teachers from all over Europe who worked together to develop this activity as part of the Science on Stage iStage 2 project.

Chemistry

Physics

Science under your skin: activities with tattoo inks

Why not make science relevant to your students' lives with some simple practical activities using tattoo inks?

By Marc Stuckey & Ingo Eilks

In recent years, tattooing has become more and more popular, especially among young people. Why? Fun, a statement of personal identity, and peer pressure are all potential motivations. However, the decision to get a tattoo should not rely simply on social or aesthetic reasons. Other considerations should include health concerns about the ingredients of tattoo inks, the risks of unclean tattooing practices, potential costs for tattoo removal, and the minimum age for getting a tattoo without parental permission.

Behind all the practices of tattooing is a lot of science: from the bio-


Image by Michael Deschenes. Licensed under Public Domain, via Wikimedia Commons

Tattoos with multiple colors imply that several inks are injected under the skin and potentially react with the body.


Image courtesy of Brainsil / iStockphoto

chemical effects of tattoo inks to the chemistry of pigments. To make science more relevant to the lives of our students, we have developed a lesson plan for lower-secondary schools that uses hands-on activities related to tattoos (Stuckey et al, 2013; Stuckey & Eilks, 2014; Stuckey & Eilks, 2015). Here we present four of the activities to investigate the contents and thermal stability of tattoo inks.

Detection of metal ions in tattoo inks

Some of the components of tattoo inks, such as heavy metal compounds, can be harmful to health. A simple flame test can be used to indicate the presence of different metals in tattoo inks.

Materials

Each group of students will require:

- Wooden splints
- A Bunsen burner
- Crucible tongs
- A selection of tattoo inks (colours and brands)

Procedure

1. Dip the end of a splint into a small drop of tattoo ink.
2. Using the crucible tongs, hold the splint in the flame of the Bunsen burner.

Flame test on blue tattoo ink

Image courtesy of the authors

3. Record the colour of the flame. The colour corresponds to particular metal atoms in the ink. For example, blue tattoo inks regularly produce a green flame due to the presence of copper atoms.
4. Cut off the used end of the splint or use a new one to repeat the experiment with a different ink sample.
5. Suggest which metals are contained in which inks.

Discuss with your students whether there are allergy or safety concerns about these metals. For example, red inks containing chromium salts can often cause allergic reactions.

Identifying the compounds in the inks

While there is a European regulatory framework for tattoo chemicals, not all coutries have signed up to it. In some countries, such as Germany, tattoo inks must be licenced and comprehensibly labelled. Not all brands of tattoo ink provide this level of detail, however; although they are not licenced for use in Germany, they can be bought cheaply over the Internet. If your tattoo inks are comprehensibly labelled, your students can investigate their contents in more detail.

1. Referring to the labels, list the colouring agents in the inks, including the 'CI' number.

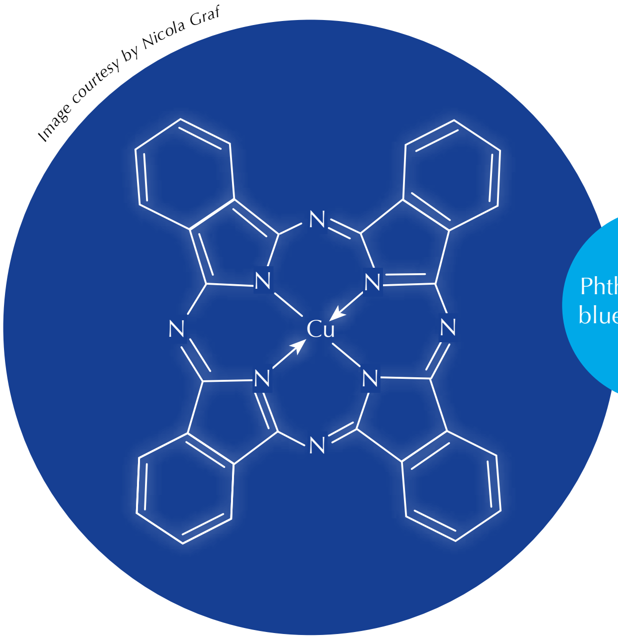
REVIEW

- **Chemistry**
- **Biochemistry**
- **Personal, social, health and citizenship education (PSHCE)**
- **Ages 14–16**

Although not yet ubiquitous, tattoos have become more prevalent in recent years and getting tattooed may now be regarded as a rite of passage into adulthood by many school pupils. The activities described by Stuckey and Eilks highlight an additional aspect of tattoos that such pupils need to consider when deciding whether or not to "get inked," namely the chemical compositions of the inks that are implanted into the skin during tattooing.

