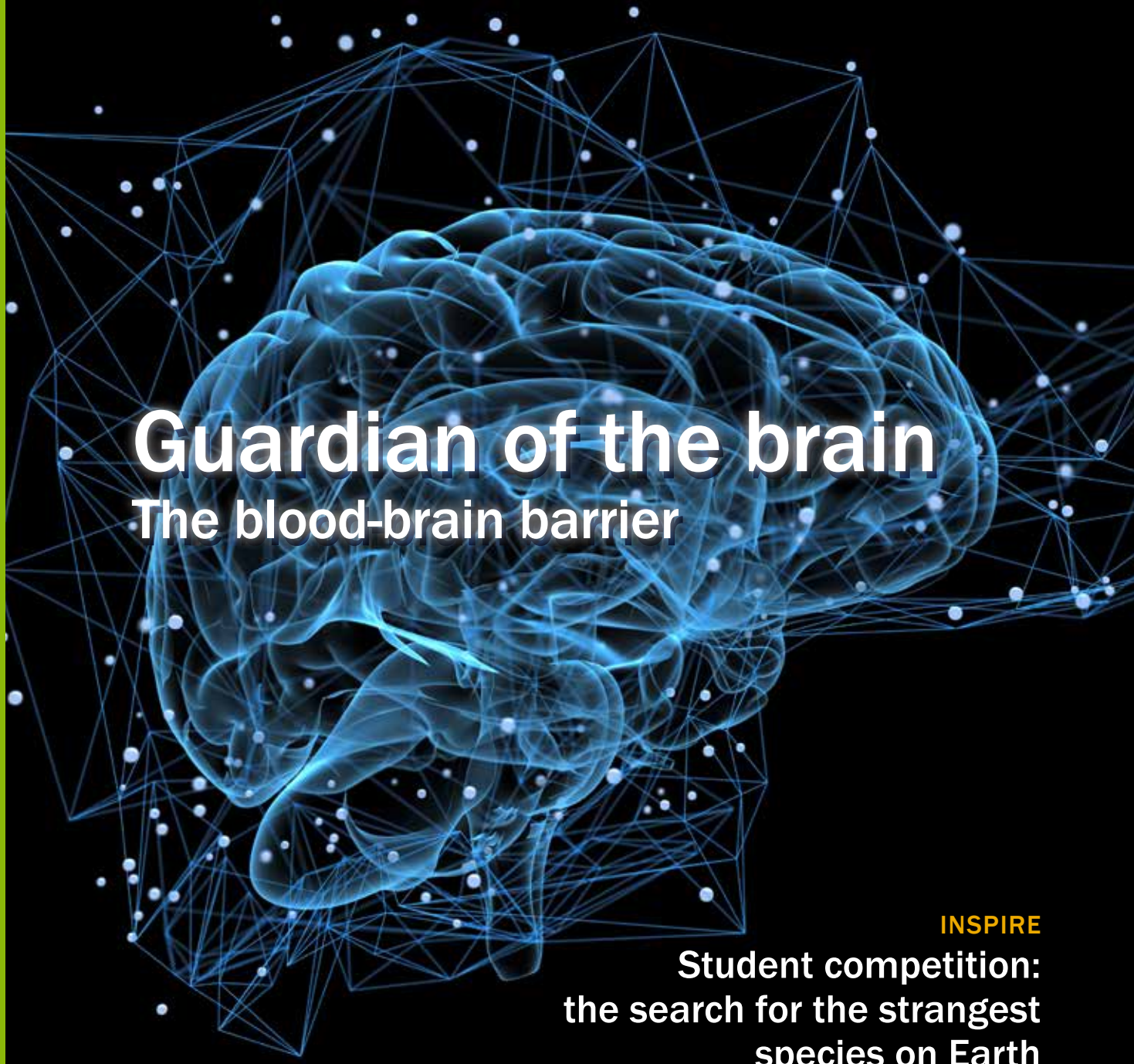
Winter 2017 | Issue 42

Science in School

The European journal for science teachers



Guardian of the brain

The blood-brain barrier

INSPIRE

Student competition: the search for the strangest species on Earth

TEACH

Natural experiments: taking the lab outdoors

EIROforum Published and funded by EIROforum ISSN: 1818-0353 www.scienceinschool.org

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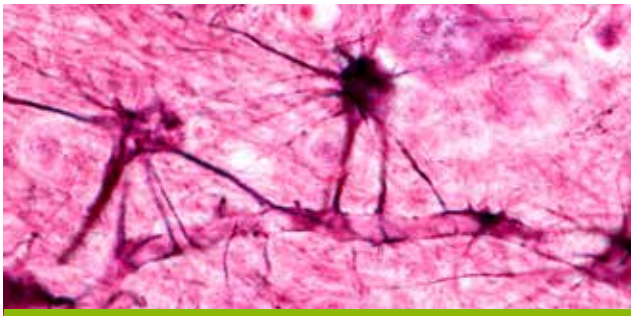


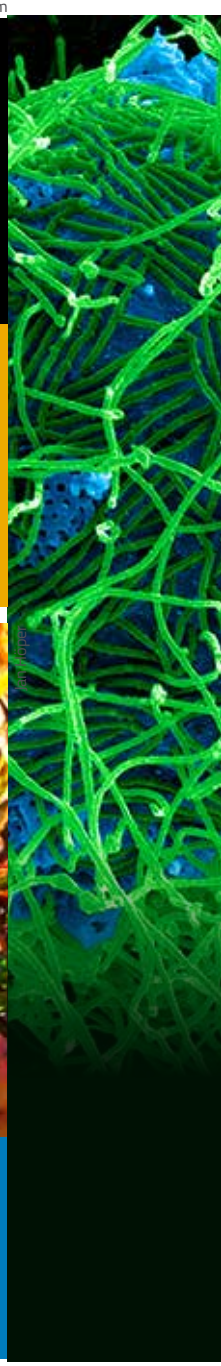
GUARDIAN OF THE BRAIN: THE BLOOD-BRAIN BARRIER 18

Insights into the brain's unique protective barrier could offer promising treatments for diseases such as multiple sclerosis and Alzheimer's.

zaferkizilkaya/Shutterstock.com

STUDENT COMPETITION: THE SEARCH FOR THE STRANGEST SPECIES ON EARTH 23

Get a glimpse into the weird and wonderful life on Earth with the three winning entries in the *Science in School* writing competition.



U.S. Department of Agriculture/Flickr

NATURAL EXPERIMENTS

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How many 'chemicals' are there in a fresh mushroom? These simple experiments reveal the hidden chemistry within natural foods.

TAKING THE LAB OUTDOORS 42

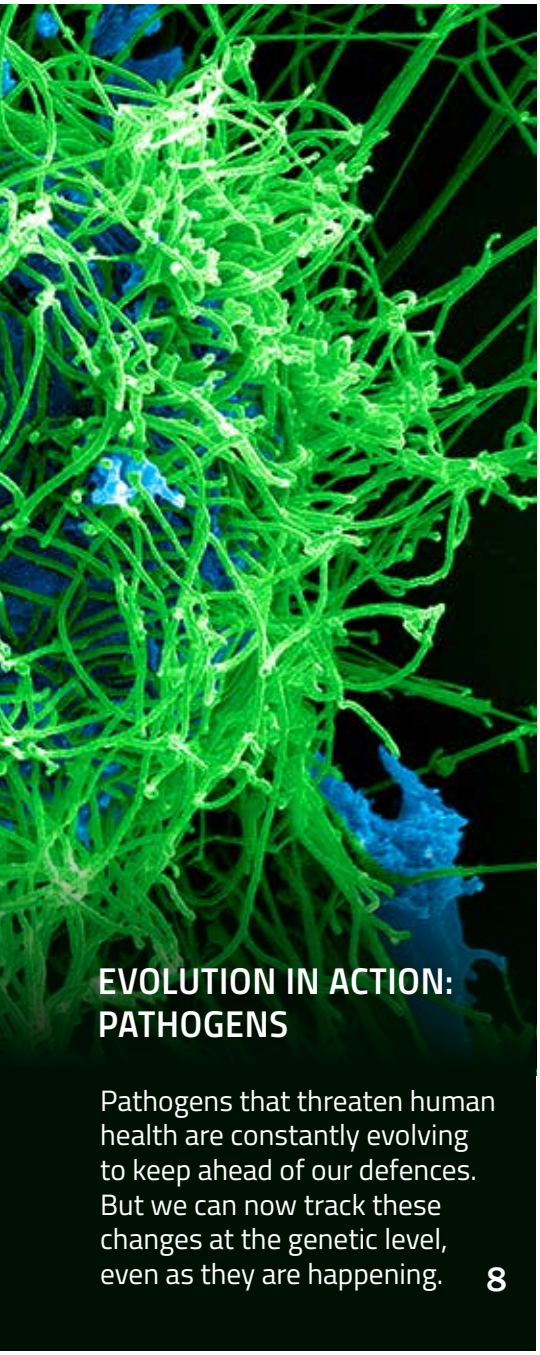
Assemble a 'backpack laboratory' and take texts for starch and glucose out into the wild.

UNDERSTAND

INSPIRE

TEACH

NIAID/Flickr



EVOLUTION IN ACTION: PATHOGENS

Pathogens that threaten human health are constantly evolving to keep ahead of our defences. But we can now track these changes at the genetic level, even as they are happening. 8

EDITORIAL

Susan Watt
Editor
Science in School
editor@scienceinschool.org

Season's greetings from *Science in School*!

Midwinter may not be the best time of year to consider moving school science lessons outdoors. But in this issue, we hear from a teacher who has made a great success of the outdoor approach, despite being located within the Arctic Circle (page 42). Another teacher finds scope for exploring chemistry with supermarket produce (page 36). Using button mushrooms, you can demonstrate that purely natural foods contain plenty of identifiable 'chemical' substances – a quality often associated solely with synthetic ingredients.

Our investigation of the natural world continues with a look at something truly down-to-earth: soil. We encourage students and teachers to get their hands dirty in activities to discover the structure and composition of soil (page 29), while learning about the role this plays in the global (and European) problem of soil erosion. Another serious world problem comes under the spotlight in the second article in our evolution series (page 8). This features a remarkable experiment in which bacteria can be seen, in real time, developing resistance to high doses of antibiotics – all captured in dramatic video images.

On the more theoretical side, we consider some striking facts about the rarest of substances: antimatter (page 14). And at the microscopic level, we look at how the blood-brain barrier was first identified, and how understanding this unique structure is leading to new treatments for diseases such as multiple sclerosis (page 18).

Finally, some seasonal entertainment: we bring you the winning entries of our writing contest for young people, whom we asked to tell us about 'the strangest species on Earth' (page 23). They rose splendidly to the challenge, and we hope you enjoy reading these short pieces. And if you are a physics teacher whose class deserves something light-hearted at the end of term, try the tray-balancing game so students can learn about the physics of levers while they play (page 49).

We wish you all a good break, and a happy and healthy New Year. We look forward to seeing what new scientific developments 2018 brings, and to sharing these with you through *Science in School*.

Susan Watt

Interested in submitting your own article? See: www.scienceinschool.org/submit-article

Crash-tolerant cars, toxic tattoo ink and the first X-ray laser light

CERN
Short animations for long-lasting questions

Would you believe that mysteries like dark matter can be explained in less than five minutes? CERN scientists and TED-Ed animators recently took on this challenge – and the results can be seen in their two new animations, which together have reached more than 700 000 views in the first few months after their release.

CERN scientists and TED-Ed animators recently produced two animations to explain some of the most difficult questions about our Universe. (Image source: https://ed.ted.com)

In the first video, entitled 'Is it possible to create a perfect vacuum?', CERN's Rolf Landua and Anais Rassat explain how we make a vacuum on Earth, how particles are created in a vacuum, and to what extent the Universe is considered 'empty' or 'full'.

In the second animation, 'Could we create dark matter?', viewers are invited to join the search for the enigmatic matter that makes up 85% of our Universe. We don't know what dark matter is made of, and we've yet to directly observe it, but scientists believe that we may be able to create it in the Large Hadron Collider.

Watch the videos 'Is it possible to create a perfect vacuum?' and 'Could we create dark matter?' on the TED-Ed website. See: https://ed.ted.com/lessons/is-it-possible-to-create-a-perfect-vacuum-rolf-landua-and-anais-rassat or use the direct link http://tinyurl.com/ybj49gyj https://ed.ted.com/lessons/could-we-create-dark-matter-rolf-landua or use the direct link http://tinyurl.com/y8vl4bbp

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

EMBL
Edith Heard announced as next EMBL Director General

In June, the European Molecular Biology Laboratory (EMBL) Council selected Edith Heard as the organisation's fifth Director General. Professor Heard's tenure is scheduled to begin on 1 January 2019. She is currently director of the Genetics and Developmental Biology Unit at *Institut Curie* and holds the chair of Epigenetics and Cellular Memory at the *Collège de France*, both in Paris, France.

"I am extremely honoured to be offered this opportunity to serve European science as Director General of EMBL", said Edith Heard. "As a deeply committed citizen of Europe, I will endeavour to promote the scientific excellence and service to the scientific community that characterise EMBL", she said.

Edith Heard, who has been selected as EMBL's next Director General

EMBL

For more information, visit the EMBL news website. See: https://news.embl.de/lab-matters/embl-next-director-general/

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

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

ESA
500 new European companies from space

Investment in young companies by the European Space Agency (ESA) has now fostered more than 500 start-ups that are adapting space technology and satellite services for use on Earth. From healthcare to manufacturing, sport to agriculture, the ESA technology transfer programme is positioning Europe at the forefront of innovation.

Among these start-ups is a drone delivery service developed by entrepreneurs in Portugal; a French start-up offering improved direct communication with the ground for aircraft pilots and Wi-Fi for their passengers' electronic devices; and a German company that has developed a treatment for bacterial infection in wounds by applying 'cold plasma', which is based on experiments on the International Space Station.

To read the full press release, visit the ESA website. See: www.esa.int/Our_Activities/Space_Engineering_Technology/TTP2/500_new_European_companies_from_space or use the direct link http://tinyurl.com/y9xckkqo

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

ESA

A drone flies through the streets of Lisbon, Portugal to distribute a parcel, as part of a new delivery service developed by a Portugese start-up.

ESO/K Ohnaka

Using ESO's Very Large Telescope Interferometer, astronomers have constructed this image of the red giant star Antares.

ESO
Mapping the surface of stars

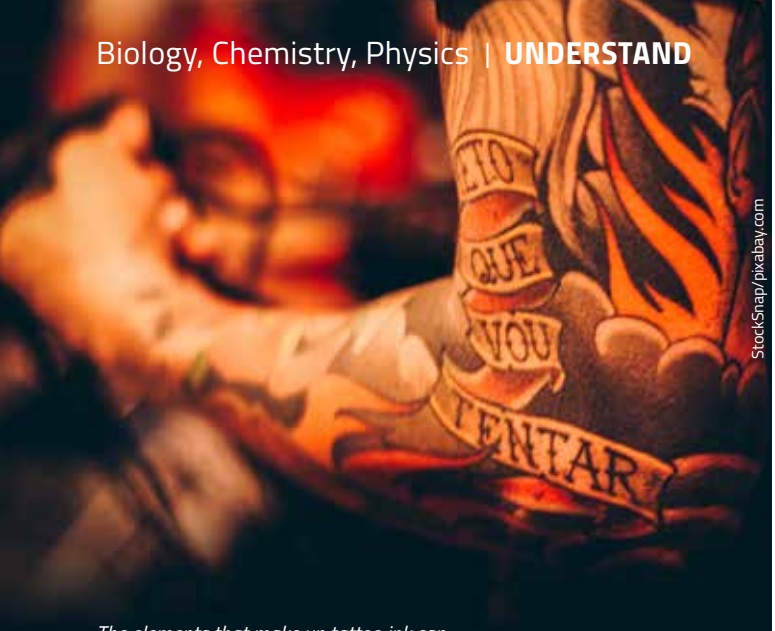
For the first time, astronomers have mapped the motion of material on the surface of a star other than the Sun. The velocity map of Antares, a red giant star, was made thanks to the Very Large Telescope Interferometer (VLTI) of the European Southern Observatory (ESO).

Surprisingly, the map revealed turbulent, low-density gas much further from the star than predicted, indicating that an unknown process may be moving some of the stellar material.

The VLTI is a unique facility that combines the light from the four telescopes of the Very Large Telescope (VLT) array to create one virtual telescope. With the equivalent resolving power of a mirror up to 200 metres in diameter, the VLTI can reveal fine details far beyond what can be seen with a single VLT telescope.

To read the full press release, visit the ESO website. See: www.eso.org/public/news/eso1726/

ESO is the foremost intergovernmental astronomy organisation in Europe and the world's most productive ground-based astronomical observatory, with its headquarters in Garching, near Munich in Germany, and its telescopes in Chile. See: www.eso.org



StockSnap/pixabay.com

The elements that make up tattoo ink can travel in nanoparticle form inside the body.

ESRF

How tattoo ink travels inside the body

For someone wanting a new tattoo, choosing a parlour where they use sterile needles is important. But how many people give any thought to the chemical composition of the tattoo ink itself? A new study has highlighted that understanding the potential impurities in tattoo ink is essential, too.

The study, which was carried out by scientists in Germany and at the European Synchrotron Radiation Facility (ESRF), looked at how tattoo ink travels inside the body. Most tattoo inks contain organic and inorganic pigments, but they also include preservatives and contaminants such as nickel, manganese or cobalt. These substances can be taken up by lymph fluid or blood and are then transported to the lymph nodes.

The study provides the first analytical evidence that the pigments – including any toxic impurities – travel within the body in nanoparticle form. "The problem," says Bernhard Hesse, one of the authors of the study, "[is that] we don't know how nanoparticles react."

Two beamlines at ESRF were crucial to the breakthrough, which also involved scientists at the German Federal Institute for Risk Assessment, the Ludwig-Maximilians University and the National Metrology Institute of Germany.

To read the full press release, visit the ESRF website. See: www.esrf.eu/home/news/general/content-news/general/scientists-find-that-nanoparticles-from-tattoos-travel-inside-the-body.html or use the direct link http://tinyurl.com/ydc597mb

For more information on the study, read the original research paper. See:

Schreiver I et al. (2017) Synchrotron-based ν-XRF mapping and μ-FTIR microscopy enable to look into the fate and effects of tattoo pigments in human skin. *Scientific Reports* **7:** 11395. doi: 10.1038/s41598-017-11721-z

Situated in Grenoble, France, ESRF operates the most powerful synchrotron radiation source in Europe. See: www.esrf.eu

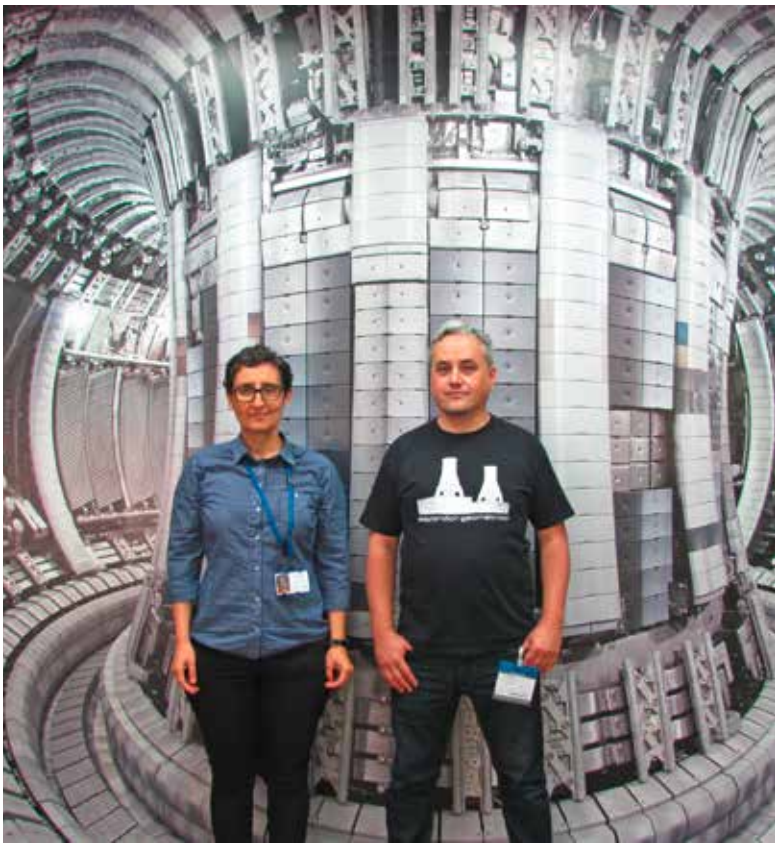
EUROfusion

JET: a muse for musicians

The Joint European Torus (JET) – EUROfusion's flagship device and the largest tokamak in the world – is not just an inspiration for fusion energy researchers; it is now capturing the imagination of musicians. Electronic music band *Poupées Électriques* has recorded the futuristic sounds of the fusion reactor for their latest album, which will be released shortly.

The band's frontman, Carlos Arillo, was looking for sounds that conveyed the theme of futurism when he ran into an old friend, Ana Manzanares, a researcher at JET. Ana convinced Carlos that the tokamak would be ideal. "I was left speechless by the richness of JET's tunes. They come with a large spectrum of frequencies and dynamic changes", says Carlos. The term 'fusion' in music has indeed taken on a completely new meaning!

EUROfusion manages and funds European fusion research activities, with the aim to realise fusion electricity by 2050. The consortium comprises 30 members from 26 European Union countries as well as Switzerland and Ukraine. See: www.euro-fusion.org



EUROfusion/Private

Ana Manzanares (scientist at JET) and Carlos Arillo (musician) in JET's entrance hall.

