Winter 2019/20 | Issue 49

Science in School

The European journal for science teachers

Finding the recipe for life on Earth

INSPIRE

Phenomenal physics

TEACH

Solving crimes with chemistry

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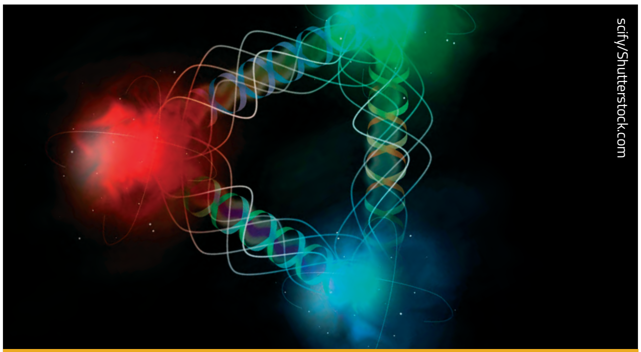
HUNTING FOR EXOPLANETS 08

The possibility of worlds beyond our own has fascinated people for millennia. Now technology is bringing these other worlds – or exoplanets – within reach of discovery.



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EDITORIAL

Susan Watt
Editor
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Welcome to issue 49 of *Science in School*. In this issue, we have plenty of intriguing science questions to get your brain working again after the holidays.

Have you ever wondered how life on Earth began? Or how scientists detect distant planets outside our Solar System? To start this issue, we take a look at the latest scientific thinking – and speculation – on the origins of life (page 13), and explore breakthrough research on exoplanets, which was recently recognised with a Nobel Prize (page 8).

Staying with space, we challenge students to devise a plan for growing plants on the Moon (page 33). Closer to home, we show you how to use a common forensics technique to reveal fingerprints (page 29). And if all this activity leaves you needing a break, we have some science crossword puzzles to keep you entertained (page 26).

In the previous issue, we promised an update on the results of our survey of readers' views on *Science in School* and the changes ahead. Thank you again to everyone who took part and sent us their thoughts. We were delighted with the very positive sense that emerged from the replies. It's clear that *Science in School* is highly valued by readers, and we in turn very much value your interest in the journal.

There are changes ahead, however, and we will be keeping readers updated in the coming months via our newsletter, so make sure you are subscribed – just log into your account via our website.

One important change is that this is the last print issue of *Science in School* for a while. But we are continuing online, bringing you a regular supply of science articles and classroom activities. We'll be uploading something every month, so do keep checking the website to see what's new.

In the meantime, we wish you all a fantastic start to the new decade!

Susan Watt

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

Energy-efficient devices, next-generation telescopes, and sustainable paint from beetle scales

Pixel-sensor chip developed for use in X-ray imaging and particle detection

CERN

CERN
Turning technology into applications

Technologies developed for the Large Hadron Collider (LHC) have many applications outside the world of high-energy physics. One example is pixel-sensor chips, which are used in detectors at the LHC to track the paths of electrically charged particles. In the late 1990s, scientists realised that they could adapt the chips for use in medical imaging – and so the 'Medipix2' chip was born. A recent symposium at CERN commemorated the two decades since the Medipix2 collaboration was established in 1999. Over the past 20 years, the chips have evolved, thanks to the Medipix and subsequent Timepix collaborations.

The chips have been used in a variety of applications, both within medicine and beyond – from measuring radiation exposure to spotting forgeries in the art world. Timepix chips have been used on board the International Space Station since 2012 to measure the radiation dose that astronauts are exposed to, and the Medipix3 chip was recently used to confirm the authenticity of an alleged Van Gogh painting.

Learn more about the Medipix and Timepix chips on the CERN website. See: https://home.cern/news/news/knowledge-sharing/medipix-two-decades-turning-technology-applications

The CERN laboratory sits astride the Franco-Swiss border near Geneva, Switzerland. It is the world's largest particle physics laboratory. See: www.cern.ch