For the science teacher, this tattooing context shows the contemporary relevance of methods of chemical analysis and toxicology studies: paper chromatography and thin layer chromatography may be carried out in school science laboratories, provided that the solvents required are common. Questions about the regulation of consumer chemicals are also raised, and could be a topic for research by pupils. Furthermore, these investigations provide an opportunity to enter into discussions about the personal, legal and health issues associated with tattooing, which may also lead into discussions about self-image, peer pressure and decision making. A science teacher considering carrying out these investigations would be well advised to speak to/involve colleagues involved in their school's personal, social, health and citizenship education programme, (or equivalent) in order to gain some insight into the pastoral issues that could arise.

Matthew Fletcher, Kingswood School, UK



Phthalocyanine blue (CI 74160)

2. Consult Colour Index[w1], an online reference database of dyes and pigments, to determine the identity of the chemicals. For example, CI 74160, which is found in some blue tattoo inks, is the pigment phthalocyanine blue, a copper complex.
3. How do these results compare to the results of the flame tests in the previous activity?
4. What can you find out about these pigments? For example, are there any health concerns? What other purposes are the pigments used for? Some tattoo pigments, for instance, are also found in car finishes.

Garden cress exposed to red tattoo ink

If your tattoo inks are not comprehensibly labelled, why might this be a problem?

Stability of tattoo inks

Students can also investigate the thermal stability of different tattoo inks. It is important that the inks are thermally stable to avoid changes once they are tattooed into the skin.

Materials

- Porcelain crucibles with lids
- Crucible tongs
- A tripod
- Metal gauze
- A Bunsen burner
- A selection of tattoo inks

Image by The Dame; image source: via Wikimedia Commons

Image courtesy of the authors

Certified and well labelled tattoo inks (left) and cheap alternatives available online (right)

Procedure

1. Put a drop of one ink into a porcelain crucible.
2. Put a lid over the crucible and place it on the gauze above the Bunsen burner.
3. Heat the crucible for 30 seconds, then remove from the heat using the tongs.
4. Remove the lid and record any changes in the appearance of the ink drop.
5. Repeat for the other inks.

Many tattoo inks are quite heat resistant but others rapidly decompose into a muddy brown mass. When tested by our students, some of the cheap inks bought via the Internet decomposed rapidly. There are also reports of some inks losing their colour when exposed to sunlight.

Investigating the impact on enzyme activity

The potential health impact of tattoo inks can be investigated by looking at their effects on enzyme activity.

Image courtesy of the authors

Red tattoo inks heated for 30 seconds.

Materials

- Beakers
- Petri dishes
- Aqueous hydrogen peroxide (3%)
- Raw potatoes
- A selection of tattoo inks, diluted with water to a thin, water-like, consistency.

Procedure

1. Carefully cut a potato into pieces around $1 cm^3$.
2. Place one piece of potato into one of the diluted tattoo inks and leave for 10–15 minutes.
3. Remove the piece of potato and place it in a Petri dish of hydrogen peroxide solution.
4. Observe what happens.
5. Repeat for the other tattoo inks.
6. Place one piece of potato that has not been treated with ink in the Petri dish full of hydrogen peroxide solution.

Potatoes contain the enzyme catalase, which catalyses the decomposition of hydrogen peroxide into water and oxygen. The piece of potato that was not treated with tattoo ink will react strongly with the hydrogen peroxide solution, causing effervescence as oxygen is generated. The reactions of the treated pieces of potato will vary, as many of the metal ions used in tattoo inks (such as copper) inhibit the action of catalase.

7. How might the observed effects on the potato pieces translate to the human body? Are the effects cause for concern?

References

Stuckey M et al (2013) The meaning of 'relevance' in science education and its implications for the science curriculum. *Studies in Science Education* **49**: 1–34. doi: 10.1080/03057267.2013.802463

Stuckey M, Eilks I (2014) Raising motivation in the chemistry classroom by learning about the student-relevant issue of tattooing from a chemistry and societal perspective. *Chemistry Education Research and Practice* **15**: 156–167. doi: 10.1039/C3RP00146F

Stuckey M, Eilks I (2015) Chemistry under your skin? Experiments with tattoo inks for secondary school chemistry students. *Journal of Chemical Education* **92**: 129–134. doi: 10.1021/ed400804s

The online supporting information of this article includes instructions for performing the experiments.