European XFEL
First X-ray laser users

The first users have now started experiments at the new international X-ray laser at European XFEL. In this first round of beam-time, a total of 14 groups of up to 80 users each are travelling to the new research facility from across the globe. Until March 2018, each group will have about five days of 12 hours of beam-time at the FXE and SPB/SFX instruments to carry out experiments.

The FXE instrument will enable research into extremely fast processes. It will be possible to create 'molecular movies' showing the progress of chemical reactions. The first experiments conducted at FXE include using different spectroscopy methods to track ultrafast reactions and electron movement in model molecules, probing organic light-emitting diodes, and investigating the recombination of nitrogen and oxygen in the muscle tissue protein myoglobin.

The SPB/SFX instrument will be used to gain a better understanding of the shape and function of biomolecules, such as proteins, that are otherwise difficult to study. Several of the first experiments at this instrument focus on ways to reduce the amount of precious sample used for examining biological processes. Other groups are studying biological structures such as viruses, and processes such as the splitting of water molecules in photosynthesis.

More instruments are scheduled to be available for users until the end of next year.

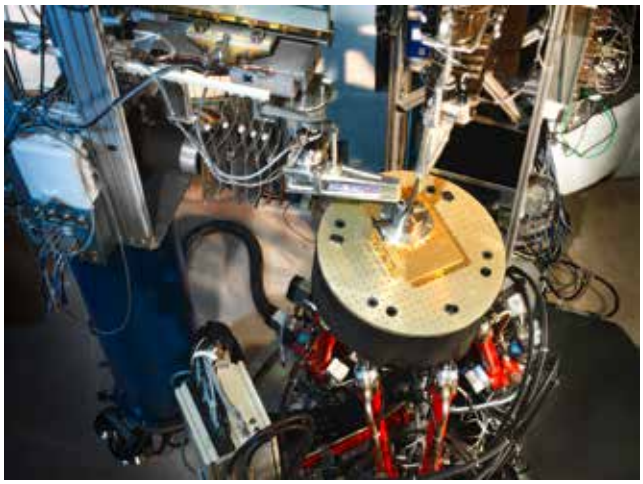
European XFEL is a research facility in the Hamburg area in Germany. Its extremely intense X-ray flashes are used by researchers from all over the world. See: www.xfel.eu

European XFEL

The first two user groups at European XFEL

ILL
Neutrons lead the way for optimised crash-tolerant cars

ILL



ILL's SALSA instrument performs diffraction experiments with engineering applications

Boron steel is an ultrahigh-strength steel used across a variety of industries. It is particularly attractive to the automotive industry, due to the reduced vehicle weight and the increased passenger safety that it provides.

However, scientists at the *Institut Laue-Langevin* (ILL) have found a strong correlation between residual stress in boron steel and spot welding – an important process used to join metals for motor vehicle manufacturing.

The study used neutron diffraction experiments carried out at ILL's SALSA instrument. The findings highlight the need for alternative welding methods that have a less damaging impact on boron steel and can lengthen the lifetime of the material, ultimately providing better passenger safety in stronger, yet lighter, vehicles.

Based in Grenoble, France, ILL is an international research centre at the leading edge of neutron science and technology. See: www.ill.eu

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

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

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

Illustration of the Ebola virus, showing surface protein molecules that help the virus to enter cells

Science Photo Library/De Angelis, Maurizio

Evolution in action: pathogens

Pathogens that threaten human health are constantly evolving to keep ahead of our defences. But we can now track these changes at the genetic level, even as they are happening.

By Jarek Bryk

One of the main driving forces of evolution is natural selection – where individual organisms with a particular genetic makeup produce more offspring than others in a given environment, leading to adaptations in that organism that allow it to survive, while others perish.

As Darwin established, this process of positive natural selection – whereby traits that increase an organism's 'fitness' become dominant in a population – contributes to the diversity we see in living species. But it is also a factor in processes that endanger our own survival, such as the spread of viral infections and the emergence of antibiotic

Strains of bacteria that are resistant to existing antibiotic medicines are an increasing problem.

AKuptsova/pixabay.com

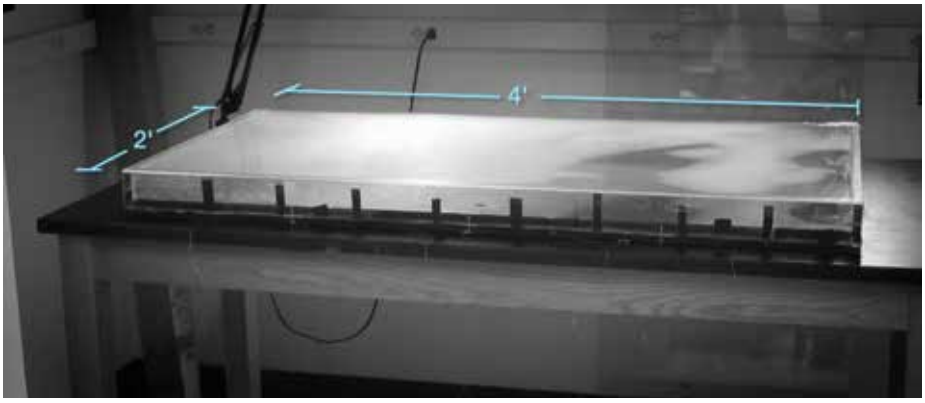
resistance in bacterial pathogens. However, thanks to ingenious laboratory experiments (see, for example, Bryk, 2017) and advances in gene sequencing technology, such as hand-held sequencing machines, we can now track this process quickly and precisely – not only in the laboratory, but just about anywhere in the world. This has proved hugely valuable for understanding the evolution of disease-causing micro-organisms.

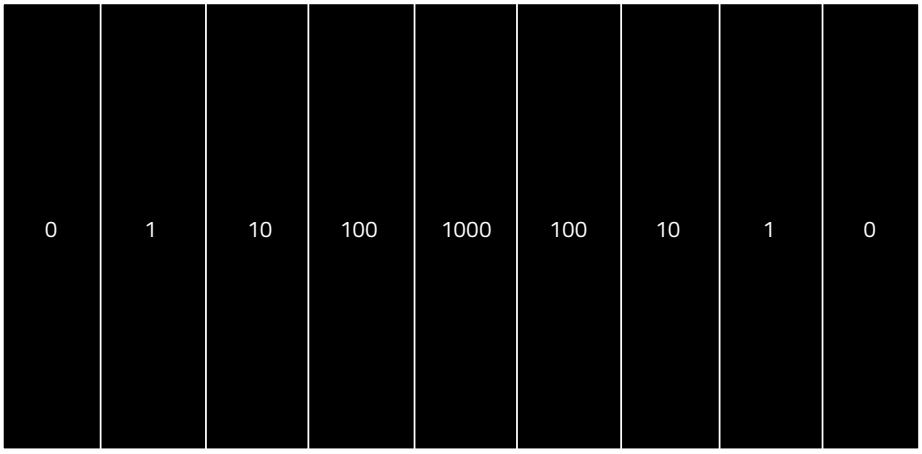
In this article, we focus on two remarkable studies that look closely at how such pathogens are constantly evolving, revealing the patterns of genetic change – and the limiting factors – behind this process.

Antibiotic resistance under the spotlight

A textbook example of evolution by positive natural selection is the emergence of antibiotic resistance in pathogenic bacteria. The use of antibiotics applies a selective pressure to a population of bacteria, which mutate and reproduce very quickly. As a result, any genetic variants that protect bacteria from the antibiotic remain in the population, and all the other variants will disappear.

This process has been dramatically caught on camera by Dr Michael Baym, a researcher at Harvard University, USA and a self-professed antibiotic resistance fighter. In 2015, Baym set up a clever contraption to visualise how resistant bacteria spread in an environment with antibiotics. He used a giant rectangular Petri dish, 60 cm wide by 120 cm long (a standard Petri dish is 9 cm in diameter) filled with agar, a jelly-like medium for growing bacteria, which had been dyed black. Crucially, he infused the agar with concentrations of antibiotic that increased in steps along the length of the dish (figure 1), from zero antibiotic at the ends to 1000 units of antibiotic in the centre sections – which should be enough to kill any bacteria outright. He set up a spotlight and camera over the dish, so that any colonies of bacteria would be





Kishony Lab, Harvard Medical School and Technion – Israel Institute of Technology

Figure 1: Top: the giant Petri dish used by Baym and colleagues. Above: the different regions of the dish, with concentrations of antibiotics increasing by a factor of 10 at each step

REVIEW

- ✓ Evolution
- ✓ Genetics
- ✓ Population genetics
- ✓ Nature of science
- ✓ Ages 14–19

One of the main problems in teaching evolution is the dimension of time. Because human life is short compared to the timeframes in which the great evolutionary processes take place, the concept of change over time is a basic difficulty in understanding evolution. So, examples of evolutionary processes that take place over a period compatible with human perception provide opportunities to overcome these problems.

The experiment described in this article offers a very good view of how the elements of time and mutations affect evolution. Teachers could use this article to teach evolution, by demonstrating that evolution can take place over a short period. The article is also helpful in explaining the central role of mutations during evolution, as a source of diversity that is then acted on by natural selection. And because the experiment involves a familiar idea – the use of antibiotics – it is easy to understand.

Panagiotis K Stasinakis, biology teacher,
4th High School of Zografou, Greece

clearly visible as white spots against the background of the black agar. Then, he inoculated the plate with *Escherichia coli* (*E. coli*) bacteria at the very ends of the dish, where no antibiotic was present – and waited for the process to begin (figure 2).

So, what happened? The *E. coli* could move within the top layer of the agar, so when the bacteria ran out of food in their own neighbourhood, they moved on to another region (figure 3). Their growth, however, was inhibited by the antibiotic in the neighbouring area, so that only bacteria with mutations allowing them to survive this exposure could spread further. So the first region containing antibiotic (in a concentration of just one unit) was invaded initially by single mutants. These reproduced, with their progeny fanning out over the entire region – until they themselves encountered the next region with a higher concentration of antibiotic. At the boundary, the bacteria paused again until new mutations providing increased tolerance to the antibiotic emerged.

This process was repeated at each boundary until, after 11 days of bacterial growth, *E. coli* bacteria covered the entire surface of the giant dish, with the bacteria in the centre of the dish having evolved resistance to antibiotic concentrations 1000 times higher than those near the edges (figure 4). Each step in this process was captured on a now-famous video[w1].

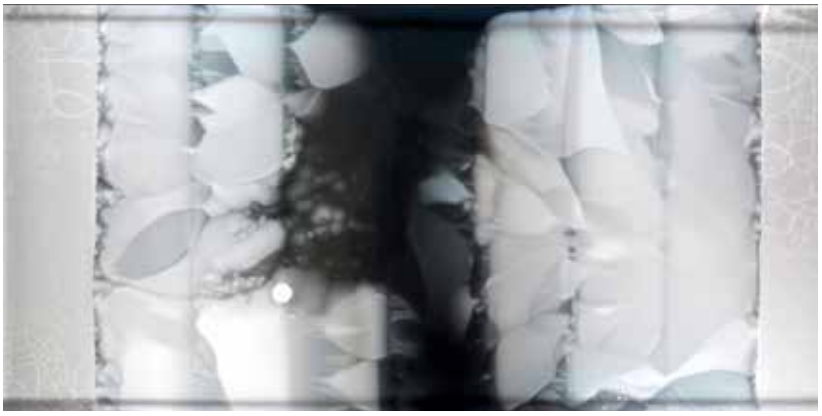
As the researchers could see the spread of bacteria frame by frame, they could also sample bacteria from critical points

> **"The bacteria in the centre of the dish had evolved resistance to antibiotic concentrations 1000 times higher than those near the edges."**

Figure 2: The dish with bacteria recently added at each end

Kishony Lab, Harvard Medical School and Technion – Israel Institute of Technology

Figure 3: The emergence of the first bacterial population (arrowed) able to survive in a low concentration of antibiotic



Kishony Lab, Harvard Medical School and Technion – Israel Institute of Technology

Figure 4: Bacterial growth after 11 days. Bacteria in the centre are resistant to a dosage of antibiotic 1000 times higher than in figure 3.

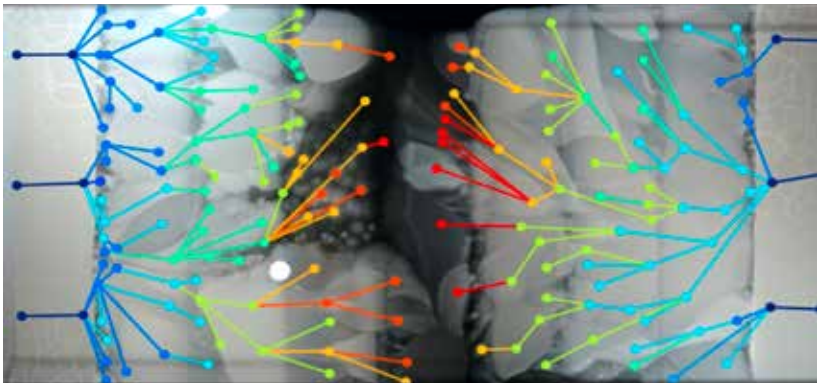


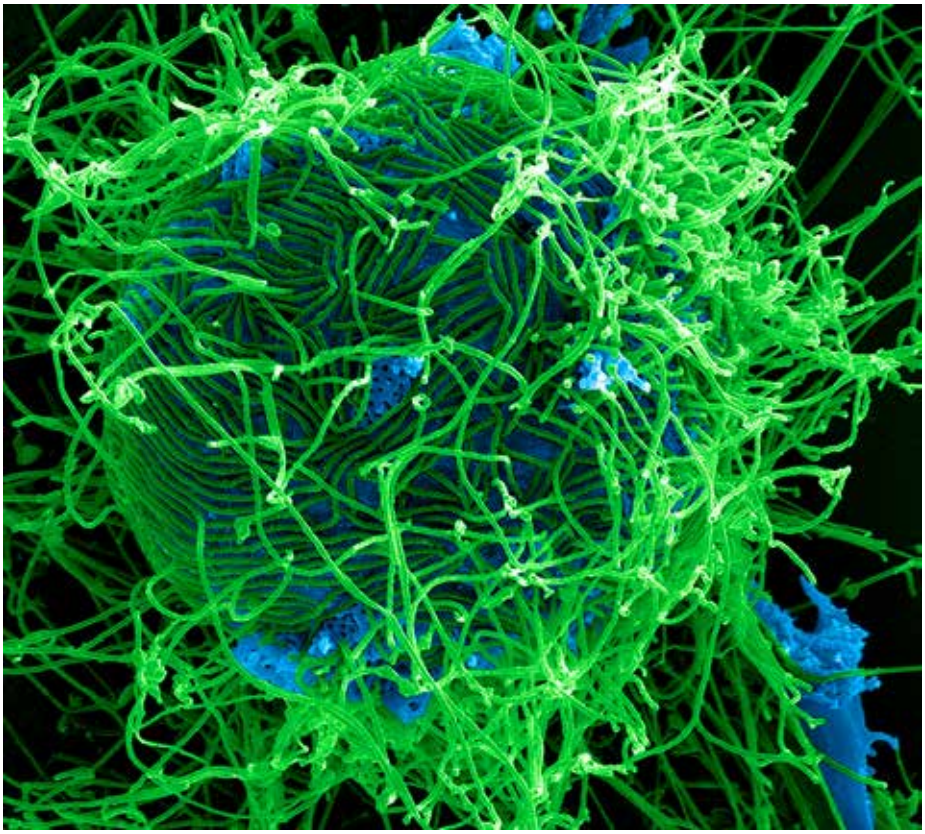
Figure 5: Bacterial mutations visualised as 'family trees', established by sequencing the DNA of colonies from different stages of the dish

where particular mutants originated. By sequencing these genomes, they were able to pinpoint the changes in each step on the evolution of the resistance (figure 5).

It turned out that many of the mutations occurred multiple times, so it seems that some paths to resistance are more common than other. In addition, some mutations occurred in genes that apparently had nothing to do with the antibiotic, which illustrated an important point in the development of resistance: the need to adapt to the antibiotic is a burden on basic metabolic processes, so in the absence of antibiotics, resistant bacteria often grow more slowly than the non-resistant ones. The extra mutations were needed to compensate for the metabolic burden, and this may be another reason for the pause of growth at the boundaries where the antibiotic concentration increased.

In a further step in this experiment, Baym and his colleagues made another crucial observation. If they made the difference between antibiotic concentrations in neighbouring regions much larger, no mutants could survive in the next region, and bacterial growth stopped completely at the first boundary. This phenomenon can be explained by the same principle: when the selective pressure of antibiotics in the environment is really high, it is nearly impossible for bacteria to grow at all, because the mechanisms needed to overcome such a burden require too many mutations at once – so the bacteria die.

NIAID/Flickr



Electron microscope image of Ebola virus particles (green) attached to an infected cell (blue)

CDC Global/Wikimedia Commons

Healthcare worker carrying out temperature screening for fever before allowing entry to a building during the 2013–15 Ebola epidemic

The Ebola epidemic

Another example of the evolution of microbial pathogens that has been intensively studied is one of the deadliest human pathogens: the Ebola virus. The 2013–2015 Ebola epidemic was the longest and largest so far, with 28 646 cases and 11 323 deaths recorded by June 2016. The duration of the epidemic, coupled with the arrival of rapid gene-sequencing technology that could be deployed in the field, allowed researchers to trace the evolution of this virus as it was infecting new patients.

Led by US-based geneticists Dr Pardis Sabeti (Harvard University), Dr Jeremy Luban (University of Massachusetts Medical School) and Dr Andrew Rambaut (University of Edinburgh), the scientists studying Ebola constructed a 'family tree' of the virus as it spread through West Africa over two years (Park, 2015). Each branch of the tree represented a new set of mutations that allowed the virus to grow and multiply better than other strains. By comparing viral genomes collected from patients in

different countries and at different times, the team established that the main variant of the virus originated in Guinea – and that it was able to spread further only after it had acquired five new mutations. As it moved from Guinea into Sierra Leone in May 2014, another mutation appeared and became much more common in that region (Diehl et al., 2016)[w2]. The new mutation was first observed in just a single patient, but it was so successful that 97% of the 200-plus Ebola genomes analysed in the whole study were descendants of that mutant. This is a remarkable success story of a strain that had emerged only two years before (see figure 6).

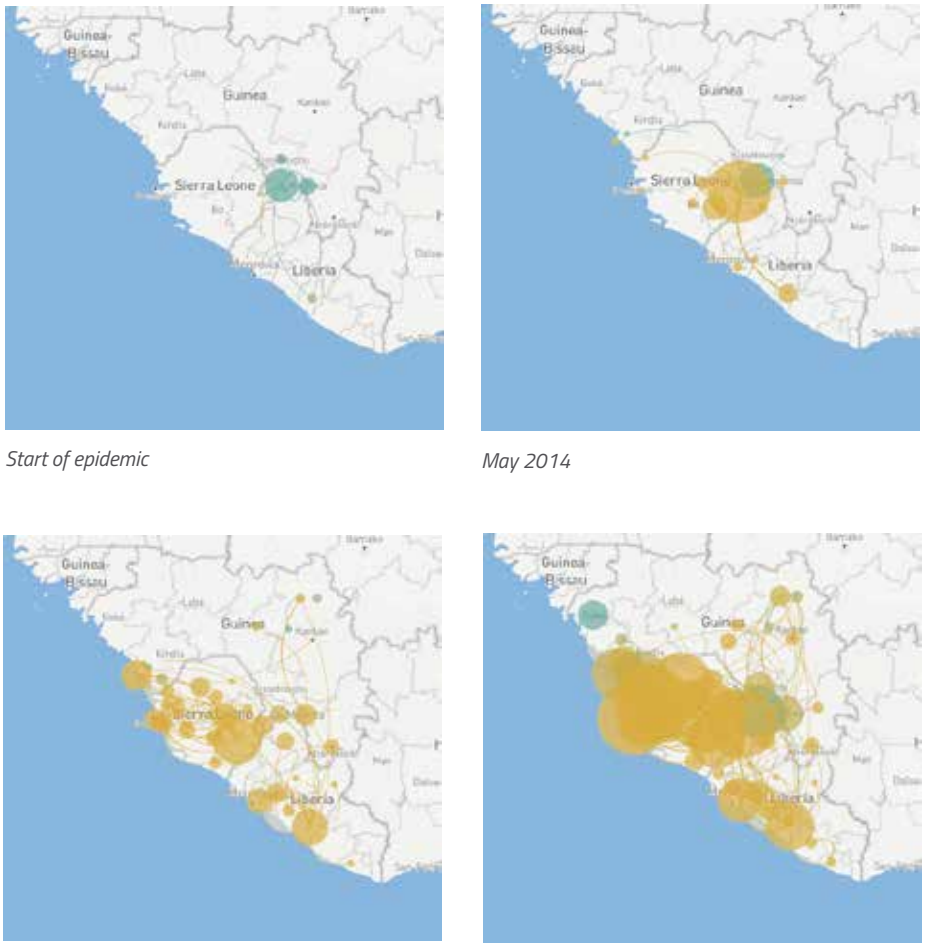
More importantly, the study revealed some genes in the Ebola genome that had changed much more than expected,

Cumulative number of Ebola infection cases over time in 2014. The arrow marks the approximate date of emergence of the successful new variant of the virus. (Adapted by Jarek Bryk from Diehl et al., 2009.)