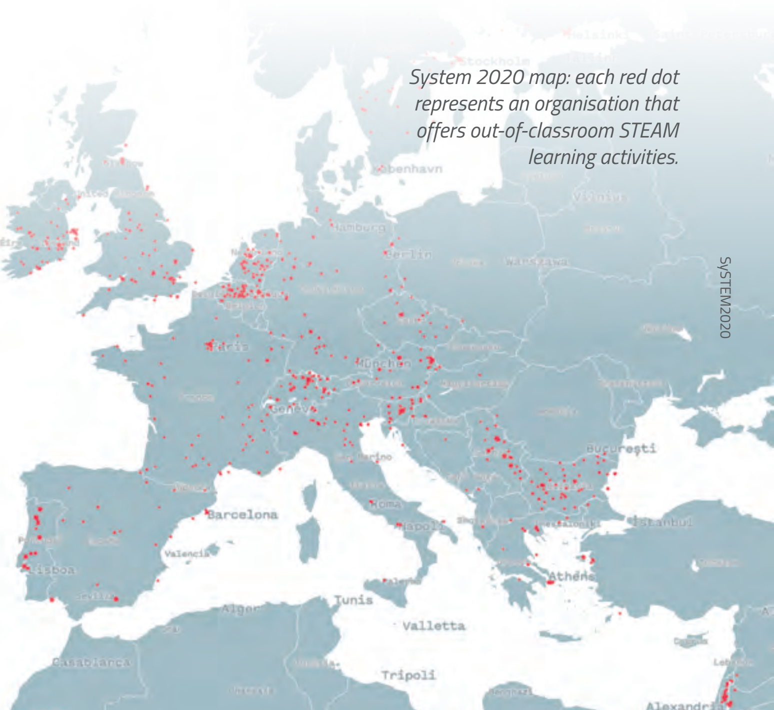
EMBL
Putting science learning on the map

Engaging with activities and experiences outside the school classroom is an important aspect of a student's development. To enable students to better access such experiences within the realm of STEAM (science, technology, engineering, arts and mathematics), the European Molecular Biology Laboratory (EMBL) is on a mission to map STEAM initiatives as part of the European project SySTEM 2020.

The project aims to assess the impact of science learning outside the classroom. So far, SySTEM 2020 has brought together 20 organisations across 22 European countries, adding over 2200 entries to the map. As well as allowing users to find STEAM activities across Europe, the information gathered from the project will be used in research that could ultimately influence education policy at both regional and European levels.

Learn more about the SySTEM 2020 project on the project website, and find the interactive map of out-of-classroom STEAM learning activities across Europe. See: https://system2020.education/

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



System 2020 map: each red dot represents an organisation that offers out-of-classroom STEAM learning activities.

SySTEM2020

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

ESA
How to characterise an exoplanet

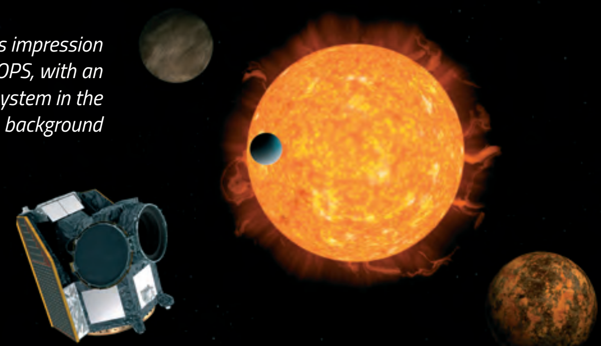
Exoplanet science is a rapidly evolving field (see also page 8). Since the first discovery of an exoplanet orbiting a Sun-like star in 1995, over 4000 exoplanets have been detected. The European Space Agency (ESA) is now carrying out its next endeavour in this field: the Characterising Exoplanet Satellite (CHEOPS) mission, which was scheduled to launch in mid-December 2019.

CHEOPS will observe bright, nearby stars that are already known to host exoplanets. The aim of the mission is to characterise some of these alien worlds, focusing on exoplanets with sizes between those of Earth and Neptune. The satellite uses 'ultra-high-precision transit photometry' to measure precisely the diameter of the exoplanet. This information, combined with existing measurements of the exoplanet's mass, gives the bulk density of the planet, which in turn sets constraints on its composition and internal structure. This will indicate, for example, if a planet is predominantly rocky or gassy or perhaps has oceans.

This first-step characterisation provides key insights into the formation and evolution of these small planets – a critical step in our search for life beyond our Solar System.