Resources

German-language instructions for carrying out these and other activities related to tattoos can be downloaded free of charge from the Profiles Bremen website. See: http://tinyurl.com/pwy64k9

Full teaching and learning materials for the activities (in German) can be found in:

Stuckey M, Eilks I (2014) Tätowierungen - Chemie, die unter die Haut geht. *RAABits Chemie Sekundarstufe I*, February: 1–30

Web reference

w1 – The Colour Index is an online reference database of dyes and pigments. See: www.colour-index.com

Marc Stuckey is a teacher at the IGS Wilhelmshaven (comprehensive school), Germany, and a former student in Ingo Eilks' chemistry education research group based at the University of Bremen, Germany.

Together they developed this activity and are grateful for the generous support of the Profiles project funded by the European Union under the 7th Framework Programme for Research Funding, Science in Society, under grant agreement number 266589.

Image by The Dame; image source: Wikimedia Commons

Image courtesy of Karen Haydock

Do leaves need chlorophyll for growth?

When next teaching photosynthesis, try these simple experiments with variegated plants.

By Kranti Patil, Gurinder Singh and Karen Haydock

Are your students familiar with the following statements?

Plants make their food by photosynthesis.

Leaves are green because they contain a green pigment (chlorophyll).

Photosynthesis cannot occur without chlorophyll.

If students believe these statements, then what will they think when they see a white leaf? They may be confused and wonder how a white leaf – which does not appear to have chlorophyll – can make its own food. They may ask, "How does a white leaf survive?"

Here, we describe some simple ways of using variegated plants (e.g. variegated bhendi, *Talipariti tiliaceum)* to investigate the relationship between the presence of green pigment, food production and leaf growth.

While investigating these relationships, we might make two hypotheses. One is that the white leaves will be stunted because they contain less chlorophyll, which is needed for photosynthesis to occur. An alternative hypothesis is that the white leaves, or the white parts of leaves, will not be stunted because the leaves still contain a dense network of veins that

A variegated bhendi shrub, *Talipariti tiliaceum*

Image courtesy of Gurinder Singh

Image courtesy of Karen Haydock

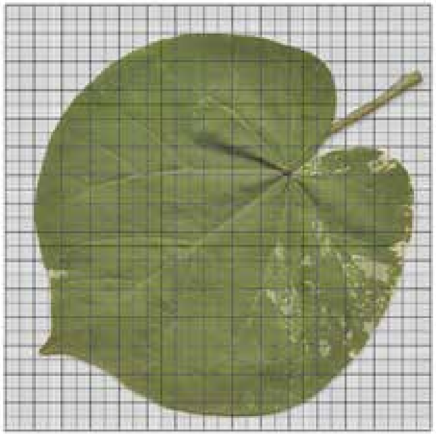


Figure 1: Placing the leaf on a piece of graph paper helps measure the area

can carry food from one part of the leaf to another, or from green leaves to white leaves.

The following activities provide different ways for these two hypotheses to be investigated. The activities arose from a research project to investigate how school students learn science when they ask their own questions and try to answer them by planning and doing their own investigations. We initially designed experiments based on questions that we thought students might ask when presented with a variegated bhendi. Next, we interacted informally with some students to see what questions they actually asked. We then organised a three-day workshop for students aged 11–13, during which they carried out some of the activities that we had devised and also investigated some of their own questions (including "Are white leaves thinner?" and "Do white leaves wilt faster?").

Some of the activities take no more than half an hour; other investigations can run over several days or months. They all require no more than basic school equipment and are aimed at students aged between nine and 14; in some cases they can be adapted to students as old as 19.

REVIEW

- **Biology**
- **Maths**
- **Photosynthesis**
- **Ages 9–19**

This article suggests many practical activities that can be used to teach how photosynthesis works. Not only will the students gain a deeper understanding of photosynthesis, the measurements and calculations involved in some of the experiments could be used to integrate science and mathematics. The article could also be used as a starting point to explain the scientific method and how scientists work.

Mireia Güell, Spain

Are white leaves smaller than green leaves?

Suitable for students aged 9–14, this activity is a good way to integrate science and mathematics as it motivates students to learn how to measure the surface area of odd-shaped objects.

1. Take representative samples of white and green leaves.
2. Measure and record the size of each of the leaves.
3. Compare the measurements of the white and green leaves.

Allow your students to suggest their own methods to determine the size of the leaves – these might include comparing sizes by placing one leaf over another or using graph paper to measure the surface areas (figure 1).

We found that the answer may be biased if an inadequate sampling method is used. Young students sometimes do not understand that finding just one white leaf that is smaller than one green leaf is not adequate evidence to make a generalisation. If all the students in a class make measurements and there is variation in the results, then the students may confront the contradictions they find. Even then, some students may disregard incongruent evidence, thinking that it is 'wrong'. This could be an appropriate occasion to discuss elementary statistics and probability. Students could discuss what kind of sampling would be 'fair': for example, purposely choosing leaves of certain sizes, picking all or a certain number of the leaves from one branch, or using a particular number of leaves.A truly meaningful investigation would require fairly sophisticated statistics, more suitable for older students (aged 16–19).