> **"The main variant of the Ebola virus originated in Guinea and was able to spread further only after it had acquired five new mutations."**

including those for protein molecules located on the outside of the virus. These viral proteins are thought to be a target for human antibodies that fight the infection, so rapid changes in these proteins will help the virus to avoid neutralisation by the host – a pattern that is therefore driven by natural selection.

These genes have now become a promising focus for research to counter the spread of the virus in any future epidemic. Finding out more about the mechanisms of evolution is also helping researchers to develop effective strategies to combat pathogens in the future.



Start of epidemic | *May 2014*

November 2014 | *Overall totals*

Figure 6: Maps showing the spread of two variants of the Ebola virus in Guinea and neighbouring countries. Green circles indicate (by size) the number of patients infected by the strain that began the epidemic in Guinea, while yellow circles represent the number infected by the new strain that emerged around May 2014. (Source: nextstrain.org)

Leasmhar/Wikimedia Commons

Hospital in Kenema, Sierra Leone, in June 2014. During the epidemic, people were tested here for the Ebola virus.

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Diehl W E et al. (2016) Ebola virus glycoprotein with increased infectivity dominated the 2013–2016 epidemic. *Cell* **167**: 1088–1097

Web references

w1 Watch the video created by Michael Baym and colleagues showing *E. coli* spreading through regions of increasing antibiotic concentrations on the 'mega-plate'. See: https://vimeo.com/180908160

w2 Watch an animation showing the spread of the Ebola virus, and how the new strain that emerged around June 2014 affected this. See: www.nextstrain.org/ebola?c=gt-GP_82

Resources

Visit *The Atlantic* website for an accessible article on the Baym experiment and its implications. See: www.theatlantic.com/science/archive/2016/09/stunning-videos-of-evolution-in-action/499136/

Read the scientific paper in the journal *Science* reporting the Baym experiment:

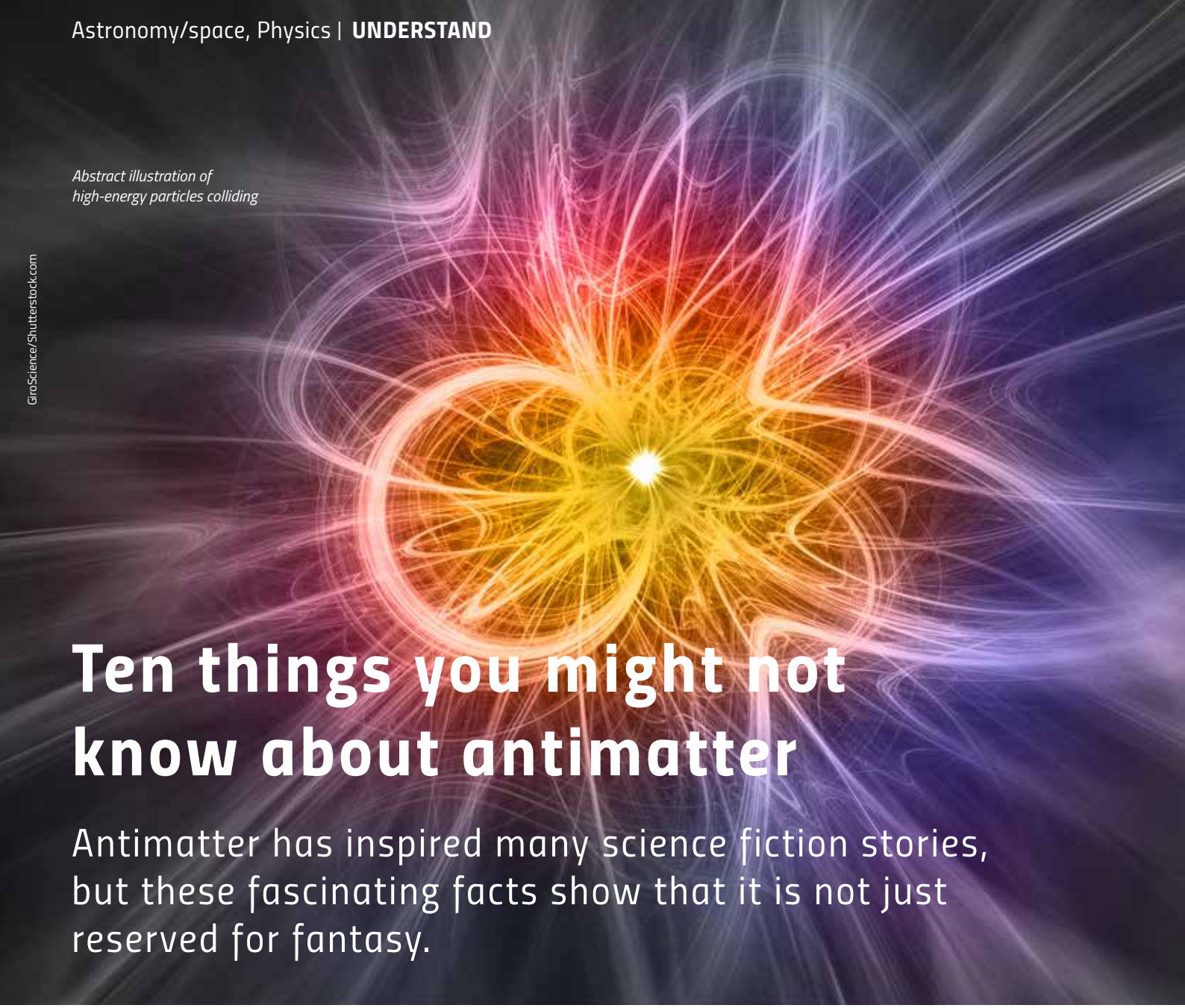
Baym M et al. (2016) Spatiotemporal microbial evolution on antibiotic landscapes. *Science* **53**: 1147-1151. doi: 10.1126/science.aag0822

Watch researcher Pardis Sabeti's TED talk about fighting Ebola. See: www.youtube.com/watch?v=G8RxjxdUulE

Read a blog post about the Ebola surveillance work, with links to media coverage of the research and technology behind it. See: http://lab.loman.net/2016/02/03/behind-the-paper-real-time-portable-sequencing-for-ebola-surveillance/

A guide to Ebola can be found on the Médecins Sans Frontières website. See: www.msf.org.uk/issues/ebola

Dr Jarek Bryk is a lecturer in molecular biology at the University of Huddersfield in the north of England. He teaches genomics and evolution and studies how allele frequencies change in wild populations of wood mice and weasels. Find him online at http://bryklab.net or on Twitter at @jarekbryk.



Abstract illustration of high-energy particles colliding

GiroScience/Shutterstock.com

Ten things you might not know about antimatter

Antimatter has inspired many science fiction stories, but these fascinating facts show that it is not just reserved for fantasy.

By Diana Kwon

In the book *Angels and Demons*, Professor Langdon tries to save Vatican City from an antimatter bomb. And in Star Trek, the collision of matter and antimatter supplies energy to propel the starship *Enterprise* to faster-than-light speed. But antimatter is not just the stuff of science fiction – while these scenarios are far-fetched, there are still many facts about antimatter that will tickle your brain cells.

1. Antimatter should have annihilated all the matter in the Universe

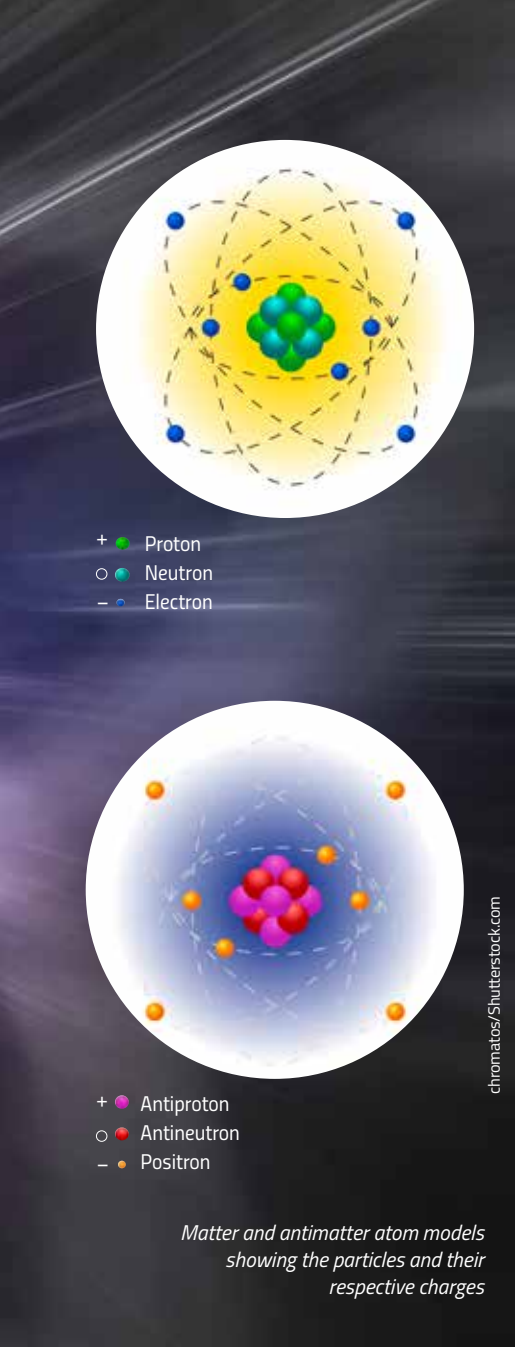
Antimatter particles are almost identical to their matter counterparts, except that they carry the opposite charge and spin. Matter and antimatter particles are produced as a pair and when they meet, they immediately annihilate each other, leaving nothing but energy behind.

This means that the Big Bang should have created and destroyed equal amounts of these particles. So why do we exist in a Universe made almost entirely of matter? As far as physicists can tell, it is because, in the end, there was one extra matter particle for every billion (10^9) matter-antimatter pairs. Physicists are hard at work trying to explain this asymmetry.

2. Antimatter is closer than you think

Small amounts of antimatter constantly rain down on Earth in the form of cosmic rays – energetic particles from space. These antimatter particles reach our atmosphere at a rate ranging from fewer than one per square kilometre per century to more than 10 000 per square metre per second. Scientists have also seen evidence of antimatter production above thunderstorms.

But other antimatter sources are even closer to home. For example, bananas release one positron – the antimatter equivalent of an electron – roughly every 75 minutes. This occurs because bananas contain a small amount of potassium-40, a naturally occurring isotope of potassium. As



Matter and antimatter atom models showing the particles and their respective charges

potassium-40 decays, it occasionally spits out a positron in the process.

Our bodies also contain potassium-40, which means positrons are being emitted from us, too. Antimatter is annihilated immediately on contact with matter, so these antimatter particles are very short-lived.

3. Humans have created only a tiny amount of antimatter

Matter-antimatter annihilations have the potential to release a huge amount of energy. A gram of antimatter could produce an explosion the size of a nuclear bomb.

Scientists create antimatter to study in experiments, but the amount produced is minute. All the antiprotons created at Fermilab's Tevatron particle accelerator (now inactive) add up to only 15 nanograms, and CERN's so far add up to about 1 nanogram.

The problem lies in the efficiency and cost of antimatter production and storage. Making 1 gram of antimatter would require approximately 25 million billion (10^{15}) kilowatt-hours of energy and cost over a million billion US dollars.

4. There is such a thing as an antimatter trap

To study antimatter, you must prevent it from being annihilated by matter. Scientists do this by holding the charged particles, such as positrons and antiprotons, in devices called Penning traps. These traps are comparable to tiny accelerators. Inside, particles spiral around as magnetic and electric fields keep them from colliding with the walls of the trap.

But Penning traps won't work on neutral particles such as antihydrogen. Because they have no electric charge, these particles cannot be confined by electric fields. Instead, they are held in Ioffe traps, which take advantage of the particle's magnetic properties. Ioffe traps work by creating a region of space where the magnetic field becomes larger in all directions. The particle is attracted to the area with weakest magnetic field, much like how a marble rolling around a bowl eventually reaches the bottom.

5. Antimatter might fall up

Antimatter and matter particles have the same mass but differ in properties such as electric charge and spin. The Standard Model – the theory that best describes particles and their interactions – predicts that gravity should have the same effect on matter and antimatter; however, this has yet to be seen. Experiments at CERN, such as AEGIS, ALPHA and GBAR, are trying to find out.

Observing gravity's effect on antimatter is not quite as easy as watching an apple fall from a tree. These experiments need to hold antimatter in a trap or slow it down by cooling it to temperatures

REVIEW

- ✓ Physics
- ✓ Particle physics
- ✓ Literature and philosophy
- ✓ Ages 16–19

The article provides a good insight into antimatter, giving examples of how antiparticles are important to our lives and how they can become even more important to our society. It tries to bring antimatter closer to our everyday existence, showing how small antiparticles are produced on Earth around us, and even by us.

Written in a style that stimulates further research, the article not only offers a good starting point for topics concerning particle physics, but also can be used to trigger discussions amongst pupils. Students can consider how science fiction and science interact – and which one anticipates the other – and the article can be linked to non-science disciplines such as history, literature and art.

Marco Nicolini, physics, maths and astronomy teacher, science journalist, European School of Brussels II, Belgium

Maximilien Brice/CERN

The antiproton decelerator at CERN decelerates antiprotons before sending them to several experiments studying antimatter.

just above absolute zero. And because gravity is the weakest of the fundamental forces, physicists must use uncharged antimatter particles in these experiments to prevent interference from the more powerful electrical force.

6. Antimatter is studied in particle decelerators

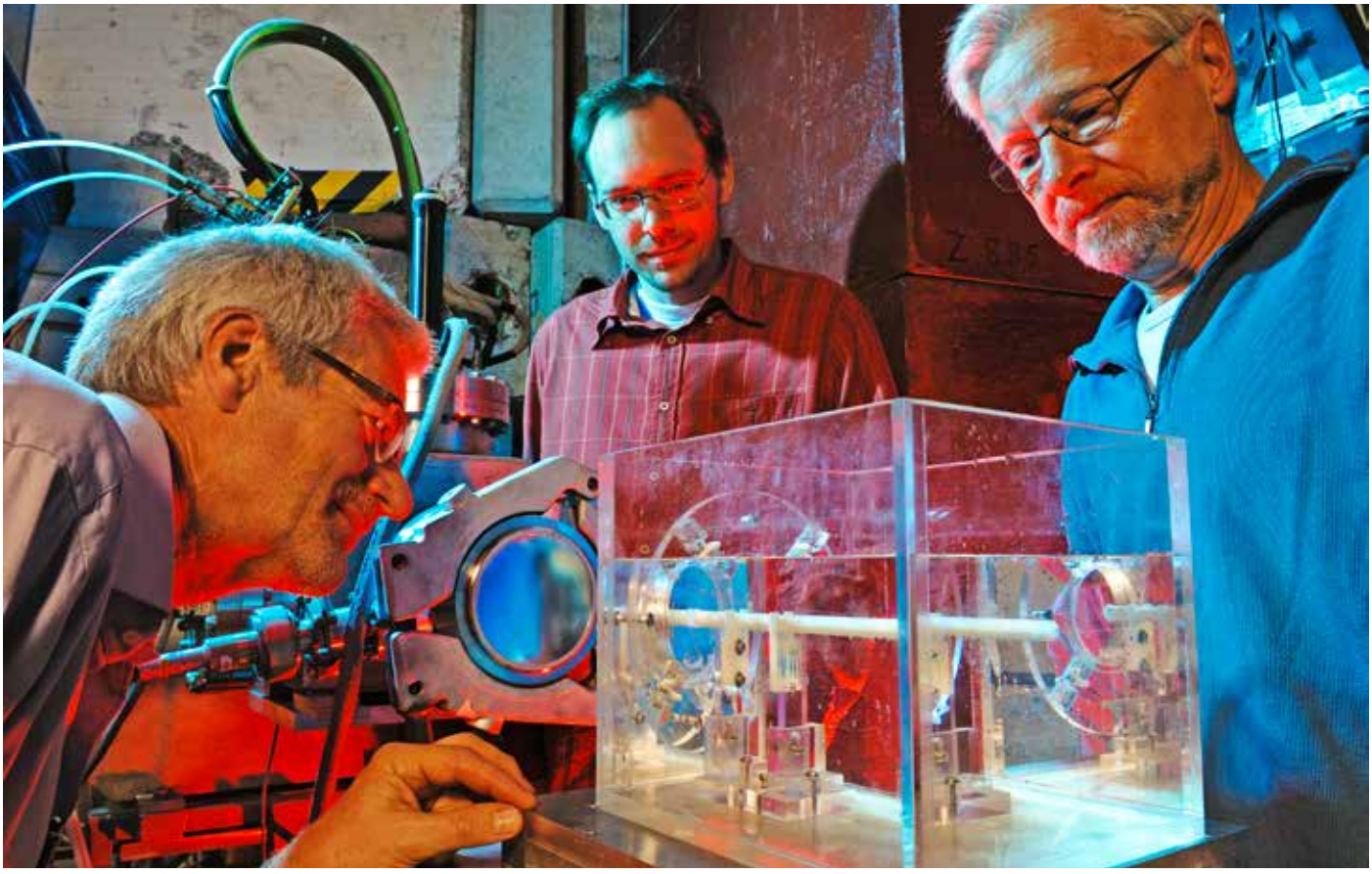
You've heard of particle accelerators, but did you know there are also particle decelerators? CERN houses a machine called the antiproton decelerator, a storage ring that can capture and slow antiprotons to study their properties and behaviour.

In circular particle accelerators like the Large Hadron Collider, particles get a kick of energy each time they complete a rotation. Decelerators work in reverse; instead of an energy boost, particles get a kick backward to slow their speeds.

7. Neutrinos might be their own antiparticles

A matter particle and its antimatter partner carry opposite charges, making them easy to distinguish. Neutrinos – nearly massless particles that rarely interact with matter – have no charge. Scientists believe that they may be Majorana particles, a hypothetical class of particles that are their own antiparticles.

To determine whether this is the case, scientists are looking for a behaviour called neutrinoless double-beta decay.



Maximilien Brice/CERN

At CERN's antiproton cell experiment (ACE), a particle beam enters a tube of cells in the centre of a tank to investigate the use of antimatter to treat cancer.

Public domain image

The Alpha Magnetic Spectrometer (centre left) on the International Space Station.

Some radioactive nuclei simultaneously decay, releasing two electrons and two neutrinos. If neutrinos were their own antiparticles, they would annihilate each other in the aftermath of the double decay, and scientists would observe only electrons.

Finding Majorana neutrinos could help explain why matter-antimatter asymmetry exists. Physicists hypothesise that Majorana neutrinos can be either heavy or light. The light ones exist today, and the heavy ones would have existed only right after the Big Bang. These heavy Majorana neutrinos would have decayed asymmetrically, leading to the tiny matter excess that allowed our Universe to exist.

8. Antimatter is used in medicine

Positron emission tomography uses positrons to produce high-resolution images of the body. Positron-emitting radioactive isotopes (like the ones found in bananas) are attached to chemical substances, such as glucose, that are used naturally by the body. These compounds are injected into the bloodstream, where they are naturally broken down, releasing positrons that meet electrons in the body. These particles annihilate each other, producing gamma rays that are used to construct images.

Physicians can already target tumours with precise beams of protons that release their energy only after safely passing through healthy tissue. But scientists working on CERN's antiproton cell experiment (ACE) studied the effectiveness and suitability of using antiprotons instead, which adds an extra burst of energy. The technique was found to be effective in hamster cells, but researchers have yet to conduct studies in human cells.

9. Leftover antimatter might still be lurking in space

To solve the antimatter-matter asymmetry problem, scientists are looking for antimatter left over from the Big Bang. They search for these particles using the alpha magnetic spectrometer (AMS), a particle detector on top of the International Space Station.

The AMS contains magnetic fields that bend the path of cosmic particles to separate matter from antimatter. Its detectors assess and identify the particles as they pass through.

10. Antimatter could fuel spacecraft

Just a handful of antimatter could produce a huge amount of power, making it a popular fuel for futuristic vehicles in science fiction.

Antimatter rocket propulsion is hypothetically possible, but there is currently no technology available to mass-produce or collect antimatter in the volume needed. One day, if we can figure out a way to create or collect enough antimatter, antimatter-propelled interstellar travel could become a reality.