Find out more about CHEOPS and receive mission updates by visiting the ESA website. See: https://sci.esa.int/web/cheops

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



Artist's impression of CHEOPS, with an exoplanet system in the background

ESA/ATG MediaLab

ESO
Construction of the ELT starts on solid ground

Scientists all over the world are waiting eagerly for the next generation of telescopes to be built. Currently, the largest ground-based telescopes can collect 1.5 million times more light than the human eye and are capable of observing very dim and faraway objects in the Universe. However, their resolution is not high enough to find Earth-like exoplanets or to provide insights into the origins of the Universe. To overcome this challenge, larger telescopes with bigger mirrors are now under construction. They will be able to collect more light and produce higher-resolution images.

One such telescope is the Extremely Large Telescope (ELT) from the European Southern Observatory (ESO). Construction is now underway for the foundation of the telescope. Eighteen of the 798 segments for the primary mirror – which will combine to form a mirror 39 m in diameter – have been produced so far and are now at the polishing stage. The ELT, which is scheduled to be completed in 2025, will be the biggest telescope on Earth.

Construction is now underway for the foundations of the ELT in the remote Chilean Atacama Desert.

ESO

Learn more about the ELT on the ESO website. See: www.eso.org/public/teles-instr/elt

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

ESRF

Beetle scales may be key to creating sustainable paint

The scales of the *Cyphochilus* beetle are one of the brightest white substances found in nature. Until now, the reason for their ultra-white appearance was not known, but recent X-ray experiments performed at the European Synchrotron Radiation Facility (ESRF) have uncovered the answer.

Researchers from the University of Sheffield, UK, used the X-ray imaging facilities at ESRF to show that it is the scales' internal nanostructure – and not pigments or dyes – that creates this ultra-white colouring. The scales have the right proportion of empty spaces in a highly interconnected nano-network, and these spaces optimise the scattering of light – creating the ultra-white appearance.

The team managed to recreate the scales' structure in the laboratory with a polymer, which could be used to create white paints in the future. Such products could provide a sustainable alternative to the titanium dioxide used in conventional white paint, which is harmful to the environment.

Read more about this study on the ESRF website. See: www.esrf.eu/home/news/general/content-news/general/ultra-white-beetle-scales-may-be-the-key-to-more-sustainable-paint.html or use the direct link https://tinyurl.com/y3duezrs

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

Close-up of the Cyphochilus *beetle, showing its white scales*

Andy Parnell/Wikimedia Commons, CC BY-SA 4.0

EUROfusion

"Why fusion?"

The summer 2019 issue of EUROfusion's magazine, Fusion in Europe

EUROfusion

Scientists estimate that, if all goes well, fusion power will start feeding into the electrical grid sometime after 2060. Given that many people alive today will not witness fusion electricity within their lifetimes, why should we continue to invest money and physicists' time into researching and realising fusion power? To explore the answer, EUROfusion's magazine *Fusion in Europe* reached out to policy makers, students, teachers, fusion researchers and the general public to ask the question, "Why fusion?"

They received a symphony of answers, which voiced support for pursuing fusion research. The benefit of fusion research, and the promise of fusion energy – even if decades away – will be worth the investment. A collection of responses was featured in the summer issue of *Fusion in Europe*, and EUROfusion hopes to continue gathering more opinions and perspectives on the topic through an online survey.

Give your thoughts on "Why fusion?" by answering the EUROfusion survey. See: https://collaborators.euro-fusion.org/collaborators/survey-comms-department

Read *Fusion in Europe* on the EUROfusion website. See: www.euro-fusion.org/media-library/newsletter