Image courtesy of Karen Haydock

Before and after of branches of white, green, or mixed white and green leaves placed in soil overnight.

Image courtesy of Karen Haydock

Varigated leaves are very varied

Image courtesy of Karen Haydock

Figure 2: Folding a leaf to find out whether the mostly green side is larger than the mostly white side

Image courtesy of Karen Haydock

Figure 3: The bulges on a bhendi leaf correspond to greener areas

Is the white half of a leaf smaller than the green half?

Some leaves have one side that is noticeably whiter than the other side. If the shortage of green pigment causes stunted growth, we might expect the whiter side to be smaller. This question can be answered without even plucking the leaves but by gently folding each leaf in half along the midrib and observing which side is larger (figure 2). This is an easy activity, even for students as young as 9.

We tested dozens of variegated bhendi leaves, and could not find a single leaf in which the half that clearly contained more white was as large as the half that contained more green, suggesting that the white parts of leaves do have stunted growth.

We also noticed that bulges on the margins of variegated leaves corresponded to green areas (figure 3). This supports the conclusion that the intervening white areas have stunted growth. It would be interesting to see whether these observations hold for other variegated plants.

Do white leaves weigh less than green leaves?

If white leaves produce less food, we might expect them to weigh less.

1. Find and pick white and green leaves of the same size. (This is not easy.)
2. Using an electronic balance, record the weight of each leaf.
3. Dry the leaves and then record their weights again. Make sure that you know which leaf is which.

To our surprise, we found that some fresh green leaves weighed considerably less than white leaves of the same size. However, after the leaves had been dried, the white ones usually weighed less than the green ones. This indicates that the white leaves initially contained more water, but that the green leaves had more bulk (dry weight). Apparently the white leaves had produced – or at least stored – less food.

Are white leaves thinner than green leaves?

White leaves might be expected to be thinner than green leaves.

1. Pick pairs of white and green leaves of similar size.
2. With eyes closed, one student should be presented with a pair of leaves (figure 4). Which leaf feels thicker – white or green?
3. Repeat until all the pairs of leaves have been tested.
4. Each pair of leaves could be tested by a different student. Alternatively, you could also investigate the objectivity of the method by having each pair of leaves tested by several students.

We concluded that the white leaves are generally thinner than the green leaves, perhaps because they are not

Image courtesy of Karen Haydock

Figure 4: Testing white and green leaves to find out which is thicker

Image courtesy of Karen Haydock

BACKGROUND

Alternatives to bhendi

We used a variegated variant of *T. tiliaceum*, a plant that is frequently grown here in Maharashtra, India, and is commonly known in Marathi as bhendi (not to be confused with the vegetable bhendi or okra, the flowers of which are similar, hence the name). There are, however, many other variegated varieties of ornamental plants that can be used.

- Variegated gingko (*Gingko biloba variegatum*)
- Variegated maples (e.g. *Acer davidii Hansu suru* or *Acer platanoides* variegatum)
- *Aralia elata* 'Aureovariegata'
- Clown fig (*Ficus aspera*)
- Some varieties of *Caladium*
- Some varieties of *Dracaena*
- Some species of *Hosta*.

We obtained slightly different results when we investigated different species. This makes our conclusions all the more interesting: perhaps not all variegated leaves have obviously stunted growth in white areas?

Image courtesy of Karen Haydock

Before and after of branches of white, green, or mixed white and green leaves were placed in water overnight.

able to make enough food and they do not get enough food from other leaves.

Do white leaves wilt faster than green leaves?

If white leaves rely on food provided by green leaves, white leaves might be expected to survive less well once removed from the plant.

1. Cut one branch that has only green leaves, one that has only white leaves, and one that has both green and white leaves.
2. Place the three branches in bottles of water and leave them overnight.
3. Optional: replicate steps 1 and 2 using warm water for one set of three branches and cold water for another three.
4. Optional: cut three additional branches and leave them in watered soil overnight
5. How do the leaves on the different branches compare the next day?

We found that the branches of white leaves were much less turgid than the branches of green leaves, while the branches of both white and green leaves were somewhere in between, confirming our prediction.

Our conclusions

Overall, our conclusion was that the white areas of variegated bhendi leaves do have stunted growth. Although the white leaves clearly receive food from the green leaves via the plant's transport system, this is apparently not sufficient to compensate for their reduced photosynthetic abilities.

How then do variegated plants survive? The simple answer is probably that we humans maintain them artificially. Can your students find any examples of variegated plants existing in the wild?