Acknowledgement

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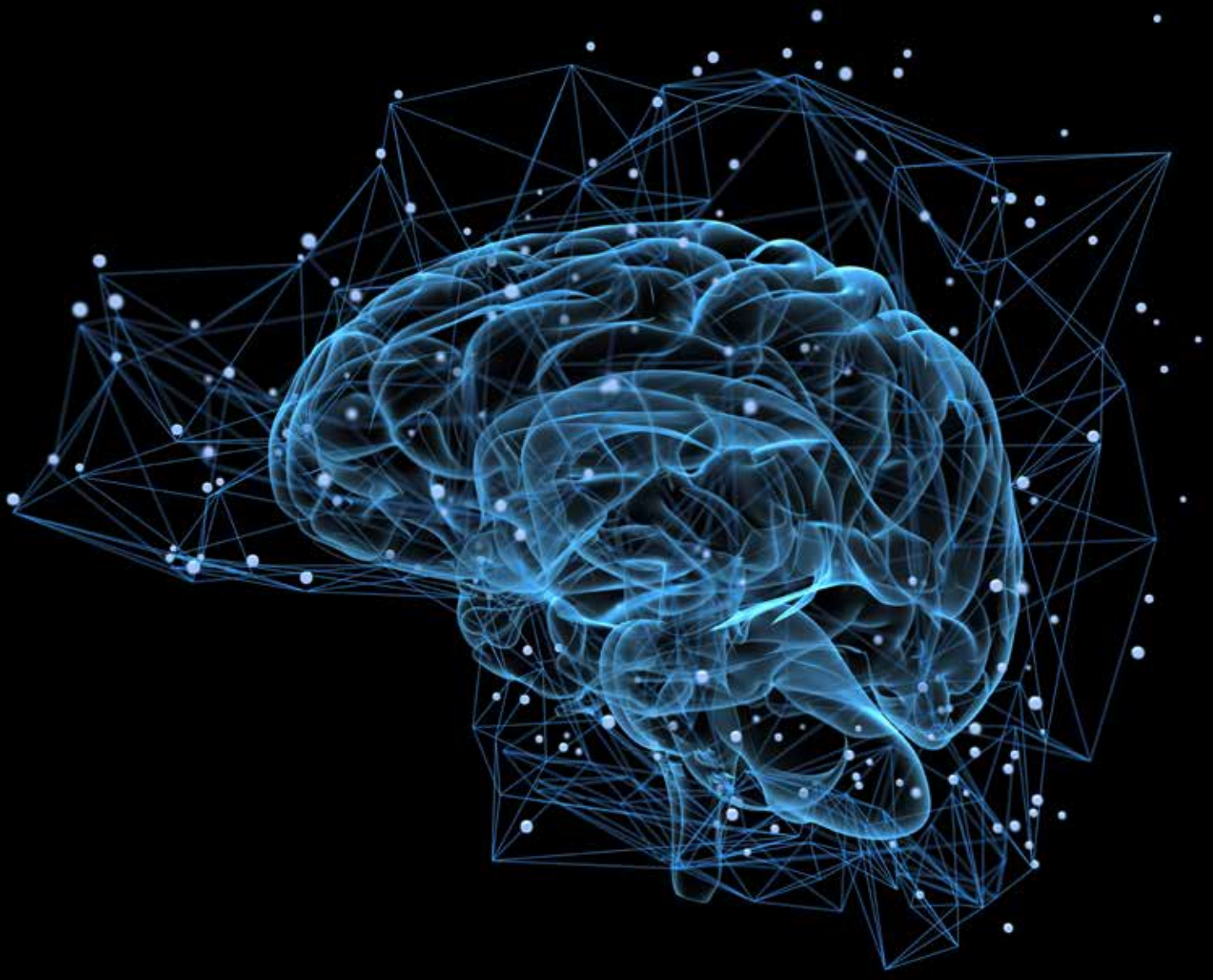
Web reference

w1 *Symmetry* magazine is a free online publication covering particle physics. It is jointly published by Fermi National Accelerator Laboratory and SLAC National Accelerator Laboratory, USA. To see the original article, visit the *Symmetry* website. See: www.symmetrymagazine.org/article/april-2015/ten-things-you-might-not-know-about-antimatter or use the direct link http://tinyurl.com/oaefu89

Diana Kwon is a freelance science journalist based in Berlin, Germany. Her work has appeared both in print and online in numerous outlets including *Scientific American*, *Quartz* and *New Scientist*.

Guardian of the brain: the blood-brain barrier

Insights into the brain's unique protective barrier could offer promising treatments for diseases such as multiple sclerosis and Alzheimer's.



Tatiana Shepeleva/Shutterstock.com

The brain is arguably the most important and sensitive organ in the human body.

By Yun Jiang

When the German scientist Paul Ehrlich injected dye into the bloodstream of mice more than 130 years ago, he came across an unusual phenomenon. The dye slowly spread across the tissue, staining every organ except one – the brain. Although Ehrlich's staining experiments would eventually culminate in his discovery of the first chemotherapy drug to treat syphilis – and earn him a Nobel Prize – this particular result puzzled him. He suggested that this lack of staining was due to the brain tissue taking up less dye.

When one of his students, Edwin Goldman, injected the dye directly into the brain instead, the explanation became more obvious. The opposite effect occurred: only the brain was stained, and the other organs were spared (see figure 1). This was the first indication of the blood-brain barrier – first termed *Blut-Hirn-Schranke* in German – separating the circulating blood from the brain and spinal cord of the central nervous system (CNS). It was not until the introduction of electron microscopy in the 1960s that this barrier was precisely located, and the tightly woven ultrastructure of the cells responsible became visible.

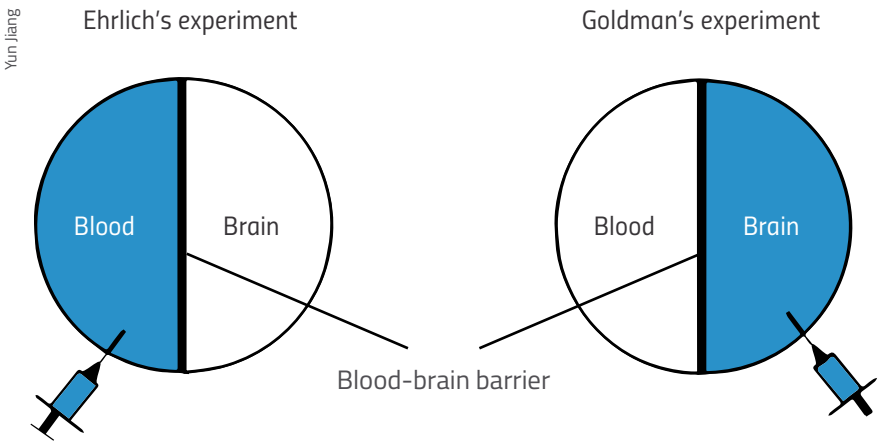


Figure 1: The dye-injecting experiments of Ehrlich and Goldman resulted in the discovery of a barrier separating the circulating blood from the brain.

What is the blood-brain barrier?

Our understanding of the brain – arguably the most important and sensitive organ in the human body – is still far from complete. But our knowledge of the blood-brain barrier has advanced considerably since Ehrlich's time.

Throughout the body, endothelial cells line the inner surface of blood vessels and lymphatic vessels. Blood

REVIEW

- ✓ Biology
- ✓ Cell specialisation
- ✓ Membrane transport
- ✓ Neurological diseases
- ✓ Ages 16–19

This article elegantly describes an observation made over 100 years ago of the distribution of a dye and the conclusion that there is a physical barrier that protects the brain. The article is engaging as it inspires the reader to reflect on the anatomically and functionally unique structure of the blood-brain barrier.

The link between damage to the blood-brain barrier and neurological diseases is important as this could lead to advances in the treatment of central nervous system diseases. The focus on multiple sclerosis is relevant given that it is the most common neurological disability among young people.

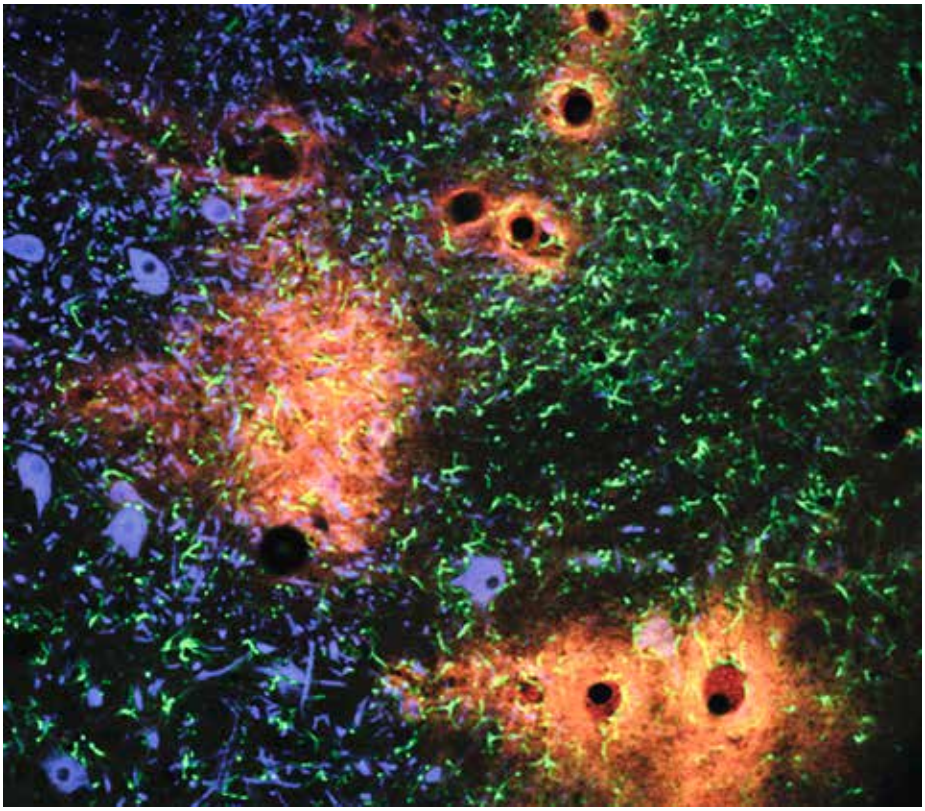
The article is useful for background reading and comprehension exercises. It could also be used for discussions such as the use of stem cells to repair the blood-brain barrier. There is potential for the article to form a starting point for extended essays.

Questions about the article could include:

- What specialisations allow the endothelial cells to form tight junctions?
- How are molecules transported across the blood-brain barrier?
- List the factors that might disrupt normal functioning of the blood-brain barrier.
- Is the term blood-brain barrier appropriate, as evidence shows it is a dynamic structure allowing controlled passage of molecules?

Dr Mary Brenan, biology teacher, Concord College, UK

Science Photo Library/Guerin, C.J./ Phd/Mrc Toxicology Unit



Light micrograph of a section through the brain showing a breakdown in the blood-brain barrier. A fluorescent tracer (orange) has been injected into the blood vessels (round, black) and is leaking out of them into the surrounding brain tissue.

"The brain needs special care and protection because many substances that are harmless to other organs could be toxic to the central nervous system."

endothelial cells, for example, control the exchange of substances between circulating blood and the surrounding tissue. The brain, however, needs special care and protection, because many substances that are harmless to other organs could be toxic to the CNS. For instance, some proteins in the plasma – such as albumin and immunoglobulin – can cause inflammation in the nervous system.

To stop these substances reaching the brain, specialised endothelial cells form a barrier to restrict the movement of substances from the circulating blood to the extracellular fluid in the CNS. The key difference between these cells and normal endothelial cells is how they are stitched together.

Tight junctions

A variety of special seals, known as tight junctions, connect the spaces between adjacent brain endothelial cells. The tight junctions are formed by proteins that span the cell membranes. Inside the cells, the proteins are anchored to the cytoskeleton (a network of fibres within a cell that helps gives the cell its shape), whereas outside the cell, they interact with the other tight junction proteins of neighbouring cells. Like double-sided tape, the tight junctions stick two cells together to prevent the passage of most molecules and ions through the space between the cells (see figure 2).

Only some small molecules (water; certain gases such as oxygen and carbon dioxide) and lipid-soluble substances (such as small fatty acids) can move passively through the barrier. Other selected molecules, such as glucose, must be transported by specialised transport proteins embedded in the cell membranes. Thus, the brain's microenvironment is maintained so that the nervous system functions optimally and the CNS is protected from harmful substances.

Besides the tight endothelium, neurons and other specialised non-neuronal cells (such as astrocytes and microglia) orchestrate the function of the blood-brain barrier (see figure 3). Together with endothelial cells, they form a dynamic structure called the neurovascular unit (NVU). If any of the cells in the NVU fail, the barrier breaks down.

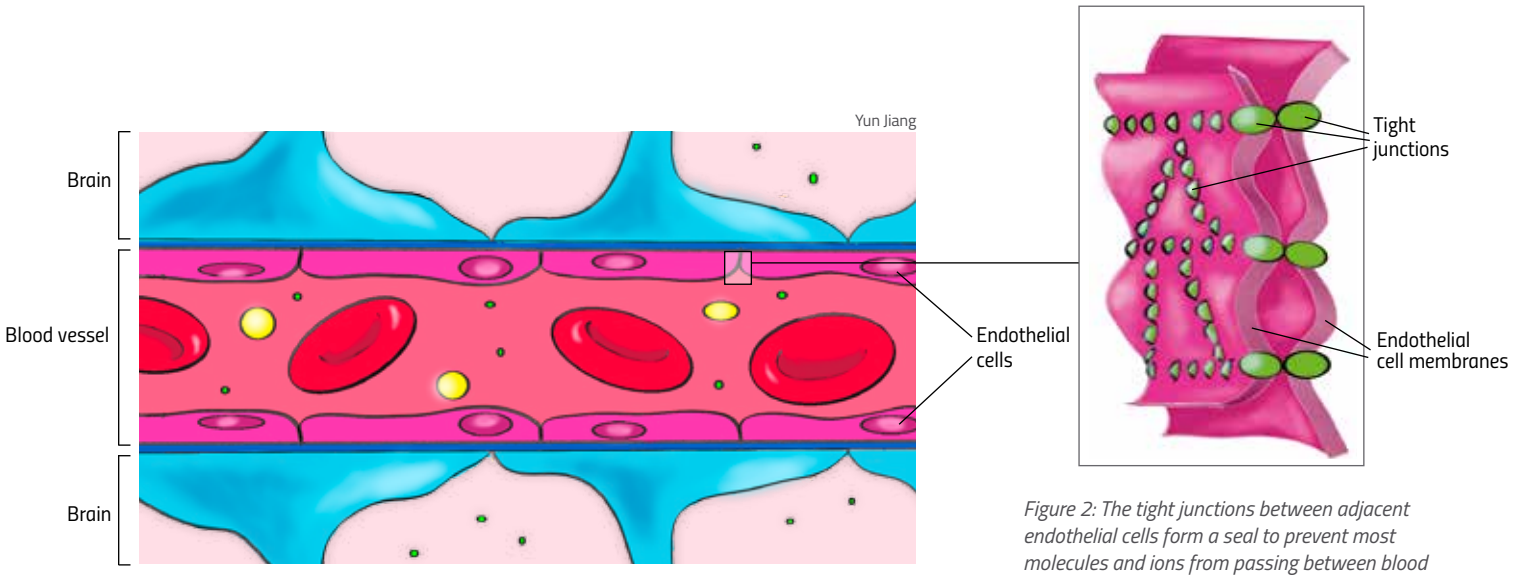


Figure 2: The tight junctions between adjacent endothelial cells form a seal to prevent most molecules and ions from passing between blood vessels and the brain.

The blood-brain barrier and neurological diseases

Various disorders, such as infection or trauma, can damage the tight junctions and the NVU, disrupting the tightly knitted structure of the blood-brain barrier. When this happens, the formerly controlled flux of molecules and ions in and out of the brain becomes erratic. Toxins, pathogens or cells of the immune system might enter the brain, causing the CNS to become inflamed. In response, cells release related cytokines – substances that are secreted following inflammation or immune system activity. This disrupts the neurons and causes them to degenerate, leading to the development of neurological diseases.

One such disease is multiple sclerosis (MS), an autoimmune disorder in which the immune system attacks the CNS. Patients experience numb arms and legs, sensations of electric shocks and problems with their vision. The development of MS is complicated, but changes to the blood-brain barrier are believed to play an important role. Scientists think that some initial inflammatory responses help to increase the permeability of the barrier, which allows immune cells to invade the

> **"Like double-sided tape, the tight junctions stick two cells together to prevent the passage of most molecules and ions through the space between the cells"**

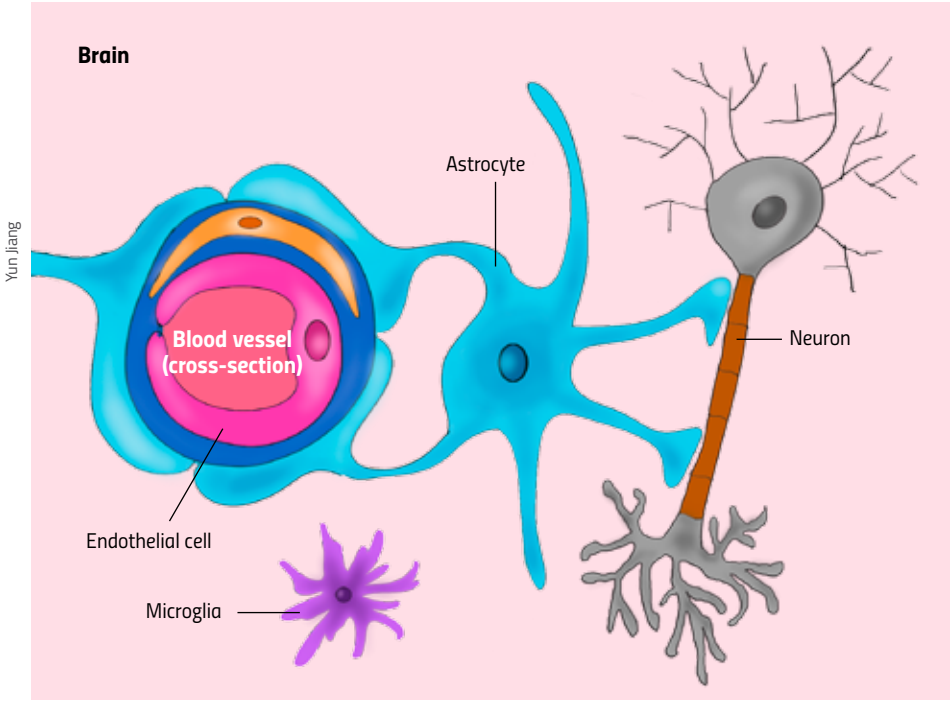
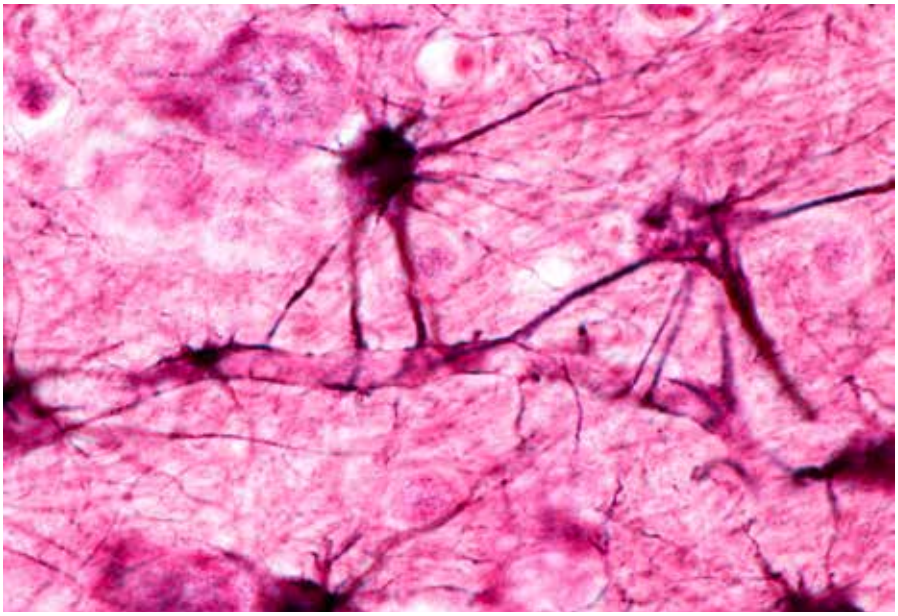


Figure 3: The brain endothelial cells, together with neurons and other specialised cells (e.g. astrocytes and microglia), form an interactive network collectively known as the neurovascular unit.

Jose Luis Calvo/Shutterstock.com



Specialised cells called astrocytes are an important component of the neurovascular unit. In this micrograph, the astrocytes are seen attached to the wall of the blood vessel.

> **"The development of multiple sclerosis is complicated, but changes to the blood-brain barrier are believed to play an important role."**

brain. This boosts the inflammatory responses in the CNS, which further disrupts the barrier and increases the damage to nerve cells.

Therapies for the future

Many studies have shown the link between the disruption of the blood-brain barrier and other neurological diseases, including stroke, epilepsy, Alzheimer's disease and Parkinson's disease. Scientists therefore believe that enhancing the repair of a damaged blood-brain barrier is a good strategy for treating neurological diseases.

One example of such treatment is the use of a steroid hormone called glucocorticoid, which reduces the unwanted inflammatory responses and is believed to influence the formation of tight junctions. Glucocorticoid has been shown to repair the blood-brain barrier in both MS patients and related mouse models (Salvador et al., 2014). However, this hormone may not be suitable for using as a long-term treatment due to its side effects, which include mood changes, gastrointestinal problems and high blood-sugar levels (Ciriaco et al., 2013; Liu et al., 2013).

Nevertheless, other potential therapies are still under investigation. Transplanting a type of progenitor cell that can generate new endothelial cells, for example, could help to reconstruct the blood-brain barrier following stroke (Kaneko et al., 2012). As studies continue, a deeper understanding of the disruption and repair of the blood-brain barrier will offer more options for the treatment of related neurological diseases.

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Resources

For an introduction to the blood-brain barrier for children, visit the University of Washington website. See: https://faculty.washington.edu/chudler/bbb.html

For a further introduction about the blood-brain barrier and the neurovascular unit, watch these videos on YouTube. See: www.youtube.com/watch?v=_e60_4ZV0zs or use the direct link http://tinyurl.com/yd7z844p and www.youtube.com/watch?v=e9sN9gOEdG4 or use the direct link http://tinyurl.com/yaex8nl3

Yun Jiang has a master's degree in biochemistry and molecular biology and is now a senior PhD student in the Institute for Experimental and Clinical Pharmacology and Toxicology at the University of Lübeck, Germany. Yun works mainly on research regarding the inflammation of brain endothelium in the development of related diseases, and she was an early stage researcher of the Marie Curie Initial Training Network.