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

European XFEL

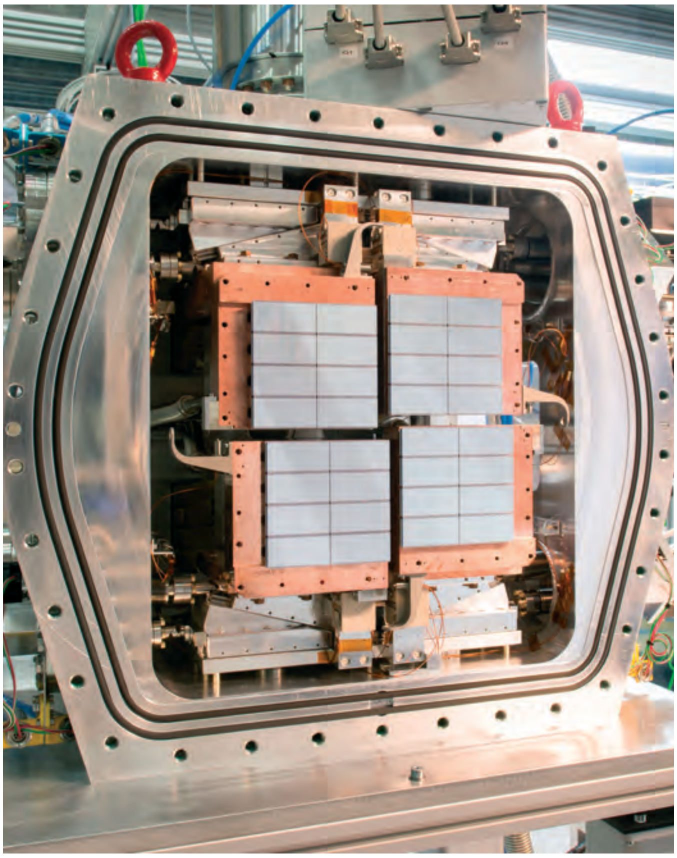
World's fastest soft X-ray camera installed

The X-ray flashes produced at the European X-ray Free-Electron Laser (European XFEL) facility allow researchers to study a variety of samples at the atomic level. The X-rays are fired at a sample to produce a distinctive pattern that is recorded by a detector. The flashes arrive in quick succession, with a time difference of 220 nanoseconds, so the detector takes many images one after another – allowing scientists to monitor high-speed molecular processes.

European XFEL recently installed and tested a new X-ray detector specifically designed for the facility's soft X-ray instruments, which use low-energy, long-wavelength X-rays. At full capacity, the new DSSC detector can acquire images at a rate of 4.5 million images per second, making use of each X-ray flash. This makes the DSSC the fastest soft X-ray detector in the world, enabling ultrafast studies of atomic structure at the nanoscale.

Find out more about the DSSC detector on the European XFEL website. See: www.xfel.eu/news_and_events/news/index_eng.html or use the direct link https://tinyurl.com/y4r3keju

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



Karsten Hansen/DESY

The DSSC detector, a new soft X-ray camera installed at European XFEL

ILL

NEUTRONS FOR SCIENCE

Meeting the need for energy-efficient devices

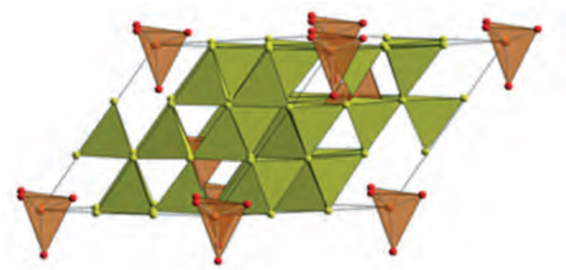
Scientists are constantly searching for new materials to help create more energy-efficient electrical devices. One such class of materials is oxide-ion conductors – solid oxides that contain highly mobile oxide ions. To better understand the properties of these conductors, scientists from the Institut Laue-Langevin (ILL) and Durham University, UK, recently used neutron scattering techniques to observe their oxide-ion dynamics at the atomic level.

One of the most promising applications of oxide-ion conductors is in solid oxide fuel cells (SOFCs). These devices convert chemical energy to electricity without creating environmentally harmful by-products. The main disadvantage of conductors currently used in SOFCs is that achieving the necessary level of conductivity requires very high temperatures (750–800°C). There is, however, one oxide-ion conductor with remarkable conductivity at relatively low temperatures: bismuth vanadate.

By studying bismuth vanadate at the atomic scale, the researchers revealed that two main mechanisms contribute to its conductivity. Using these insights, the scientists can find ways to chemically modify bismuth vanadate, as well as other similar conductors, to improve their properties further.

Learn more about the study on the ILL website. See: www.ill.eu/news-press-events/news/scientific-news/understanding-the-properties-of-oxide-ion-conductors-for-efficient-energy-devices

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



ILL

Crystal structure of bismuth vanadate. Two main mechanisms contribute to the conductor's favourable dynamics: one in the Bi-O sub-lattice (green) and the other in the V-O sub-lattice (brown).