Image courtesy of Karen Haydock

Now it's your turn

We hope this article inspires you to try these and similar activities. For example, what other questions could your students explore using bhendi or other variegated plants?

We would be interested to hear how you adapt them to your teaching environment and to learn about other experiments you might have performed using variegated plants at school. We invite you to visit the online version of this article and leave your comments[w1].

Web references

w1 – To read this article online and contribute to the comments section, see: www.scienceinschool.org/2015/issue33/leaves

w2 – For more details of Karen Haydock's teaching, research and

Image courtesy of Gurinder Singh

Image courtesy of Karen Haydock

Placing branches in soil

publications, see her website at: www.khaydock.com

Resources

For more information on variegated leaves, see the general botany section of the website of the Mildred E Mathias Botanical Garden, based at University of California, Los Angeles, USA: http://tinyurl.com/qgpl6y2

You can also find out more about variegated plants on the Union County College website: http://tinyurl.com/p2m7vgq

For a library of images of variegated plant leaves, see: http://tinyurl.com/ojpu9rr

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At the time this work was done, all three authors were members of Homi Bhabha Centre for Science Education (HBCSE), which is part of the Tata Institute of Fundamental Research in Mumbai, India.

Kranti Patil was working as a project assistant after completing her MSc in horticulture.

Gurinder Singh is doing a PhD in science education, studying how middle-school students learn science when they have the opportunity to define their own questions to investigate or even their own topics and contexts for exploration.

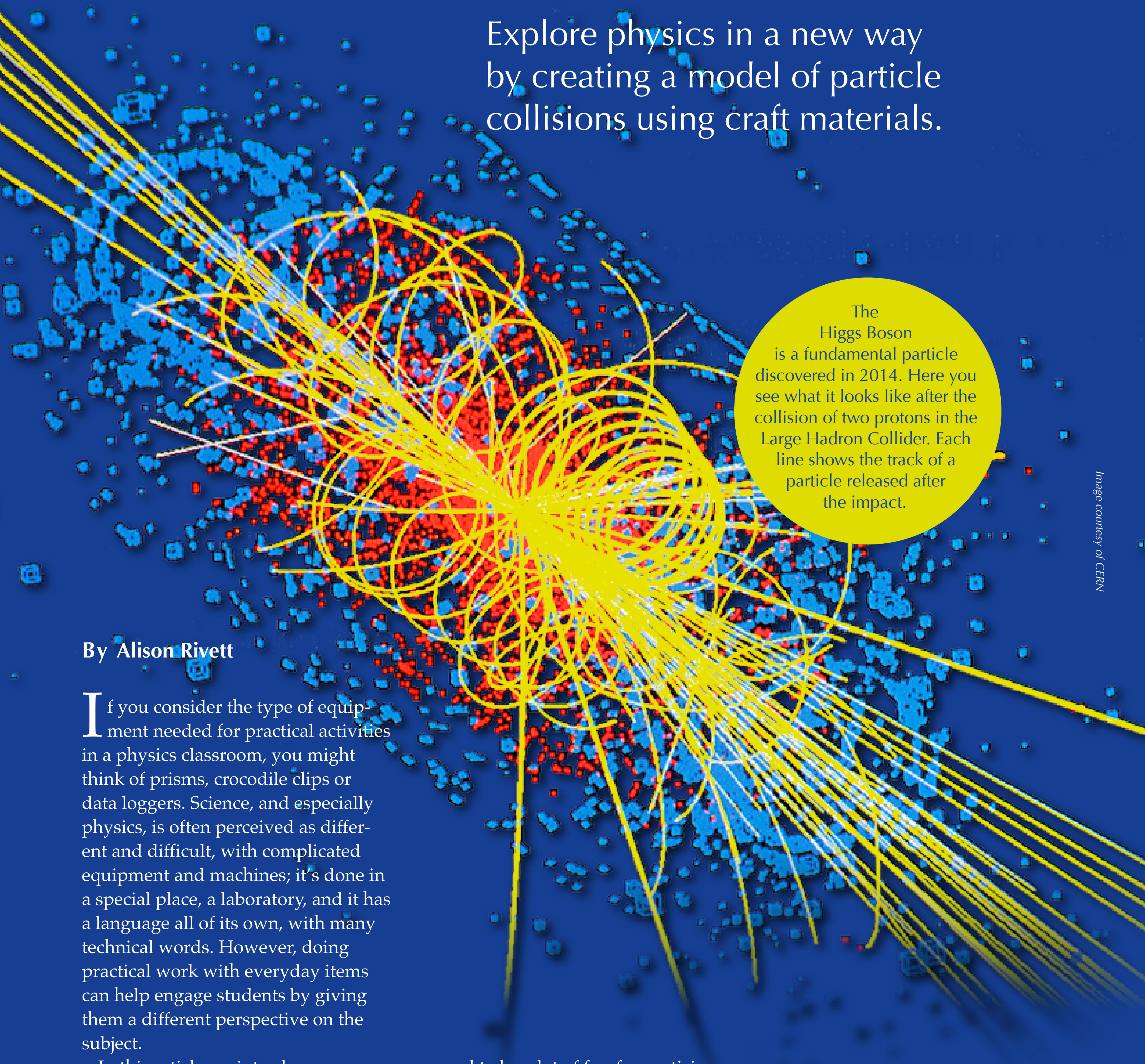
Karen Haydock is a faculty member and has been working in India since 1985 as a researcher, educationist, scientist, teacher and artist, after completing her PhD and postdoctoral studies in biophysics in the USA[w2]. She and Gurinder are writing a research paper on how students ask and answer their own questions, which includes some findings that emerged from the three-day workshop mentioned in this article.