John Hann/Flickr

Student competition: the search for the strangest species on Earth

Get a glimpse into the weird and wonderful life on Earth with the three winning entries in the *Science in School* writing competition.

In issue 36 of *Science in School,* we invited students across Europe to enter our first writing competition to tell us about their choice for the strangest species on Earth. More than 80 students submitted their work, but three entries convinced the judges that their chosen organisms – the naked mole-rat, the jellyfish *Turritopsis dohrnii*, and the freshwater polyp *Hydra vulgaris* – are indeed the strangest on Earth. Coincidentally, these species all share one unusual feature that evidently sparked many students' imaginations – they can defy ageing.

We are now pleased to share the winning entries with you, alongside commentaries from scientists working on these organisms.

Age category: 4–10

Naked mole-rat *(Heterocephalus glaber)*

Hayden Cookson (aged 7), UK

I think the naked mole-rat is the strangest organism because doctors think that it can help to cure cancer. This is because naked mole-rats never get cancer and people think they are resistant. They can move their incisors individually or together like chopsticks.

Meghan Murphy, Smithsonian's National Zoo/Flickr

The naked mole-rat

What the scientist says...

Dr Ewan St John Smith is a senior lecturer in pharmacology at the University of Cambridge and the director of the university's naked mole-rat initiative, which aims to bring together experts to identify molecular explanations for this species' highly unusual physiology.

Why do you think the naked mole-rat is so unusual?

Outwardly, naked mole-rats look like cocktail sausages with legs and teeth, but beyond this comical appearance lies a world of fascinating biology that could help scientists identify new treatments for a wealth of conditions.

Naked mole-rats are cold-blooded and live in large colonies (usually about 80 animals) headed by a single breeding female (the queen) – a highly unusual characteristic for a mammal. Naked mole-rats can live for up to 30 years, whereas a similar sized mouse has a maximum life expectancy of only about 3 years. How do naked mole-rats live so long? One reason could be their high resistance to cancer, one of the many unusual extremes displayed by this species.

Naked mole-rats respond normally to mechanical and thermal stimuli, but they do not feel pain in response to acid. Naked mole-rats can also cope for long periods of time without oxygen due to their cells being able to use fructose to power energy production during these times.

How do you use the naked mole-rat for your research?

By understanding the unusual characteristics of the naked mole-rat, we can discover more about normal physiology in other mammals. For example, understanding the genetic mechanism behind the naked mole-rat's insensitivity to acid has increased scientific understanding of how pain works. If scientists can determine why naked mole-rats are resistant to cancer, it may lead to the development of new cancer treatments. And understanding how brain cells of the naked mole-rat survive without oxygen could result in the development of novel treatments to prevent brain damage in stroke patients, which occurs when the blood flow to the brain is cut off, depriving cells of oxygen and glucose.

Hayden Cookson

Drawing of the naked mole-rat by Hayden Cookson (aged 7)

Resources

Read more about the life history of the naked mole-rat on the Smithsonian's National Zoo website. See: www.nationalzoo.si.edu/animals/naked-mole-rat

Learn more about the extraordinary traits of the naked mole-rat in this *Wired* article. See: www.wired.co.uk/article/naked-mole-rats-amazing

The Telegraph reports on how scientists discovered that naked mole-rats can survive for 18 minutes without oxygen. See: www.telegraph.co.uk/science/2017/04/20/naked-mole-rats-turn-plants-survive-without-oxygen-scientists/ or use the direct link http://tinyurl.com/ydeytbyq

Learn more about the University of Cambridge's Naked Mole-Rat Initiative. See: www.phar.cam.ac.uk/research/NMRI

Age category: 11–15

Turritopsis nutricula (now classified as *Turritopsis dohrnii)*

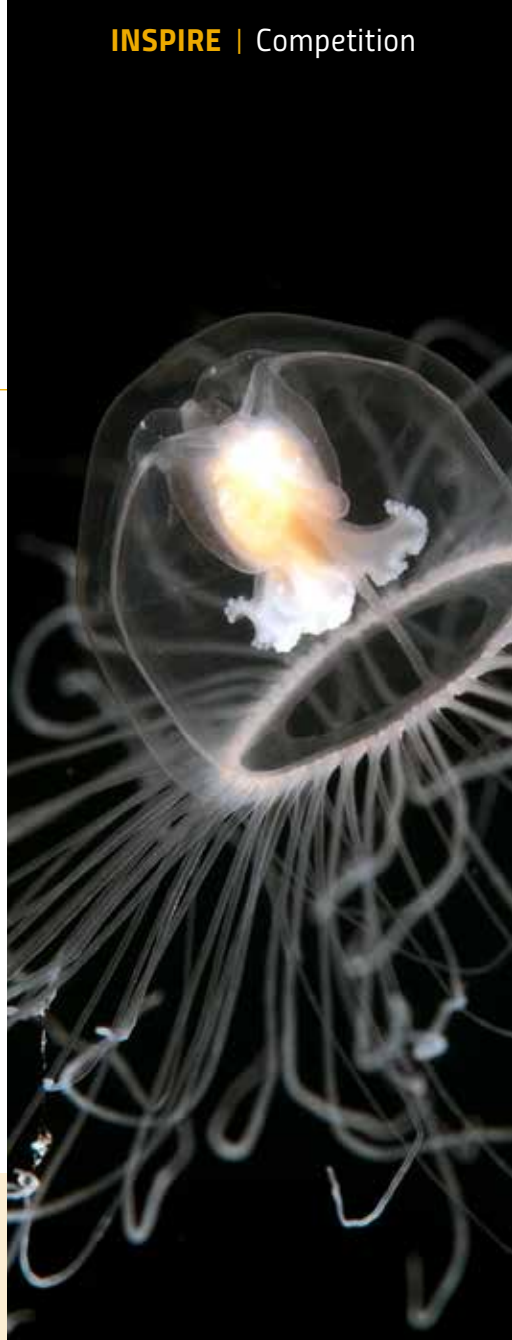
Ana Aragón, Sara Hidalgo, Xavi Valeri (aged 13), Spain

We think that the strangest organism on Earth is *Turritopsis nutricula*. It's a hydroid jellyfish of the family Oceanidae. It's originally from the Caribbean Sea, but now it's found around the world, in all the warm and tropical seas. Since scientists spotted it in Colombia, it has also been seen near Japan and in the Mediterranean Sea.

It's about 4–5 mm in diameter. It's tall with a transparent and gelatinous skin. The young organisms have eight tentacles and the adults can have 80–90 tentacles! It has a big red stomach inside, and it can shine in the dark! Scientists think that it's because it's toxic. We think that this species is strange because scientists say that it's immortal. They think that it's immortal because it doesn't reproduce in the normal way.

The reproduction is done in different ways. Some species are sexual but others are asexual. Sexual jellyfish (male and female) drop sperm and eggs into the water allowing them to fertilise

> "We think that this species is strange because scientists say that it's immortal."



The immortal jellyfish, Turritopsis dohrnii

zaferkizilkaya/Shutterstock.com

What the scientist says...

Dr Maria Pia Miglietta is an assistant professor in the department of marine biology at Texas A&M University in Galveston, USA. Her laboratory studies the evolution and genetics of Hydrozoa and jellyfish, including reverse development in *Turritopsis dohrnii*.

Why do you think *Turritopsis dohrnii* is so unusual?

T. dohrnii is a species with a very unusual life cycle. Most organisms reproduce, age and die, but *T. dohrnii* has escaped this fate. When faced with stressful conditions – such as a lack of food, sudden change in salinity, or physical damage – this jellyfish species avoids death by reverting to the polyp stage.

The jellyfish settles on the ocean floor and develops into a cyst-like mass of cells. Around 24 to 72 hours later, this cluster transforms back into a polyp, which grows into a colony that can produce hundreds of new jellyfish. This process is a true metamorphosis, albeit in the opposite direction of the normal developmental cycle, and it has earned *T. dohrnii* the name 'immortal jellyfish'.

We believe that the ability to revert to the polyp stage in unfavourable conditions makes this species a good hitchhiker in ballast waters of ships. This helps explain why *T. dohrnii* has been found in marine waters around the world, including Italy, Japan, Florida, Panama, Brazil and California.

How do you use *Turritopsis dohrnii* for your research?

My research group studies the unusual life cycle of *T. dohrnii* from genetic and cellular perspectives. We are trying to understand which genes allow *T. dohrnii* to avoid senescence, and are particularly interested in what happens in the cyst-like mass of cells at the genetic level. The unique life cycle of *Turritopsis* may help us understand the biology of ageing, regeneration and cellular differentiation.

and create larvae. Individual larvae search for a place in the sand and when they touch the ground, they become polyps. Each polyp grows and shows some tentacles and then it divides into parts, which float. Then, in the water, they join together with the tentacles facing downwards to create the jellyfish. The jellyfish grows and when it's older, its cells start to regenerate and it returns to a polyp. It can do this process in all its stages. That means that it's a species that has a life cycle in which it returns to the polyp phase after it arrives at sexual maturity.

Laboratory studies showed that 100% of the jellyfish specimens could return to the polyp phase. This species (*Turritopsis nutricula*) is the only jellyfish that has the ability to do it, because to return to the polyp phase, the jellyfish has to have some specific cells. But that doesn't mean that it is indestructible. It can die, for example, because it has some illness or because some predators eat it. Professionals say that this ability to avoid dying is probably unique in the animal kingdom – that's the reason why we think this is the strangest organism on Earth.

Resources

Learn more about the discovery of the immortal jellyfish and how scientists are studying this species in the article 'Can a jellyfish unlock the secret of immortality?' from *The New York Times Magazine*. See: www.nytimes.com/2012/12/02/magazine/can-a-jellyfish-unlock-the-secret-of-immortality.html or use the direct link http://tinyurl.com/c9yb2bf

Watch a video from SciShow explaining how *Turritopsis dohrnii* extends its life cycle. See: www.youtube.com/watch?v=2kLSiE-eNjw or use the direct link http://tinyurl.com/y9cdjfsf

A study in 2008 compared the DNA of immortal jellyfish from waters around the world and found that all the genes that the scientists looked at were identical. Read more about this discovery on the National Geographic website. See: http://news.nationalgeographic.com/news/2009/01/090130-immortal-jellyfish-swarm_2.html or use the direct link http://tinyurl.com/y7lu3rf8

Age category: 16+

Hydra vulgaris

Aleksandra Markowska, Halina Ravensdale (aged 17), Poland

Take a close look at your aquarium. Can you see anything special and peculiar?

Looking for the strangest organism on Earth, we spent several days travelling across jungles, snorkelling through depths of oceans and freezing on the North Pole, before we realised that the most bizarre animal might be closer than we had thought. Its ability to regenerate after being cut, the abysmal eating process, and the fact that it does not undergo senescence and appears to be immortal are all proof that *Hydra vulgaris* can be considered one of the strangest living organisms.

To entirely understand the extraordinary way the animal nourishes itself, we must focus on the exterior of its body. A *Hydra vulgaris* is usually about 5 mm to 15 mm long, although rarely some can reach up to 3 cm. It has a body form of a polyp. Its simple structure, consisting of a cylindrical main body, ends with several tentacles that serve as a weapon. The cnidae contain nematocytes that have neurotoxins which are released in the form of a dark thread to paralyse small water animals. The other side terminates with a foot called a basal disc used to stick to surfaces. The astonishing thing is that unlike other animals *Hydra vulgaris* has to transform its body in order to consume a prey. The transformation begins with the deformation of cells. Soon, a black

Lebendkulturen.de/Shutterstock.com

The freshwater polyp, Hydra vulgaris

maw is moulded. Following the 'mouth' construction stage, the animal sucks in the paralysed victim as the slot closes behind it, shattering any hope of escape. As staggering as it seems, it gets even more peculiar.

Now it is time for an observation. You can test *Hydra*'s regeneration abilities using a sterile scalpel blade. Cut it into two parts. After several hours, you will notice that wounding its body does not kill it – just like the mythical Larnaean Hydra, it is able to rebuild the segregated parts. This incredible process is called morphallaxis. The animal reorganises its body to form a new smaller version of itself, which is followed by the organism's growth. When we cut a hydra, the part with the head or foot will transform itself into a whole organism with a new foot or a new head, respectively. A part with neither foot nor head will form a new hydra with both of them. Ethel Browne experimented with transplanting a hypostome and foot to the middle part of another hydra and discovered the existence of the head and basal activator gradient responsible for the formation of a new head or foot when damaged. Soon, the presence of the head and basal disc inhibitor gradient that prevented more than one head or foot from forming was discovered.

> **"The astonishing thing is that unlike other animals, *Hydra vulgaris* has to transform its body in order to consume prey."**

It is common knowledge that human beings replace skin cells every three weeks. Imagine how phenomenal it would be if we could exchange all the other cells from our entire body as well at the same time, which would result in immortality. That is exactly what the *Hydra vulgaris* does – it eludes the whole process of ageing, fertility loss and dying. It is necessary to emphasise the existence of a specific pattern in nature: animals that have offspring sooner, die sooner. Hydrae have

What the scientist says...

Dr Eva-Maria S Collins is an associate professor in physics and cell and developmental biology at the University of California, San Diego, USA. Her research aims to use quantitative and biophysical approaches to answer fundamental biological questions in embryonic development and regeneration. For her studies, she works with two fascinating regenerative organisms: freshwater planarians and the cnidarian *Hydra vulgaris*.

Why do you think *Hydra vulgaris* is so unusual?

At first glance, the freshwater polyp *Hydra vulgaris* is a rather inconspicuous animal – you may even mistake it for a plant. But don't let its appearance fool you – this little creature, just a few millimetres long, has amazing capabilities: cut a piece of its body – or even dissociate the animal into a soup of individual cells – and it will regenerate into a new *Hydra*. Moreover, one can separate and recombine tissues from different individuals of *Hydra,* generating chimeric animals with different characteristics.

Since *Hydra* is such a strong regenerator, it can also reproduce asexually through budding, and purely asexual individuals actually seem to defy ageing altogether. The feeding behaviour of *Hydra* is also unusual: since they lack a permanent mouth opening, *Hydra* have to rip a hole in their 'face' every time they want to feed.

How do you use *Hydra vulgaris* for your research?

Hydra's simple anatomy, optical transparency, ease of manipulation and unusual regenerative capabilities make it an excellent model to study fundamental biological questions. For example, by understanding how *Hydra* regenerate from re-aggregated cells, we can discover important principles of how cells self-organise, which may also play a role in pattern formation during embryonic development in other organisms.

My research group is particularly interested in how mechanical forces (such as how cells push and pull on each other and their extracellular environment) guide cell behaviour and tissue organisation. If we understand how cell behaviours are regulated, we can use this knowledge to direct stem cell behaviour to repair diseased or damaged tissue – the goal of regenerative medicine.

progeny after a couple of days, thus they should die at the age of one month but they do not. To profoundly understand this phenomenon, we have to know what is happening at the molecular level. The continuous exchanging of *Hydra*'s cells is caused by the self-renewal capacity of its stem cells. A research team based in Kiel, Germany, discovered that the FoxO gene (also present in humans) is responsible for maintaining the activity of these cells.

Hydroids could be a salutary examination object in the medical area. Research conducted by a group of students at University College London, UK, found that genes associated with neurodegenerative disease are exactly alike in humans and hydrae. Hydrae possess genes specifically associated with Huntington's disease and Alzheimer's disease. Scientists continue to observe hydrae in the belief that they are capable of replacing degenerated genes, thus curing themselves of the disorders mentioned above.

> **"*Hydra vulgaris* eludes the whole process of ageing, fertility loss and dying."**

To summarise, we consider these freshwater polyps as the strangest animals on Earth not only because of their bizarre exterior or their weird eating habits, but also because these tiny creatures could assist us in breaking through obstacles that educated doctors cannot overcome with patients who have neurodegenerative illnesses.

Resources

Understand how a *Hydra*'s cells split apart when it opens its mouth with these videos from EurekAlert! and HowStuffWorks. See: www.eurekalert.org/pub_releases/2016-03/cp-itm030216.php or use the direct link http://tinyurl.com/jyvft95 and http://shows.howstuffworks.com/now/hydra-mouth-video.htm or use the direct link http://tinyurl.com/yc769jdd

Watch the animation 'The animal that wouldn't die' from Aeon to understand the regenerative power of *Hydra vulgaris*. See: www.aeon.co/videos/the-hydra-s-amazing-resilience-challenges-ideas-that-all-living-things-must-die or use the direct link http://tinyurl.com/ybkr8238

Read about the role of the transcription factor FoxO in regulating stem cell maintenance in *Hydra*. See:

Boehm A M et al (2012) FoxO is a critical regulator of stem cell maintenance in immortal Hydra. *Proceedings of the National Academy of Sciences USA* **109(48):** 19697–19702. doi: 10.1073/pnas.1209714109

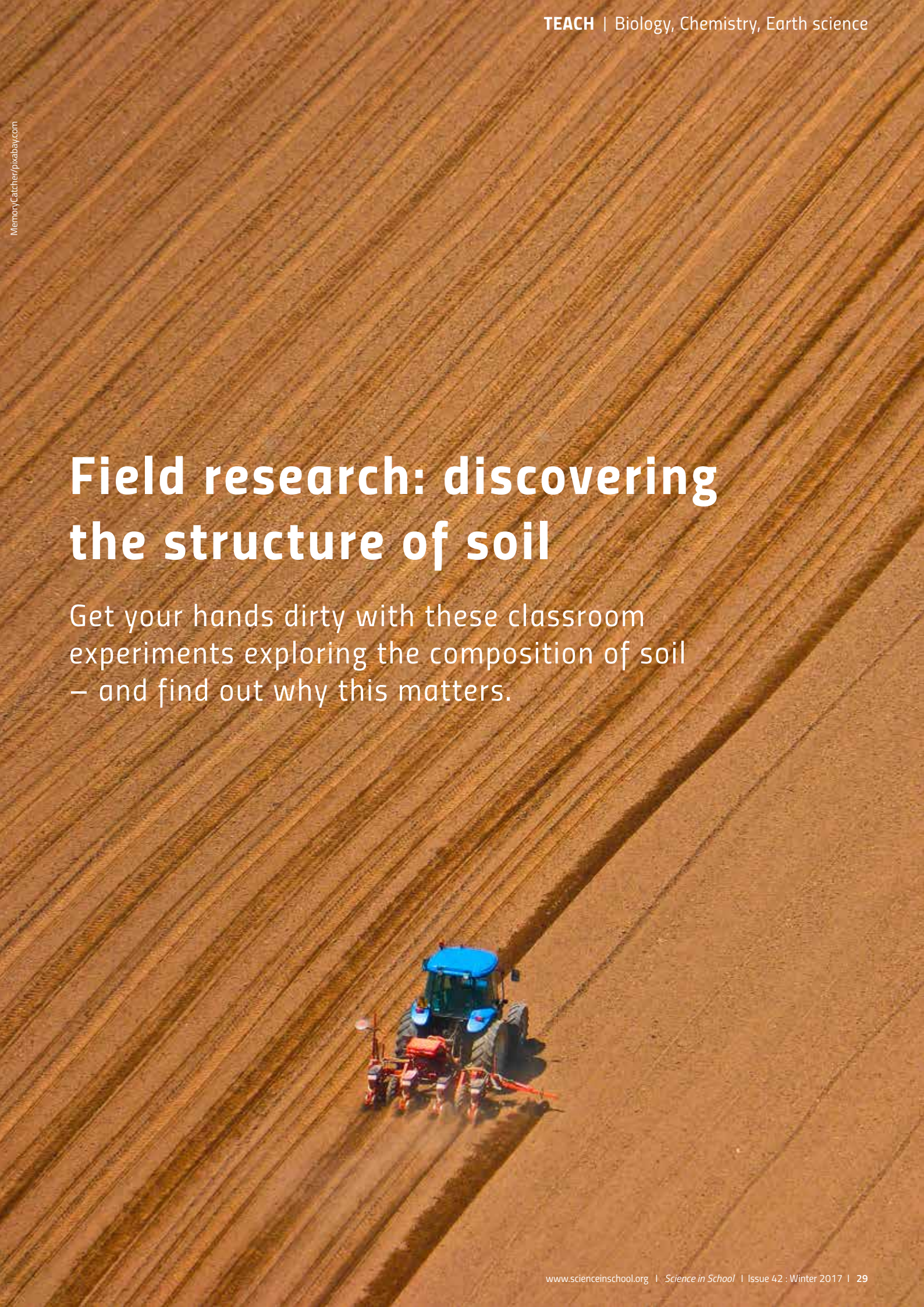
Watch the SciShow video about the immortality of *Hydra vulgaris* and what we can learn from this organism. See: www.youtube.com/watch?v=4h-tUWjesyg or use the direct link http://tinyurl.com/y94vwudo

Biologists have sequenced the *Hydra vulgaris* genome and discovered genes linked with Huntington's and Alzheimer's diseases. See: www.eurekalert.org/pub_releases/2010-03/uoc--uib031210.php or use the direct link http://tinyurl.com/yc72qn27

Learn more about the Collins laboratory's research using *Hydra* at the University of California. See: http://schoetzlab.ucsd.edu/research.html

Lebendkulturen.de/Shutterstock.com

This unusual freshwater polyp is only a few millimetres long.



MemoryCatcher/pixabay.com

Field research: discovering the structure of soil

Get your hands dirty with these classroom experiments exploring the composition of soil – and find out why this matters.