Image courtesy of Gurinder Singh

Examining a bhendi shrub

Glitter, glue and physics too

Explore physics in a new way by creating a model of particle collisions using craft materials.



The Higgs Boson is a fundamental particle discovered in 2014. Here you see what it looks like after the collision of two protons in the Large Hadron Collider. Each line shows the track of a particle released after the impact.

Image courtesy of CERN

By Alison Rivett

If you consider the type of equipment needed for practical activities in a physics classroom, you might think of prisms, crocodile clips or data loggers. Science, and especially physics, is often perceived as different and difficult, with complicated equipment and machines; it's done in a special place, a laboratory, and it has a language all of its own, with many technical words. However, doing practical work with everyday items can help engage students by giving them a different perspective on the subject.

In this article we introduce an activity using art materials. We originally designed it to be used at public events, like festivals and science fairs, but the mix of creativity and science proved to be a lot of fun for participants of all ages, and teachers who saw their enthusiasm were keen to replicate this enjoyment in the classroom.

Crafting collisions

Researchers often use models to explain phenomena and observations, but these are still just theoretical ideas and only described in words, or perhaps pictures. Using simple craft materials to represent some physical aspect of a process or object can be an excellent way to develop an understanding of abstract concepts. Hands-on activities can also engage students who may otherwise lose interest in what they perceive as a dry, academic subject.

Creative activities in the science classroom are appealing because of their novelty. Unusual activities create 'situational interest' – a temporary interest that is triggered spontaneously by the external environment, for example through curiosity or enjoyment (Schraw et al, 2001). Stimulating these reactions in the classroom is a way of hooking students' attention and getting them to think.

This activity addresses subatomic particle physics and how scientists establish knowledge in this field[w1]. It can help students to learn about and understand the standard model of particle physics and the search for the Higgs boson at the Large Hadron Collider (LHC) at CERN. The activity does not create much mess and can be done in a reasonably compact space. It works well with secondary school students but also appeals to older primary school pupils (although the concept of sub-atomic particles may be very new and challenging for them).

Image courtesy of Sam Durbin

The basics of subatomic particles

First discuss the basics of subatomic particles. What is all matter made of? What is inside an atom, a proton and a neutron? Everything around us, from galaxies, the Earth, even ourselves, is made of atoms. Despite the fact that we cannot see them by eye, atoms are not the smallest level of matter. Atoms themselves are composed of tiny particles, which in turn are made of tinier particles that group together, and so on… and we still do not know where it finishes.

That is one of the reasons why scientists are still exploring what comprises atoms: what forces keep the particles linked and whether there are more particles to be discovered. One way that scientists have to explore atoms is by smashing particles together at almost at the speed of light using particle accelerators like those at CERN. Ask your students what they think might happen when particles are smashed together very quickly.

Such collisions may break down atoms into their constituent particles, or existing particles may fuse to create bigger particles. These may resemble what existed millions of years ago at the beginning of the Universe when all its matter and energy were concentrated in a tiny space. Scientists can observe the pattern of the particles produced by a collision and use this to determine what they are by the way they move. Analysing the debris from particle collisions, therefore, allows scientists to identify what new parti-

REVIEW

✔ Physics
✔ Ages 10–15

This article presents a practical activity aimed at exploring high-energy collisions between particles. A model of visualising beam collisions and new particle creation is presented through pipe cleaner and pom-pom mobiles. This activity can be easily prepared and carried out in a classroom with pupils aged 10–15, but it will also be of interest during school or science fairs for participants within the same age range. The required materials are cheap and readily available and the instructions are easy to follow (but read them twice!). This is a golden opportunity to introduce particle physics – and why not Feynman diagrams – from a qualitative standpoint. The leaflet available online[w1] will be very useful, and a visit to www.HiggsHunters.org is strongly encouraged!

Davide Vité, Cycle d'orientation de Cayla, Geneva, Switzerland

Physics

Images courtesy of IOP - Institute of Physics

cles have been produced. See Landua 2008a and Landua 2008b for more details of how particle accelerators work and how they can help scientists understand the origin of the Universe and what it is made of.

Creating a particle collision mobile

In this activity, students create a model depicting the products created when two particles are smashed together in a particle accelerator. The particles will be represented by coloured beads, their trajectories by pipe cleaners, and the products of the collision by pom-poms. In this way, the craft model will help the students to visualise the normally abstract world of particle physics.

Materials

- Coloured elastic thread (about 20 cm)
- Coloured beads
- Pipe cleaners
- Pom-poms
- Paper tags
- Glue
- Scissors

Procedure

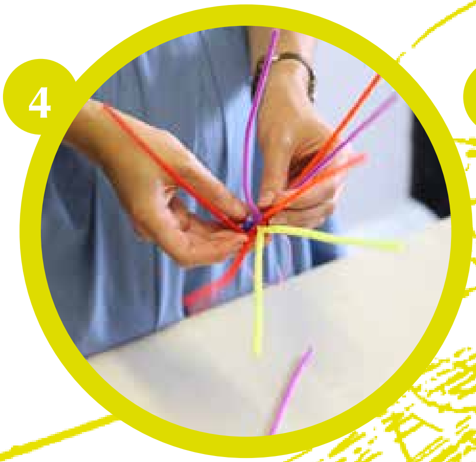
1. Thread two beads onto the elastic thread. These beads represent the colliding particles.
2. Using the elastic thread, tie a double knot around the beads. Tie another knot towards the ends of the elastic so you have a large loop.
3. Push several pipe cleaners through the small elastic loop and around the beads.
4. Bend the pipe cleaners in half around the small loop of elastic, then twist the strands together.
5. Shape the ends of the pipe cleaners into particle tracks.

Explain to your students why different particles follow different paths depending on their energy, charge and mass. Lighter particles have longer tracks while heavy particles have shorter tracks. The tracks of charged particle are curved, whereas neutral (uncharged) particles travel in straight lines. Particles with low energy follow spiral paths. Some particles may even follow branched paths.

Trajectory	Particle	Description
Long straight tracks	Photon	Pure energy
Short straight tracks	Neutrino or anti-neutrino	Small and light
Long curved tracks	Muon or anti-muon	Larger and charged
Short curved tracks	Electron or positron	Smaller and charged
Spiral tracks	Pion	An up–down quark pair
Jets (tracks starting together then branching out)	Quark pairs and gluons Z-bosons and W-bosons	Gluons stick quarks together Heavy particles that carry force

Table 1: Detailed trajectories of each particle type

Images courtesy of IOP - Institute of Physics



Show your students a couple of examples and then let them discover the remaining types once they have finished building their mobile.

6. Fix pom-poms to the end of the pipe cleaners using glue or by curling the pipe cleaners round the pom-poms.

Put results together: has anyone 'found' the Higgs Boson?

The last step in creating the particle mobile is to attach labels to the particles. To guide the labelling, provide the students with something similar to table 1, which specifies the exact trajectories of each particle type.

Once the students have added the labels to the particles in their models, discuss the different types of particles they have made. Perhaps they came up with a trajectory that does not appear in the table. If so, you can discuss what happens in particle accelerator experiments when new trajectories are found. Ask the students to give a name to their newly discovered particle.

Now that students have made the subatomic particles visible, you can extend the discussion, for example to cover what the Higgs boson is (see Hayes, 2012).

Teaching science through craft

The finished pieces can be displayed in the classroom or around the school to highlight the topic of particle physics to the school community, in the same way that artwork is exhibited publicly. Alternatively, students can take their creations home to prompt discussions about science with their families. The models are also easy to replicate should your students wish to show their parents or siblings how to make them too.

These craft activities make excellent outreach demonstrations, for example at a school open evening or science fair. Students can demonstrate the activities to their peers, younger children or visitors. This is an excellent opportunity to boost students' confidence and communication skills and allow them to share an enthusiasm for science.

An evaluation of the activity when used with the public (Durbin, 2011) showed that the combination of craft-based creativity with facilitated discussion results in increased understanding and interest. Similarly, in the classroom, allowing students to use their own imagination when exploring a topic captures their interest and helps them to understand it. Above

Image courtesy of the Science & Technology Facilities Council (STFC)

Visualisation of a proton-proton collision during the CMS experiment at CERN all, by making the abstract more comprehensible, the wonder of science can be shared and enjoyed by everyone.