By Barbara Birli, Jane Mills, Francesco Morari

Soil is essential for life on this planet. Without it, we could not grow the food we need to live. What's perhaps less well known is that soil has other important functions, too, such as filtering our water, storing it to help prevent flooding and droughts, and providing a habitat for a third of the world's biodiversity – most of which we still know very little about. Soils also have a large impact on climate change, as they can store large amounts of organic carbon and are the most important terrestrial sink for carbon dioxide (Janzen, 2004).

The way we use land has a clear influence on the way soil functions, and thus on all the benefits we gain from it. The more that soil is disturbed through building activities, intensive agriculture, digging or ploughing, the greater the loss of organic matter, which in turn increases the danger of soil erosion, where soil is washed away. Adding organic matter (such as manure) to soil can rebuild its organic content and improve the soil structure, ensuring lower nutrient loss and helping to prevent soil erosion.

Erosion is a problem for all of us: studies estimate that around 11% of European Union (EU) land is currently affected by soil erosion to a moderate or high level (that is, more than 5 tonnes per hectare per year)[w1]. Not only does erosion

"Studies estimate that around 11% of EU land is currently affected by soil erosion to a moderate or high level."

REVIEW

- ✓ Earth sciences
- ✓ Biology
- ✓ Environmental sciences
- ✓ Chemistry
- ✓ Ages 11–19

Earth science is often not the most popular subject in school curricula, and the topic of soil science in particular can be seen as quite boring. This perception can be challenged by the activities proposed in this article.

The article, which is clear and accessible for non-native English speakers, presents soil characteristics in an inspiring way through simple, hands-on experiences that are easily carried out in the classroom without special equipment. Teachers can also widen their knowledge of the topic through the suggested web resources.

Given the global importance of soil stability and soil erosion, the article is relevant in any European country. It could be used as a starting point for starting a discussion on global land use and soil erosion in relation to food production and the growing world population.

The article can also be used as a comprehension exercise. Here are some possible questions:

- Which of the following components is NOT part of the organic matter in the soil?
  a) Bacteria
  b) Humus
  c) Silt
  d) Manure
- Are the following statements true or false?
  a) Water drains easily through sandy soils.
  b) Silty soil is not fertile.
  c) Clay soil is hard to work.
  d) Loamy soil is rich in clay.
  e) Clay soil warms quickly.
  a) Gardeners prefer silty soil.
- Which is the correct sedimentation order of these soil components (from the fastest to the slowest)?
  a) Clay, silt, sand
  b) Sand, silt, clay
  c) Silt, clay, sand
  d) Silt, sand, clay

Giulia Realdon, natural sciences teacher, Italy

decrease the fertility of the land, but it also increases sedimentation in streams and rivers, clogging up waterways and leading to more flooding. And whenever farmland soil and sediments are washed into rivers, they bring the pesticides and fertilisers with them, contributing to the pollution of river habitats.

Soil structure: a student activity

For most students, particularly those who live in cities, the world below their feet remains unknown. To remedy this, we developed a two-part activity to help students gain insights into the role that soil structure and its organic matter content has for all of us. It is suitable for students aged 11–16. Activity 1 will need 1–2 hours for soil sample collection, plus 1 hour in the classroom. Activity 2 requires revisiting at hourly intervals for 4 hours.

Materials

- Two glass jars with lids (e.g. empty jam jars)
- Wire (at least 30 cm)
- Wire cutters
- Spade or trowel
- Collection bags or boxes for soil samples
- Two soil samples from different sites (see procedure section)
- Water
- Clock or stopwatch

Activity 1: Soil samples and stability

In this activity, students carry out a simple experiment to collect soil samples and test their stability, and thus learn from experience which types of soil are likely to be more prone to erosion. In the activity, topsoil from an undisturbed site is compared to soil taken from a disturbed site of a similar soil type. The activity can be carried out by individual students or in groups.

BACKGROUND

Soil structure and organic matter

The structure of the soil and how much organic matter it contains have a high impact on the rates of soil erosion.

Soil structure is the arrangement of soil particles (clay, silt and sand) into aggregates, which are groups of soil particles that bind together more strongly than neighbouring particles. A good soil structure is important because it allows air and water into the soil, which are vital for healthy plant growth. Without a good structure, soils will suffer from a lack of oxygen, waterlogging and nutrient lock-up, which means plants are unable to absorb nutrients from the soil and will ultimately perish. Soil aggregates are more stable than individual soil particles, so they increase the soil's ability to avoid breaking down when acted on by water, wind and tillage.

Organic matter in soils consists of all living and dead plant and animal matter. It includes seeds, leaves, roots, earthworms and manure, as well as bacteria, fungi and humus (decayed plant material). Soils with a higher organic matter content are better at storing nutrients and water, and at delivering them to plants. Soil structure is also very dependent on organic matter content: the higher it is, the better the soil structure tends to be. Organic matter is usually concentrated in the upper 10–40 cm of the soil, since this is where plant production and decay take place. The top layer of soils that have been disturbed by tilling or construction work may no longer be rich in organic matter, so its stability could therefore be reduced.

Procedure

1. First, obtain the two samples. These should be taken from each of the following locations:
   - The top 5–10 cm of soil from an undisturbed site (e.g. students' own garden, a park, the school garden)
   - Soil from a disturbed site (e.g. a construction site, soil that has been well dug over).
2. When taking these soil samples, walk in a zig-zag line and take a small sample (about the size of a walnut) at each turning point. Press the soil samples gently together, so you have 2–3 handfuls in the end.

Jane Mills

Turning the soil during ploughing reduces the organic matter, which can lead to weaker soil structure and eventually to erosion.

3. Fill the jars with water, and arrange the wires across the top of each jar to form simple 'baskets' that dip into the water (see figure 1).
4. Put a small soil sample from each site into a basket, both at the same time. Record the time (or start the stopwatch).
5. Observe the soil samples after one minute (figure 2) and again at one-minute intervals (up to 7–10 minutes) and record your observations. Note which soil sample seems to be most stable (stays in the basket) and which is the least stable (quickly crumbles into the jar).

Barbara Birli

Figure 1: Jars filled with water and with wire 'baskets' on top

Erebus555/Wikimedia Commons

Construction work disturbs the top layer of soil, which is normally rich in organic matter.

Students then discuss their results and try to answer the following questions:

- Which soil type was more stable when placed in the jars?
- Which of the two soil types do you think contained the most organic matter? Why?

Class discussion

Students will probably have seen from the experiment that soil from the surface layer of a lawn, orchard or a field that has not been disturbed or tilled for a couple of years will hold together in a wire mesh basket, even when immersed in water. Often the soil clods will hold together so well that the water will evaporate before the soil falls apart.

In contrast, soil that has been recently disturbed (such as a well-dug garden, a continuously tilled field or a construction site) will generally fall apart (disperse) into individual soil particles when immersed in water. The loose soil will make the water cloudy, eventually settling to form a layer of sediment in the bottom of the jar.

So why is this? One reason is that organic matter contributes to the stability of soil aggregates through the bonding properties of organic materials such as bacterial waste products, fungal hyphae and worm secretions and casts. These materials provide the 'glue' that holds soil together. Organic matter also contains hydrophobic substances, such as lipids and waxes, that can reduce the soil's 'wettability', helping it to hold together when there is a lot of water present. It also increases the quantity of very small pores in the soil, reducing the rate at which water enters the soil and the consequent disruption of the aggregates.

Volker Prasuhn/Wikimedia Commons

Soil erosion: run-off water forms channels as it flows down this field of winter wheat in Switzerland.

Activity 2: The mineral mix

All soils contain mineral matter (gravel, sand, silt, clay), as well as organic matter. In this activity, students find out about the mineral composition of their soil samples.

Procedure

1. Looking at your water-filled jars from the previous activity, select any jars where the soil has disintegrated.
2. Remove the baskets, place the lids on the jars and shake them well.
3. Watch what happens, revisiting the shaken jars after one minute and at hourly intervals for the next 4 hours. Note your observations.
4. Finally, compare your jars after four hours to the diagrams in figure 4 showing the composition of different soil types. What type of soil do you think your samples are?

Barbara Birli

Figure 2: Soil samples immersed in water, after 1 minute. Soil from a disturbed site (left) and from the surface of an undisturbed site (right)

Soil samples immersed in water, after standing for 2 minutes. Soil from a disturbed site (left) and from the surface of an undisturbed site (right)

Class discussion

After a few minutes, students will probably have seen heavier sandy particles dropping to the bottom of the jar. In 2 hours, they should see the silt separate out, and after 4 hours the water should clear completely with all the layers visible (see figure 3).

What do these layers tell us about the type of soil in the jars – and, importantly, how useful the soil is for growing crops? The answer is that it depends on the relative amounts of the different types of mineral matter, as shown in figure 4. There are four main types of soil, which each have different advantages and disadvantages for farmers:

- **Sandy soil (0–10% clay, 0–10% silt, 80–100% sand):** This is light to work with and warms quickly in spring. But water drains through it rapidly to places where the roots cannot reach it.
- **Clay soil (50–100% clay, 0–40% silt, 0–45% sand):** This retains water longer, but takes time to warm up in spring, and it can be very heavy to work with if it gets dry.
- **Silty soil (0–15% clay, 85–100% silt, 0–20% sand):** This is fairly fertile, but due to its tendency to retain moisture, silty soil is cold and drains poorly.
- **Loamy soil (10–30% clay, 30–50% silt, 25–50% sand):** This is the type that farmers and gardeners prefer. It contains a balance of all three mineral materials – silt, sand and clay.

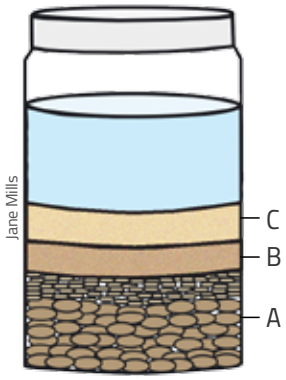


Figure 3: Diagram of a soil sample shaken up with water and left to stand for four hours, showing the layers that form. A: sand layer (forms after 1 minute); B: silt layer (forms after 2 hours); C: clay layer (forms when water clears)

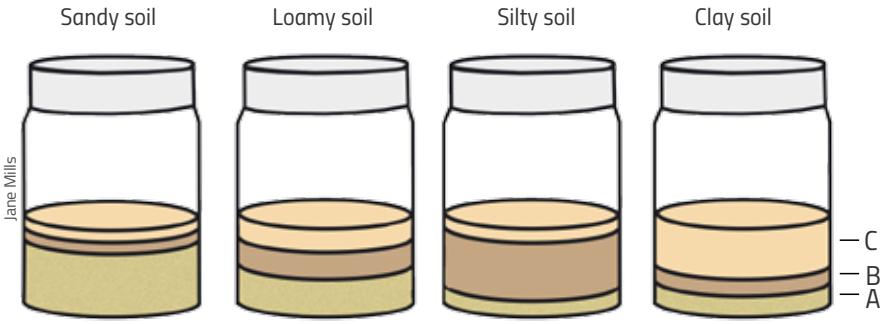


Figure 4: Types of soil, showing the different mineral compositions A: sand, B: silt; C: clay

Barbara Birli

Shake it up: mixing the soil and water before letting it stand for 4 hours

Acknowledgment

The preparation of this article was supported by the RECARE project (www.recare-hub.eu/tools-and-outputs/resources-for-schools), in which the authors are partners. The RECARE project, which is funded by the European Commission FP7 Programme, aims to find and share solutions to prevent soil degradation across Europe.

Reference

Janzen H (2004) Carbon cycling in earth systems – a soil science perspective. *Agriculture, Ecosystems and Environment* **104:** 399-417. doi: 10.1016/j.agee.2004.01.040

Web reference

w1 This factsheet from Eurostat ('Agri-environmental indicator: soil erosion') gives an overview of soil erosion in the EU. See: http://ec.europa.eu/eurostat/statistics-explained/index.php/Agri-environmental_indicator_-_soil_erosion or use the direct link https://tinyurl.com/y8xb2y9w

Resources

For an educational information about soil, visit this webpage from the US Department of Agriculture. See: www.nrcs.usda.gov/wps/portal/nrcs/main/soils/edu/

Read an accessible fact sheet on soil aggregates from Cornell University, USA. See: http://nmsp.cals.cornell.edu/publications/factsheets/factsheet95.pdf

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Jane Mills is a senior research fellow at the University of Gloucestershire, UK. Her research interest is in knowledge exchange processes, and she is leading the dissemination work on two EU-funded research projects focused on protecting the soils of Europe.

Barbara Birli holds a doctorate in technical studies (Regional Planning). As a senior scientist at the Environment Agency in Austria, she is involved in national and international projects concerned with raising awareness of soil threats, in developing educational materials and in citizen science projects.

Francesco Morari is an associate professor of environmental agronomy at the University of Padova, Italy. His primary research interests are in measuring, modelling, and mitigating environmental impacts of agricultural systems

Barbara Birli

Students work with collected samples of different soils.

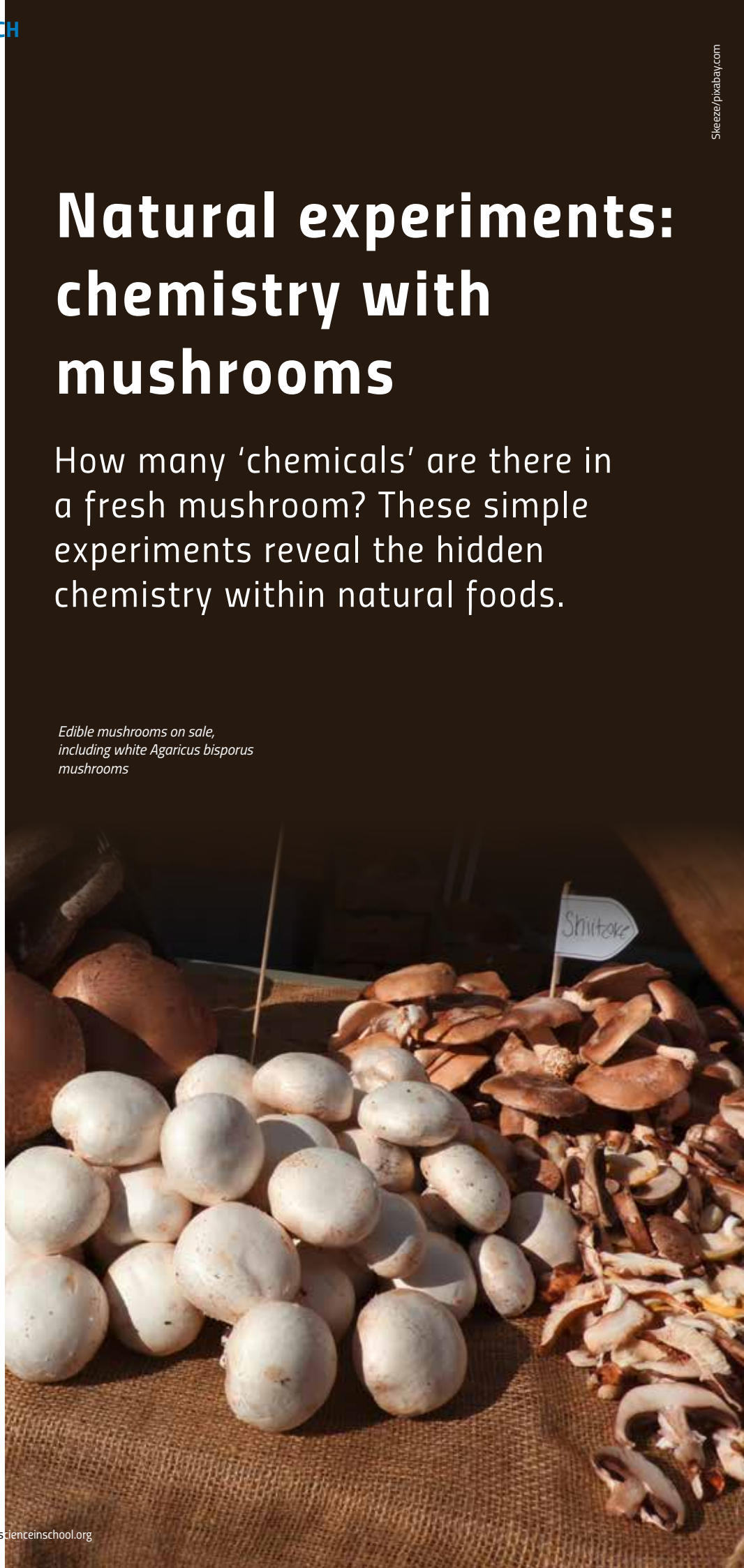
Natural experiments: chemistry with mushrooms

How many 'chemicals' are there in a fresh mushroom? These simple experiments reveal the hidden chemistry within natural foods.

Everything around us and in our own bodies consists of chemical substances, which react with each other to keep us alive. However, many students do not see chemistry as part of their everyday lives; in fact, chemistry is often seen as the opposite of 'nature' – and even as something dangerous to be avoided. For example, many foods are advertised as 'free of chemicals', as if the substances they contain consist not of molecules and compounds, but of something else entirely.

> "Chemistry is often seen as the opposite of 'nature', and even as something dangerous to be avoided."

This of course is an important misunderstanding, which is quite likely to lead to mistakes and unscientific decisions. In the following two articles (Natural experiments), we look at ways of tackling this misunderstanding. Both articles use chemical methods to analyse natural, raw foods – first in the laboratory, then outdoors. Whatever their results, carrying out these experiments confronts students with the indisputable fact that healthy, natural foods are also substances within the realm of chemistry.



Skeeze/pixabay.com

Edible mushrooms on sale, including white Agaricus bisporus mushrooms

By Farina Bunjes, Peter Fleischmann, Verena Pietzner, Martin Rühl, Holger Zorn

Mushroom chemistry

Food is a major part of our daily lives, so it makes sense to use foods as a way of connecting chemistry with everyday life. Mushrooms are an interesting example, because they contain a variety of substances that can be quite easily identified. This may surprise students, who are likely to begin the experiments with few expectations about the composition of mushrooms. These substances include carbohydrates, fats and proteins, as well as vitamins and minerals as more minor components, as students can discover for themselves.

In these experiments, we apply standard laboratory chemistry tests to edible mushrooms. The experiments are suitable for chemistry classes in secondary school. They can be carried out by the students themselves in around 1 hour including discussion. Some additional time is needed for teachers to prepare the materials for experiments 2 and 3.

What are mushrooms?

Mushrooms are fungi, which are not plants or animals, but form their own taxonomic kingdom. They are eukaryotic organisms, which distinguishes them from bacteria. Like plants, mushrooms absorb organic nutrients from surrounding substrates by osmosis, but their structure and way of reproducing is quite different from plants. And like animals, mushrooms are heterotrophic organisms: they need to take in food and cannot make it themselves. Fungal cells form a net of fibres called a mycelium, hidden in the soil. This is branched like a root system and is responsible for the nutrient uptake. Fungi also have a fruiting body, which grows above ground and is the (sometimes edible) part we call a mushroom (see figure 1).

Nutritionally, mushrooms are a valuable part of our diet. Among other nutrients, they contain sodium, chloride and potassium ions, which are needed to maintain water balance; plus phosphate ions for the stability of bones and teeth and the formation of red blood cells; and vitamin C, which acts as a protective agent for cells and helps the body to incorporate iron.

In the following experiments, we used mushrooms from commercially grown *Agaricus bisporus* fungi as the sample materials, in either fresh or dried form. In culinary terms, these are known as champignons, button mushrooms or (when mature and brown) portobello mushrooms.

Safety note: For all the experiments, students should wear safety glasses and follow the usual safety rules for chemistry classes, as some of the reagents are harmful or corrosive. Please also see the general safety note on the *Science in School* website (www.scienceinschool.org/safety) and at the end of this print issue.

Experiment 1: Testing for protein

Allow approximately 5 minutes for the Biuret test, and 10 minutes for the ninhydrin test (see procedure section below).

Materials

- Sodium hydroxide solution (1 mol/l)
- Copper(II) sulfate solution (1 mol/l)
- Ninhydrin solution (2% w/w)
- Fresh edible mushrooms (e.g. button mushrooms) – enough for one mushroom per student or group
- Bunsen burner
- Watch glass
- Knife (not too sharp)
- Small dropper pipettes
- Tongs

Procedure

Proteins can be detected using both the Biuret and the ninhydrin tests. These procedures are described here separately.

U.S. Department of Agriculture/Flickr

Figure 1: The fruiting body of a cultivated mushroom

REVIEW

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

The authors have identified a major challenge in science: students, and a significant portion of the wider public, do not appreciate that everything around them – and even their food – is made up of chemicals.

The experiments described in this article, which are suitable for senior students working in a laboratory, are a great way to show that food is chemical in nature, using mushrooms as the example studied. The exercise also links aspects of chemistry with biology, and may broaden students' experience by providing practical work that is not usually covered in the science curriculum.

Tim Harrison,
School Teacher Fellow,
University of Bristol

Biuret reaction

1. Cut a mushroom in half (see figure 2, left).
2. Using the pipette, coat the cut surface of the mushroom with a thin layer of the sodium hydroxide solution.
3. Place a drop of a copper(II) sulfate solution on the surface of the mushroom (see figure 2, middle).
4. If protein is present, the colour will change from light blue (the colour of copper(II) sulfate solution) to dark blue or violet. This colour change is due to the formation of a copper-protein complex.

Ninhydrin reaction

1. Place a slice of fresh mushroom onto a watch glass.
2. Sprinkle a drop of ninhydrin solution onto the mushroom.
3. Using tongs, hold the mushroom slice into the non-luminous part of a Bunsen burner flame (which should not be roaring).
4. Take the mushroom slice out of the flame and look at the colour.
   If protein is present, a deep violet compound will be formed (see figure 2, right).