Acknowledgement

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This article is freely available online and can be found at: http://tinyurl.com/nqx2473

Web reference

w1 – Instruction leaflets about this and two additional craft activities exploring galaxies and planets can be found on the Institute of Physics website (www.iop.org) or via this direct link: www.tinyurl.com/creativephysics

The three activities are suitable for a wide range of ages and do not require any pre-existing ability. The science behind the activities involves topics that are regularly in the news and still being actively researched, providing an opportunity to make links with real-world physics.

Resources

Further pictorial instructions on the particle physics model can be found on the Physics.org website. See: www.physics.org/creativephysics

To learn more about CERN and the search for the Higgs boson, see: www.cern.ch

The CERN education site provides lesson plans and resources on particle physics. See: http://education.web.cern.ch/education

To build your own particle accelerator, see:

Brown A, Merkert J, Wilson R (2014) Build your own particle accelerator. *Science in School* **30**: 21–26. www.scienceinschool.org/2014/issue30/accelerator

Encourage your students' interest in these topics with citizen science projects from the Zooniverse, which enable your students to discover their own Higgs boson using real scientific data. See: www.HiggsHunters.org

Some simple learning strategies to promote situational interest in the classroom can be found here: http://singteach.nie.edu.sg/issue48-research04

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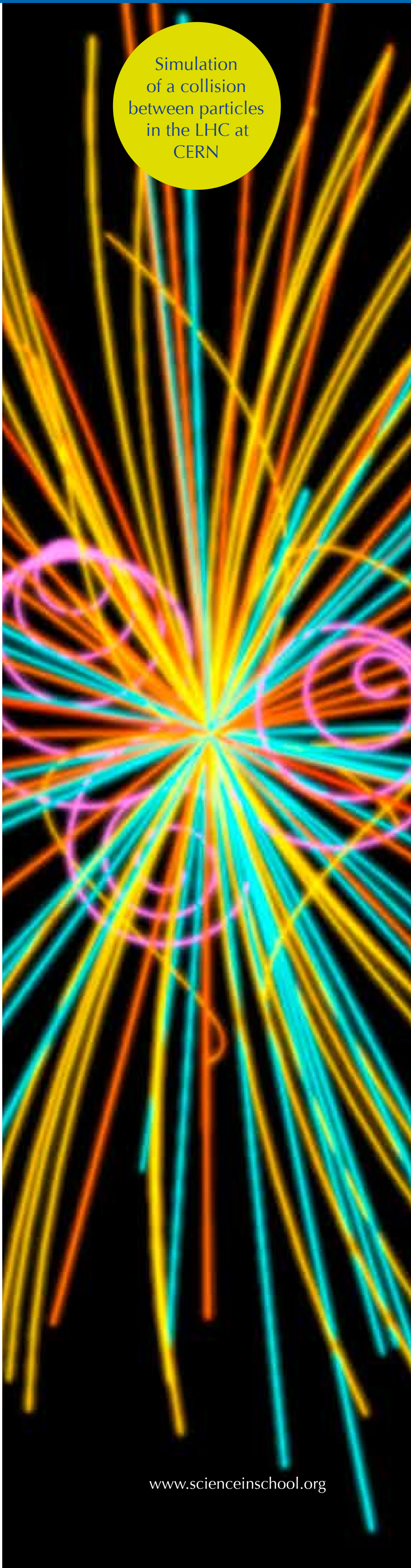
Image courtesy of the Science & Technology Facilities Council (STFC)



Simulation of a collision between particles in the LHC at CERN

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CERN

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

EMBL

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

ESA

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

ESO

ESO is the foremost inter-governmental astronomy organisation in Europe and the world's most productive ground-based astronomical observatory by far. It operates telescopes at three sites in Chile – La Silla, Paranal and Chajnantor – on behalf of its member states. At Paranal, ESO's Very Large Telescope is the world's most advanced visible-light astronomical observatory. ESO is a major partner in the revolutionary astronomical telescope ALMA and is building the 39-metre European Extremely Large Telescope, the E-ELT. See: www.eso.org

ESRF

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

EUROfusion

The European Consortium for the Development of Fusion Energy (EUROfusion) comprises representations of 28 European member states as well as Switzerland and manages fusion research activities on behalf of Euratom. More than 40 European fusion laboratories collectively use the Joint European Torus (JET), which has remained the world's largest magnetic fusion device since it was built in 1983. Smaller national experiments in Germany, Switzerland, and the United Kingdom complement the experimental programme. The aim is to realise fusion electricity by 2050 See: www.euro-fusion.org.

European XFEL

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

ILL

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