The deep violet compound is called Ruhemann's purple. It is produced when ninhydrin reacts with the amino acids found in proteins.

BACKGROUND

The composition of cultivated mushrooms

The following information may be useful for teachers to use in discussions following the experiments.

Carbohydrates

Starch is not present in cultivated mushrooms, and glucose is almost completely absent. Fungi contain mainly chitin and cellulose as structural components of the cell walls. They also contain trehalose (a sugar) and mannitol (a sugar alcohol).

Lipids (fat)

Lipids are found in very fine droplets within the cytoplasm of fungi, and in the fungal cell wall (as lipid bilayers). Mushrooms contain 0.3 g fat per 100 g of fresh mushrooms, which is a relatively low proportion.

Minerals

Mushrooms are rich in minerals – especially potassium, with a surprisingly high level of 390 mg per 100 g of fresh mushrooms. Phosphorus is also present (about 60 mg per 100 g), mostly as phosphate. The sodium content of around 5 mg per 100 g fresh mushrooms, however, is low, as are the calcium and iron contents. Fresh mushrooms contain about 93% water, although the water content depends on the age of the fruiting body, with young fruiting bodies generally containing less water.

Vitamins

Mushrooms contain significant amounts of vitamin C (about 2.1 mg per 100 g of fresh mushrooms), plus some B vitamins (including B1, B2, B6 and the amide of niacin, B3). Mushrooms are also rich in nicotinamide (5.2 mg per 100 g of mushrooms).

Farina Bunjes

Figure 2: Left: fresh, untreated mushroom; middle: positive Buiret reaction; right: positive ninhydrin reaction

Pexels/pixabay.com

Farmers' markets have become popular in many countries, and are associated with a more 'natural' and sustainable lifestyle.

Experiment 2: Testing for vitamin C

Duration: approximately 15 minutes. Teachers need to allow 45 minutes beforehand to prepare the iron(III) chloride filter paper. To do this, soak the filter paper in 1% w/w iron(III) chloride solution and then leave until well dried (about 30 minutes).

Materials

Each student (or group) will need:

- Potassium hexacyanoferrate(III) solution (1% w/w) in a vaporiser/sprayer
- One filter paper soaked in iron(III) chloride solution and dried
- One fresh mushroom
- Knife (not too sharp)
- Fume hood

Procedure

1. Cut a mushroom in half, and press the freshly cut face of the mushroom onto the filter paper (see figure 3, left).
2. Remove the mushroom. Working under a fume hood, spray the filter paper with the potassium hexacyanoferrate(III) solution. Take care to avoid breathing the vapour.

The potassium hexacyanoferrate(III) solution makes the paper turn light blue, as the soluble form of Prussian blue (or Turnbull's blue) is produced. If vitamin C is present, the Fe(III) ions will be reduced to Fe(II) ions, forming a darker blue compound (see figure 3, right).

Farina Bunjes

Figure 3: Left: iron(III) chloride filter paper with mushroom print; right: after treatment with potassium hexacyanoferrate(III) solution, showing presence of vitamin C in the mushroom print

Experiment 3: Testing for potassium and sodium

Duration: approximately 10 minutes. Prepare the dried mushrooms in advance by slicing the mushrooms and drying them overnight at 105 °C in a drying cabinet.

Potassium and sodium can be detected from their characteristic flame colours. Using cobalt glass to filter out the yellow sodium flame makes the pale lilac potassium flame more visible.

Materials

- Dried mushroom slices
- Bunsen burner
- Crucible tong
- Cobalt glass or other blue light filter

Procedure

1. Hold a dried mushroom slice with the crucible tongs into a non-luminous flame of a Bunsen burner.
2. Observe the flame colour. A yellow-orange colour indicates the presence of sodium, while a lilac colour indicates potassium.
3. To see the lilac flame more easily, look at the flame through the blue filter, which filters out the yellow colour of the sodium flame.

Experiment 4: Testing for phosphate ions

Duration: approximately 45 minutes (15 minutes for the experiment plus 30 minutes for the ash preparation). Teachers will also need 15 minutes to pre-prepare the ammonium molybdate solution.

Materials

For the ammonium molybdate ($(NH_4)_2MoO_4$) solution:

- 10 g of ammonium molybdate tetrahydrate
- 20 g of ammonium nitrate
- 7 ml concentrated ammonia solution (30% w/w)
- Distilled water
- Volumetric flask (100 ml)
- Pipette

For the experiment, each student (or group) will need:

- Distilled water
- Dried mushrooms (a few slices)
- Dilute nitric acid (2 mol/l)

Farina Bunjes

Farina Bunjes

Figure 4: Observation of flame colours while burning dried mushrooms. Left: a typical flame colour in the presence of sodium; right: after a while, a mixed flame colour with the typical lilac due to potassium is visible.

Farina Bunjes

Mushroom ash, produced by burning dried mushrooms

- Porcelain dish
- Pestle (for grinding)
- Bunsen burner
- Filter funnel and filter paper
- Test tubes and test tube rack
- Pipette
- pH indicator paper

Procedure

Prior to the lesson, teachers should prepare a solution of ammonium molybdate, $(NH_4)_2MoO_4$ solution: place 20 g of ammonium molybdate tetrahydrate and 20 g of ammonium nitrate into the volumetric flask. Add 7 ml of concentrated ammonia solution (using a pipette), and fill up the flask to 100 ml with distilled water, dissolving completely.

The rest of the procedure is suitable for students.

1. Prepare the mushroom ash. First, place some dried mushrooms in a porcelain dish and grind them up, then burn the dried mushrooms with a non-luminous Bunsen burner flame until they turn to ash.
2. Dissolve the mushroom ash in distilled water (not more than 10 ml), and then filter the solution to get rid of the insoluble parts, collecting the filtrate.
3. Acidify the filtrate with dilute nitric acid so that the pH is below 6. Note: you will need the resulting acidified

Farina Bunjes

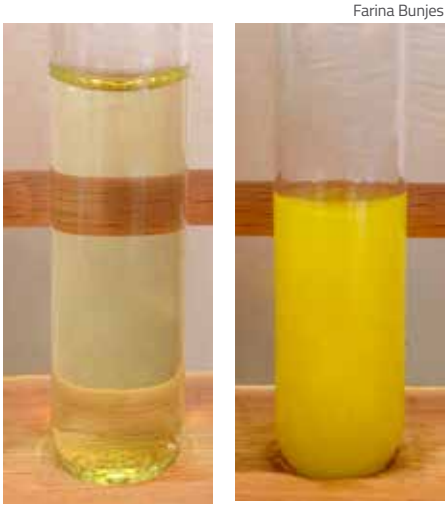


Figure 5: Left: the filtered mushroom ash solution shortly after adding ammonium molybdate solution; right: the solution after heating, showing the lemon yellow precipitate

ash solution for the next experiment, as well as for this one.

4. Use a pipette to put 5 ml of the acidified mushroom ash solution into a test tube, and then add approximately 10 drops of the ammonium molybdate solution using another pipette (figure 5).
5. Heat the solution for two minutes with a Bunsen burner, then place the tube in a test tube rack to let it cool down.

If phosphate ions are present, a lemon yellow precipitate of ammonium phosphomolybdate ($(NH_4)_3PMo_{12}O_{40}$) will be formed (see figure 5).

Experiment 5: Testing for chloride ions

Duration: approximately 5 minutes

Materials

- Acidified solution of mushroom ash (see Experiment 4)
- Silver nitrate solution (5% w/w)
- Test tube
- Pipette

Procedure

1. Put 3–5 ml of acidified mushroom ash solution in a test tube.
2. Add a few drops of silver nitrate solution to the test tube using a pipette.

A white precipitate indicates the presence of chloride ions (see figure 6). The silver chloride (AgCl) precipitate is finely dispersed, so the liquid has a cloudy white appearance.

Discussion

Using these experiments, students themselves can identify some important chemical compounds in mushrooms – which are also nutrients. This can provide a basis for discussing aspects of chemistry that have an impact on daily life. For example:

- How would you respond if someone says, 'I prefer food that is chemical-free'?
- How do mushrooms support a balanced diet?
- Can you think of an experiment that helps us to distinguish between plants and mushrooms? (Remember that mushrooms cannot carry out photosynthesis, but plants can.)
- In these experiments, we have not tested for starch and glucose. What do you think the results would be if you tested for these substances?

Farina Bunjes

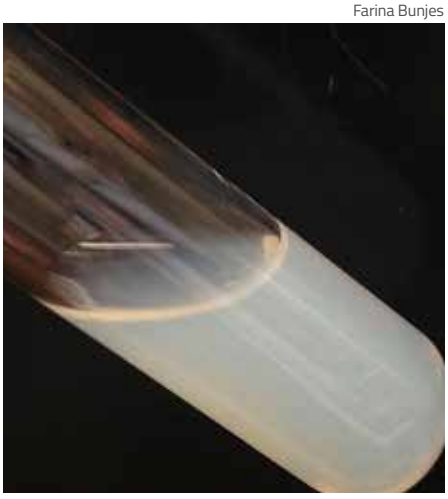


Figure 6: Cloudy white precipitate of silver chloride in a solution of mushroom ash, indicating the presence of chloride ions

Resources

Read a research article on school students' attitudes to science and nature. See:

Krischer D, Spitzer P & Gröger M (2016) 'Chemistry is toxic, nature is idyllic' – investigation of pupils' attitudes. *The Journal of Health, Environment, & Education* **8**: 7-13. doi: 10.18455/08002

For more information about the chemistry involved in the various tests, see the following resources:

Biuret test: https://en.wikipedia.org/wiki/Biuret_test

Ninhydrin test: www.chem.ucalgary.ca/courses/351/Carey5th/Ch27/ch27-3-3.html

Vitamin C: Teepoo S (2012) A new simple and rapid colorimetric screening test for semi-qualitative analysis of vitamin C in fruit juices based on Prussian blue. *Journal of Applied Sciences* **12**: 568-574. doi: 10.3923/jas.2012.568.574

Phosphate test: https://en.wikipedia.org/wiki/Phosphate_test

Silver chloride: www.chemguide.co.uk/inorganic/group7/testing.html

For links to food databases providing scientific reference values for a huge range of foods, see the European Food Information Resource: www.eurofir.org/food-information/food-composition-databases-2/#

Verena Pietzner is professor of chemistry education at Oldenburg University, Germany. Peter Fleischmann is a senior scientist at the Institute of Chemistry at Oldenburg University, and Farina Bunjes holds a master of education degree in chemistry and mathematics, also from Oldenburg University. Holger Zorn is a professor and Martin Rühl is an assistant professor for food chemistry and food biotechnology at Giessen University, Germany.

Natural experiments: taking the lab outdoors

*A fieldfare (*Turdus pilaris*), feeding on mountain ash berries*

Assemble a 'backpack laboratory' and take tests for starch and glucose out into the wild.

By Jan Höper

Many teachers like to take their classes on field trips. So why do we usually confine chemistry lessons to the laboratory or classroom? The benefits of outdoor teaching are well documented (Malone & Waite, 2016; Dillon et al., 2006), and include both cognitive and skills-based aspects. It's also well known that, for most students, solving puzzles is more exciting than reading textbooks or listening to lectures.

For these reasons, we decided to develop an enquiry-based approach to science lessons, where students act as 'detectives', first creating their own hypotheses in the classroom, then gathering information outdoors and applying their findings to the hypotheses.

In this article, we describe an activity focused on measuring the levels of glucose and starch found in plants and fungi. We equip the students with an investigation bag containing everything they need for the chemistry fieldwork. At the end of the activity, the students return to the classroom to discuss their findings.

Jan Höper

REVIEW

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

In this article, the author confronts the idea that chemistry is often seen solely as a laboratory-based activity divorced from the 'real world'. A remedy is provided in the form of a chemistry fieldwork exercise, which enables students and teachers to take some fundamental chemistry (usually used in biology lessons) into the field, either as part of the normal curriculum or as a science club activity. Practical work outside a laboratory may require a little more organisation, such as complying with health and safety regulations concerning school field trips, but the efforts will be worthwhile.

Tim Harrison, School Teacher Fellow, University of Bristol

The activity is suitable for students from 16 years of age, due to the chemistry involved and the sources of error that need to be considered. The whole teaching sequence takes approximately 3–4 hours.

Testing for starch and glucose

To test for starch, we used the iodine test in the form of Lugol's solution (aqueous potassium iodide and iodine), as this simple test is well suited to taking out of the classroom, and only needs one droplet to produce a result.

Replacing the traditional test for glucose

Traditionally, Fehling's reaction is used to test for glucose (and other reducing sugars). However, as some of the chemicals involved are environmentally toxic or corrosive, we wanted to replace this test.

Instead, we used glucose test strips designed for urine analysis. These give a semi-quantitative result, providing a more informative, as well as a safer and more convenient, test for field work. We tried out test strips from three different manufacturers, and we recommend using those that show glucose concentrations of up to 5% – for example, the Keto Diabur Test 5000 made by Roche.

Sources of error

Because the test strips are designed for use only with urine, there are some important sources of error that need to be considered when using the strips in other contexts, as they may reduce

Jan Höper

Field work in the Artic: students enjoy fine weather while studying science outdoors

BACKGROUND

How do glucose test strips work?

In commercially available urine glucose tests, two enzymatic reactions are coupled.

First, glucose is oxidised in a reaction that produces gluconolactone ($C_6H_{10}O_6$) and hydrogen peroxide (H_2O_2):

$$C_6H_{12}O_6 + O_2 \xrightarrow{\text{glucose oxidase}} C_6H_{10}O_6 + H_2O_2$$

To make the reaction visible, the hydrogen peroxide is then reduced by another enzyme (a peroxidase), and in the process oxidises a chemical substance called a chromogen. The chromogen gradually changes its colour as it is oxidised, so the final colour depends on the amount of glucose originally present.

Finally, to find the glucose concentration, the colour obtained is compared with a row of colour blocks provided in the kit (see figure 1 and figure 2).

Jan Höper

*Figure 1: Testing redcurrants (*Ribes rubrum*) for glucose: the test strip matches to a high reading on the reference scale.*

Jan Höper

*Figure 2: Testing dandelion (*Taraxacum officinale*) leaves for glucose, showing a lower glucose concentration than in berries*

the accuracy of the readings obtained. These include:

1. **Colour:** the strong colour of some fruits and vegetables can mask the colour of the test result, which has to be compared with colours on a scale to find the glucose concentration.
2. **Chemistry:** plant saps or juices are complex mixtures of molecules and ions, some of which can interfere with the chemical reactions involved in the test. For example, large amounts of ascorbic acid may lower the test result.
3. **Viscosity:** thick liquids can give misleading results as there is more liquid on the test stick, and the glucose molecules take longer to reach the stick as they have further to diffuse.
4. **Practicality:** some test kits have scales that are difficult to distinguish, and some kits measure more factors than glucose (such as ketones or proteins) with up to ten test squares on a strip, which can be confusing for students.

Phase 1: Learning to use the tests

Working in groups, students learn to use the tests before leaving the classroom. This initial activity takes around 20–30 minutes. The investigation bags should be made up beforehand.

Safety note: When carrying out the starch test, students should wear gloves and safety glasses, as the solution can cause skin and eye irritation.

Materials

- Glucose (dextrose) in tablet form
- Apple juice, or glucose solutions (e.g. 0.1% (0.1 g/100 ml) and 1% (1.0 g/100ml))
- Food containing lots of starch (e.g. potato, bread), or a starch suspension
- Investigation bags, each of which should contain the following (see figure 3):
  - Glucose test strips
  - Lugol's solution (starch test)
  - Pestle and mortar (or other small dish) to extract juice from the samples
  - Knife (to cut branches or roots)
  - Wipes and distilled water (to clean the tools)
  - Box for litter
  - Magnifying glass
  - Cutting board (optional)
  - Gloves and safety glasses

Procedure

1. Distribute the investigation bags, providing one bag per group of students.
2. Ask the students to read the instructions on the glucose test kits in preparation for conducting a test with the glucose solutions or apple juice. Remind students that the test square should be dipped into the sample liquid for just one second and excess liquid removed. They will need to wait (normally between 30 seconds and 2 minutes) before reading the result.

Jan Höper

Figure 3: The investigation bag with its content for glucose and starch testing

3. For starch testing, place one droplet of Lugol's solution on the sample under test. The solution will change to black if starch is present, or remain orange-brown if the test is negative.

Phase 2: Deciding on the hypotheses to test

Allow about 20–30 minutes for this discussion phase.

Procedure

1. Remind students of what they already know about glucose as the central molecule in cellular respiration, and also as the product of photosynthesis in plants (and thus the basis of the energy flow from producers to primary consumers in ecosystems). In organic chemistry, glucose is the building block of many carbohydrates.
2. Set students the task of working as 'molecule detectives' who search for answers by detecting glucose and starch in the natural environment. Ask the students, who should work in groups of 3–5, to formulate hypotheses about starch and glucose that they can then investigate. Table 1 below shows some examples of hypotheses, with the reasons why students may propose them – which may be false or invalid.
3. Collect and discuss the hypotheses as a class, and task each group with investigating at least one hypothesis. Ideally, each group should have one investigation that will result in a high glucose reading, and one that will result in a low or no glucose reading.

Hypothesis	Proposed reason
Berries have a high concentration of glucose. (True)	They taste sweet. (True)
Green leaves contain glucose. (True)	Glucose is the product of photosynthesis, which happens in chloroplasts. (True)
Tree resin contains glucose. (False)	It is a waste product of plants. (False)
There is a lot of starch in roots and seeds. (True)	Plants store energy as starch. (True)

Table 1: Examples of hypotheses proposed by students

Jan Höper

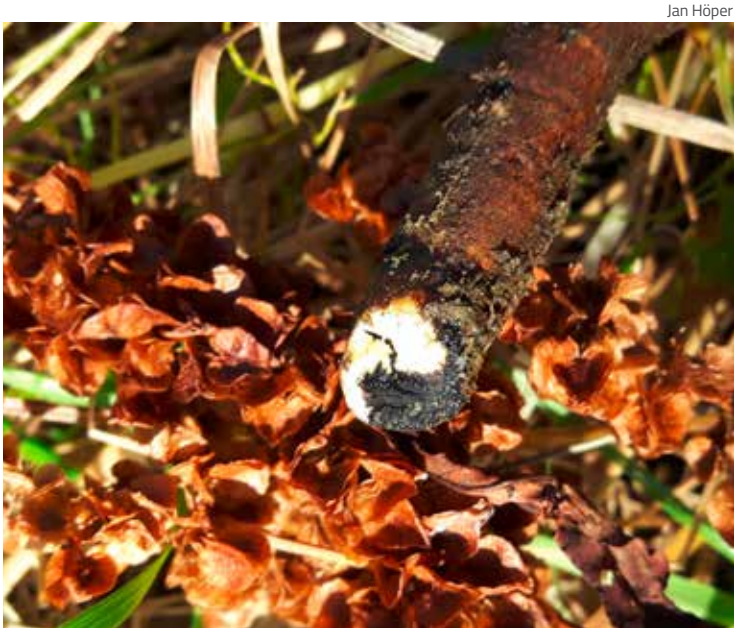


*Figure 4: Testing roots for starch: a positive result on a dock plant (*Rumex longifolius*)*

Jan Höper

Chemistry students in the field: collecting berries

Phase 3: Field work

We suggest 30–60 minutes for the outdoor phase of the activity; the time needed depends partly on weather conditions. Students will need appropriate outdoor clothing, and taking a first-aid kit is a sensible precaution.

Before the fieldwork begins, check the location where the students will carry out the investigation, and consider the season. Is the location safe? Are there enough plants, berries and other materials to test, and do your students have permission to pick them?

Materials

Each group of students will need:

- Investigation bag (as for phase 1)
- Cameras, smartphones and/or notebooks, to record the species investigated and results obtained
- Optional: field guide about common plants in the area

Procedure

1. Go with your students to the location, keeping the groups gathered together so that you can answer any initial questions.
2. Working in groups, students gather samples to test their hypotheses. Samples may include any of the following:
   - Berries
   - Leaves
   - Roots
   - Stems
   - Flowers
   - Seeds
   - Tree bark
   - Wood (from tree branches and twigs)
3. Students test their samples for glucose and starch using the equipment in the investigation bag. When testing for starch, use the magnifying glass to see details – for example, in grass seeds.
4. Students collect all their belongings and any litter before returning to the classroom.

Phase 4: Analysis and discussion

Allow at least 45–60 minutes for analysis and discussion back in the classroom. At the start, advise the students not to worry if their results seem inaccurate, as it is just as important to think about the sources of error in the measurements (outlined on pages 43-44) on to account for the results they obtained.

Procedure

1. First, students write up their field notes and results from the outdoor phase. In their groups, they discuss their results and draw conclusions about their initial hypotheses in a way that can be presented to the class.
2. Students then use the internet to find out scientific reference values for the items they tested outdoors. It is quite difficult to find glucose levels for specific plant sources online; see the resources section at the end of this article for suggested websites. Remind students to take extra care when converting units, so that they can compare values from the test sticks to sources on the internet or in books. For some inedible items, students can try thinking of a similar species that is edible and find those

values in a nutrient database, as we did with dandelion leaves and lettuce (see table 2).

The examples here give a realistic idea of the results you can expect: sometimes the values are nearly identical, and in other cases there are large differences.

Discussion

The whole class should discuss the actual results obtained by each group, their conclusions about their hypotheses, and the comparisons with the databases.

Topics for discussion of the results could include the following:

- Why is there more glucose in berries than in leaves?
- Why is there no starch in berries, but a lot in roots?

Questions relating to the data comparison could include:

- Why are the test results and the database values different?
- How much of this difference is due to measurement errors in the test itself?
- How much of the difference is due to natural variation?

Extension activity… and beyond

As a further research project, students can follow up the discussion about starch to dig deeper into the different carbohydrates produced by plants.

We have extended this outdoor teaching approach to other topics in chemistry, for example: finding different metals and metal ions in the rural or urban vicinity; investigating campfire chemistry; studying the phase transitions of water; and measuring carbon dioxide levels. What other opportunities might there be in your location?

Item	Glucose concentration using test strips (%)	Equivalent item from database (USDA)[w1]	Database value for glucose concentration (%, as g/100g)
Red currants (very ripe)	c. 5	Currants, red and white, raw	3.2
Raspberries	c. 2	Raspberries, raw	1.9
Dandelion sap	0.5–1.0	Various lettuces	0.2–0.9

Table 2: Comparison of glucose concentration results from student tests and from a database

Jan Höper

Blueberry and crowberry bushes. Like many other berries, these contain high levels of glucose.

Acknowledgement

This teaching unit is part of a project called 'The mobile chemist', which received financial support from the Department of Education at The Arctic University of Norway. More information about the project is available from the author, who can be contacted at jan.hoper@uit.no

References

Dillon J et al. (2006) The value of outdoor learning: evidence from research in the UK and elsewhere. *School Science Review* **87(320)**: 107-111

Malone K, Waite S (*2016*) *Student outcomes and natural schooling: Pathways from evidence to impact report* 2016. Plymouth: University of Plymouth. www.plymouth.ac.uk/research/oelres-net

Web reference

w1 The US Department of Agriculture database provides scientific reference values for a huge range of foods. See: https://ndb.nal.usda.gov/ndb/

Resources

See the list of ingredients in a banana, showing how complex natural products are: https://jameskennedymonash.wordpress.com/2013/12/12/ingredients-of-an-all-natural-banana/

Find out more about the iodine test for starch:

http://brilliantbiologystudent.weebly.com/iodine-test-for-starch.html

http://chemistry.elmhurst.edu/vchembook/548starchiodine.html

For additional food databases, see:

Europe: www.eurofir.org/food-information/food-composition-databases-2/#

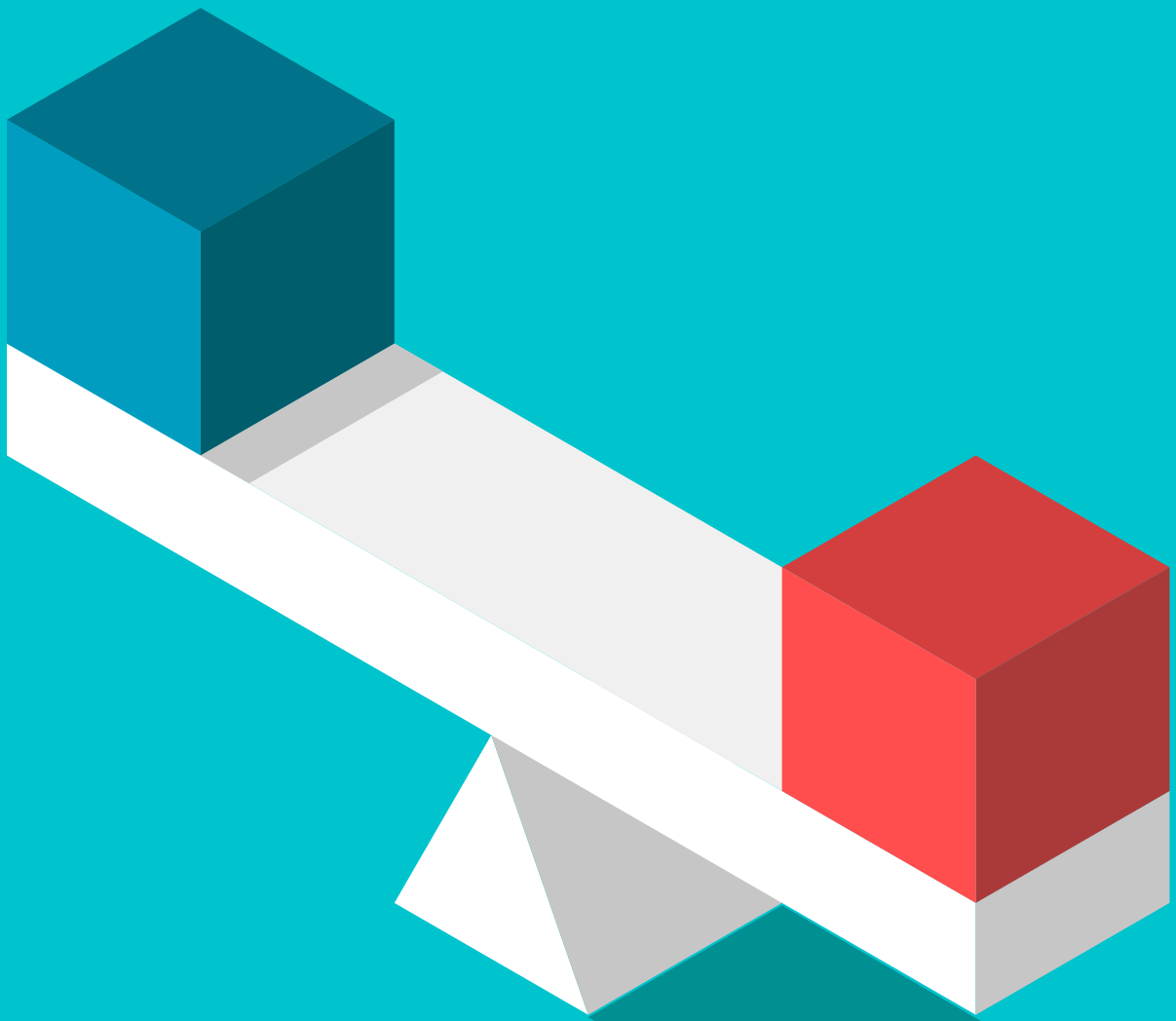
Denmark: http://frida.fooddata.dk/ShowList.php?compid=149

Read an academic study of school students' attitudes to chemistry compared to nature: Krischer D, Spitzer P, Gröger M (2016) 'Chemistry is toxic, nature is idyllic' – investigation of pupils' attitudes. *The Journal of Health, Environment & Education* **8:** 7-13. doi: 10.18455/08002

Jan Höper is a science teacher and biologist who is passionate about field work. He has taught biology and chemistry at secondary schools in Germany, Italy and Norway, and has worked as a museum educator at Tromsø University Museum. He is now a lecturer in science education at The Arctic University of Norway, Tromsø.

Jan Höper

The landscape around Tromsø, Norway, where the activities took place



Balancing act: the physics of levers

Can you stop the tray from tipping? Learn about the law of the lever to beat your opponent in this simple game.

By Mária Bilišňanská, Marián Kireš

We encounter various types of lever in our everyday lives: opening a drink with a bottle opener, cutting paper with scissors, taking the lid off a paint pot using a screwdriver, and – the simplest of all – playing on a seesaw in the park. Yet, the principle of levers is sometimes so natural to us that we do not pay any attention to how it actually works.

In this easy game, pairs of students aged 11–19 take it in turns to add wooden blocks or objects to a tray balanced on a pivot. By competing to keep the tray level, students learn about the physics of levers – simple machines that make work easier by reducing the force needed to move a load. They can understand the moment of a force and the balance law of a lever (Haverlíková, 2011).

Competitive students will strive to understand the basic principles so they can beat their opponents, and a practical game will enrich the learning process and contribute to a creative atmosphere in the classroom. The activity, including time for explanations and questions, will take around 1.5 hours.

Physical principles of the lever

Prior to the activity, introduce your students to the physical principles behind the lever. There are four basic elements to consider when using a lever:

- Pivot – the point around which something turns
- Beam – a wooden plank or solid rod that rests on the pivot
- Load – the item or object being moved or lifted on the beam
- Force – the effort or input needed to move the beam and the load

When you use a lever, you apply a turning force (the moment) around the pivot to move the load. Moments reduce the effort needed to move the load by increasing the distance over which it is acting. This explains why less force is needed to open a door by pushing at the side furthest from the hinge than at the side closest to the hinge. When you push at the hinge side of the door, you must apply more force because the distance is smaller.

Mária Bilišňanská

In the game, pairs go head-to-head and take it in turns to add an object to the tray.

REVIEW

- ✓ Physics
- ✓ Principle of moments
- ✓ Ages 11–19

What a fantastic way to investigate the principle of moments! The authors illustrate a series of fun activities through which participants can explore the idea of levers, moments and equilibrium. Teachers can recreate these inquiry-based, hands-on activities with their students through the guided steps.

The suggested questions promote discussions among participants, and the varying levels of difficulty make the activities ideal for a wide range of ages. For younger students, the game could just entail moving the blocks towards and away from the pivot to balance the lever. Older students can use the equations to estimate how the lever will behave.

Catherine Cutajar,
physics lecturer,
St Martin's College,
Malta

Mária Bilišňanská

Figure 1: For the game, each team requires a plastic tray, cupboard handle and wooden building blocks.

A moment can be calculated using the following equation:

$M = F \times d$

where:

M = moment of the force (Nm)

F = applied force (N)

d = perpendicular distance between the pivot and the point where the force is applied (m)

The balancing game

Once students understand the physical principles behind the lever, they can consider how to use physics to win the game.

Materials

Working in pairs, each team will need:

- A tray (beam) – we used a plastic tray approximately 45 x 30 cm
- Cupboard handle or object with flat base and spherical top (pivot)
- Wooden building blocks or other objects (these act on the tray with force *F*)

See figure 1 for example materials.

Pre-game questions

Before your students go head-to-head in the game, they can apply their knowledge of levers to answer the following questions:

If you start off with a balanced tray, what would happen when you add an object to the tray?

Depending on the weight of the object and where it is placed on the tray, there can be no visible effect, or the tray can rotate, tilt or fall over.

Mária Bilišňanská

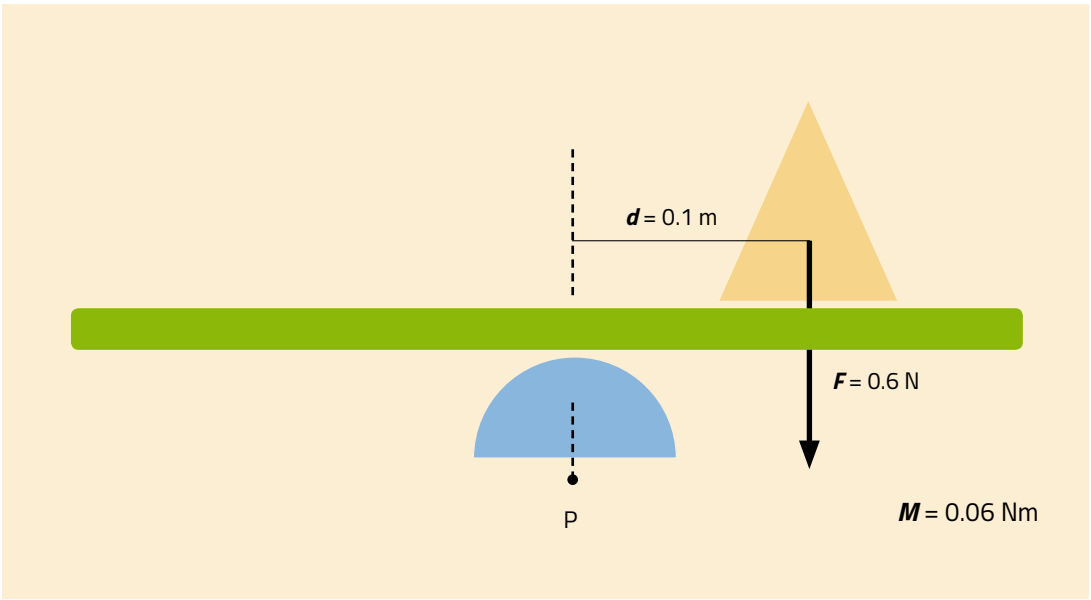
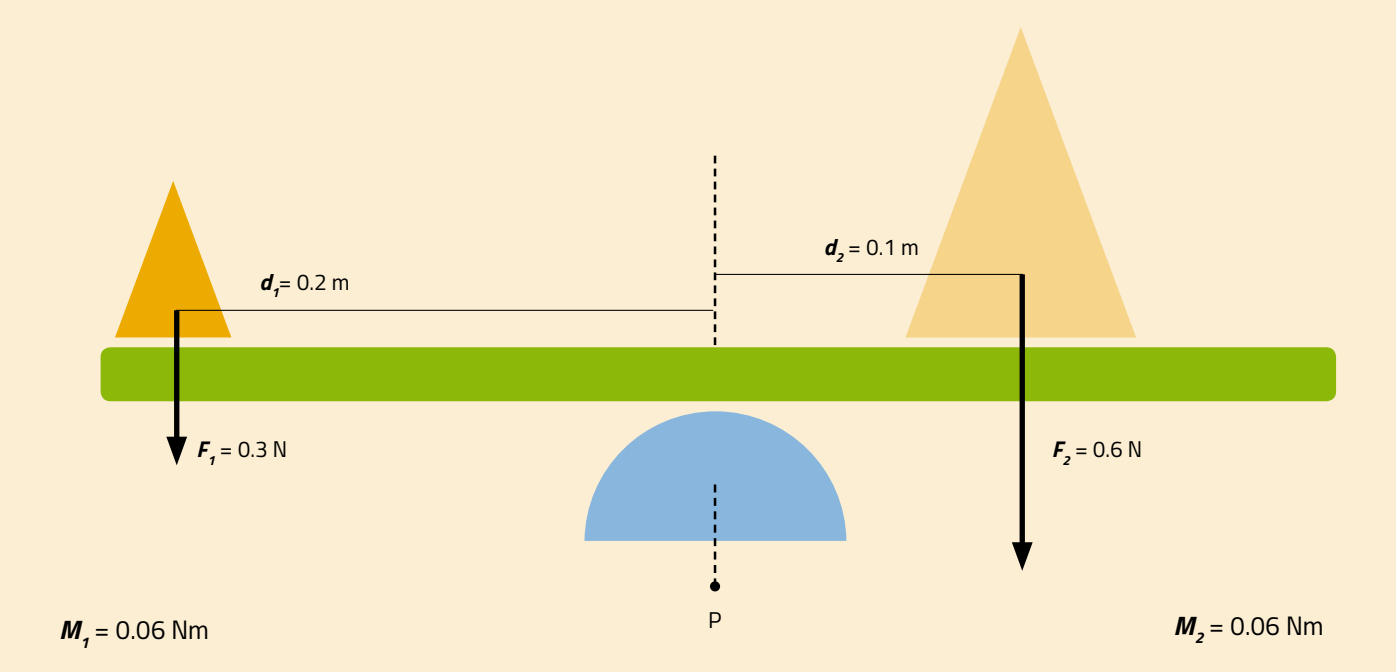


Figure 2: The object applies a force (F) of 0.6 N at a distance of 0.1 m from the pivot (P). This results in a moment (M) of 0.06 Nm, and would cause the tray to tilt.



Mária Bilišňanská

Figure 3: For a tray to remain balanced, the total anticlockwise moments ($M_1 = F_1 \times d_1$) should be equal to the total clockwise moments ($M_2 = F_2 \times d_2$) so $F_1 \times d_1 = F_2 \times d_2$. P: pivot

An object is added to the balanced tray, making it tilt. Why? Where would the object need to be placed to cause the most tilting?

When an object is placed at a distance from the pivot, a moment is established, causing the tray to tilt. The moment of a force is directly proportional to the distance between the body and the pivot ($M = F \times d$), so if the same object is placed further from the pivot, the tray will tilt more. If the object is placed at a distance too far from the pivot, the tray will tip and touch the table. The effect also depends on the weight (F) of the object.

An example is shown in figure 2. If a load acting on the tray with a force of 0.6 N is placed at a distance of 0.1 m from the pivot, the moment may be calculated as follows:

$M = F \times d$

$= 0.6 \text{ N} \times 0.1 \text{ m}$

$= 0.06 \text{ Nm}$

The resulting moment of force would make the tray tilt.

If we put the same load further from the pivot, e.g. 0.2 m away, the moment of force would increase to 0.12 Nm, which would cause the tray to tilt further or to touch the table.

Where should you place an object so that an empty or balanced tray remains balanced?

When an object is placed on the pivot, the moment of force is equal to zero ($d = 0$) so there is no visible effect on the tray.

Your opponent places an object on the tray, causing it to tilt. Where should you place your object to rebalance the tray?

To keep the tray balanced, you must follow the physical principles related to the moment of a force. When an object is in equilibrium, the total anticlockwise moments should be equal to the total clockwise moments ($F_1 \times d_1 = F_2 \times d_2$).

There are a few possibilities:

- Place an identical object (same weight, same shape) opposite to your opponent's object on the tray. It should be at the same distance from the pivot as the distance between the opponent's object and the pivot.
- Place a lighter object opposite to your opponent's object but at a greater distance from the pivot than their object. For example, an object two times lighter should be placed at a distance two times greater.

In figure 3, the object that acts on the tray with a force of 0.3 N is two times lighter that the object opposite, which acts on the tray with a force of 0.6 N. If we want to balance the moment of force, the lighter object must be placed at a distance two times greater.

$M_1 = F_1 \times d_1$
$= 0.3 \text{ N} \times 0.2 \text{ m}$
$= 0.06 \text{ Nm}$

$M_2 = F_2 \times d_2$
$= 0.6 \text{ N} \times 0.1 \text{ m}$
$= 0.06 \text{ Nm}$

- Place a heavier object opposite to your opponent's object but closer to the pivot than their object.

If you keep the position of an object the same but vary the weight of the object, what is the effect on the moment?

Placing a heavier object on the tray will cause the tray to tilt more. This is because the moment (M) is directly proportional to the applied force (F) and the perpendicular distance (d).

Mária Bilišňanská

Figure 4: The tray is balanced on top of the pivot.

Playing the game

After your students have considered the questions, they are ready to play the game.

1. Balance the empty tray on the pivot (see figure 4), attempting to keep the tray as level as possible.
2. Sitting opposite their opponent, students take it in turns to add an object to the tray from a shared pile of wooden building blocks or other objects. Allow 5 minutes to practice before starting the game.
3. The aim of the game is to keep the tray balanced. Students compete until one person places an object on the tray and causes it to tip and touch the table. The other student is the winner and gains one point.
4. If neither student causes the tray to fall, and there are no more objects left in their pile, the students gain one point each.
5. Carry out a set of five games to determine the winner of the pair. The winners go on to the next round, making a new pair with another winner. The sets continue until there is only one winner.
6. Students who have been eliminated can support those who are still playing, or they can play for fun with other eliminated students.
7. Alternatively, to save time, use the scoring system to determine the highest scoring students from the first round. These students then compete in a final playoff, with the eliminated students as spectators.

Basic rules

- During their turn, students can either add an object to the tray or change the position of an existing object on the tray.
- Only a single object can be placed on the tray at a time, and players can place only one object during their turn.
- Objects can be placed on top of each other.
- Players can skip a turn up to three times during the set, but a player cannot skip more than two successive turns.

These rules can be varied, as agreed between the teacher and students.

Note: to increase then friction to stop the objects gliding off the tray when it tips, place a piece of paper on the tray.

Discussion

To encourage the students to think about the physical principles of levers and moments during the game, ask them some of the following questions:

- How could you make the game more difficult for your opponent?
- Based on your experience, how could you advise your friend so they become the winner?
- What part of the game was most difficult?
- What most surprised you about the game?
- Did the position of the object on the tray matter?
- Did the weight of the object on the tray matter?

You could repeat the pre-game questions to see if the activity has strengthened students' understanding of the topic.

Extension

You can increase the difficulty of the game by making some changes:

- Start by placing all the objects on the tray and in each turn, take away an object. Unlike when an object is added, the student cannot hold the object to estimate its weight and anticipate what will happen when they add it to the tray.
- Use a pointier pivot (e.g. place the tray on the tapered end of a hard-boiled egg or use an alternative cupboard handle) to reduce the surface area between the tray and the pivot.
- Use a smoother tray and a polished metal pivot to reduce friction.
- Use smoother objects to reduce the friction between the tray and the objects. The objects will glide on a tilted tray until it tips.
- Add or remove bigger, heavier, asymmetrical or inhomogeneous objects (an object that does not have the same weight in all parts) that cannot be placed on top of each other.
- Use a lighter tray so that the effect of adding an object is greater.
- Use a tray where the weight is not distributed equally (e.g. the four corners are heavier than the centre of the tray).

Mária Bilišňanská

Where should the block be placed to keep the tray balanced?

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Reference

Haverlíková V (2011) SCHOLA LUDUS serious educational games: The problem of mechanic balancing in virtual and real games. *2011 14th International Conference on Interactive Collaborative Learning* pp 615-619. New York: IEEE. ISBN: 9781457717475. doi: 10.1109/ICL.2011.6059660

Web reference

w1 Learn more about Science on Stage by visiting their website. See: www.science-on-stage.eu

Resource

Watch this TED-Ed video for an introduction to the physics of levers. See: www.youtube.com/watch?v=YlYEi0PgG1g or use the direct link http://tinyurl.com/y8l5ml3v

Mária Bilišňanská is a PhD student studying the theory of physics education at the Pavol Jozef Šafárik University in Košice, Slovakia. Her thesis focuses on the role of experimentation in developing the skills of upper secondary-school science students.

Marián Kireš is an associate professor at the Institute of Physics at the Pavol Jozef Šafárik University in Košice, Slovakia.

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