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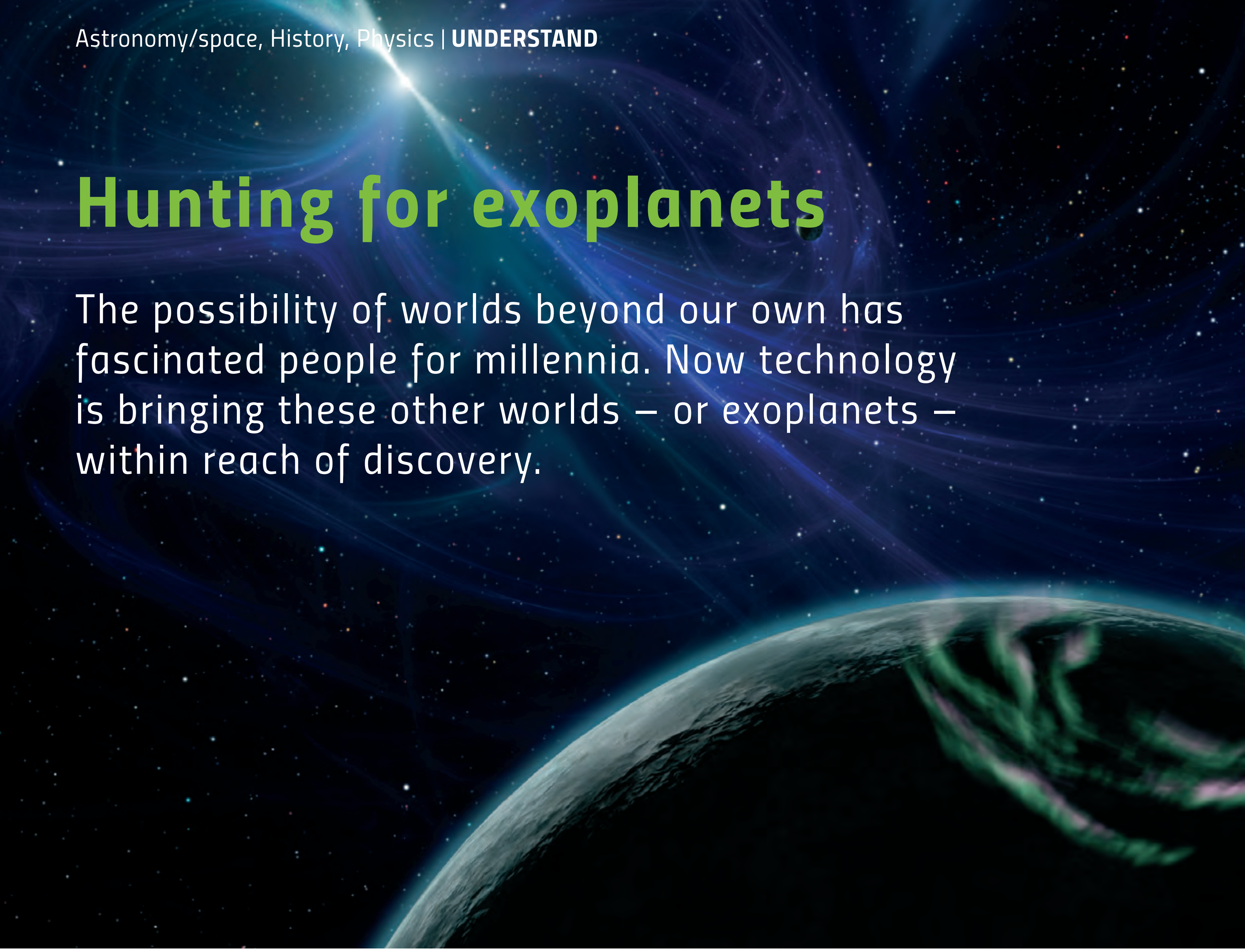
To browse the other EIRO news articles, see: www.scienceinschool.org/eironews



Hunting for exoplanets

The possibility of worlds beyond our own has fascinated people for millennia. Now technology is bringing these other worlds – or exoplanets – within reach of discovery.

By Wolfgang Vieser

“There are infinite worlds both like and unlike this world of ours.” So said the ancient Greek philosopher and atomist Epicurus in the fourth century BCE. But just as Greek ideas of a heliocentric Solar System were lost in the turmoil of history, Epicurus’s notion of a boundless cosmos was swept aside by the dominant philosophy of Aristotle, who claimed that “there cannot be more worlds than one.”

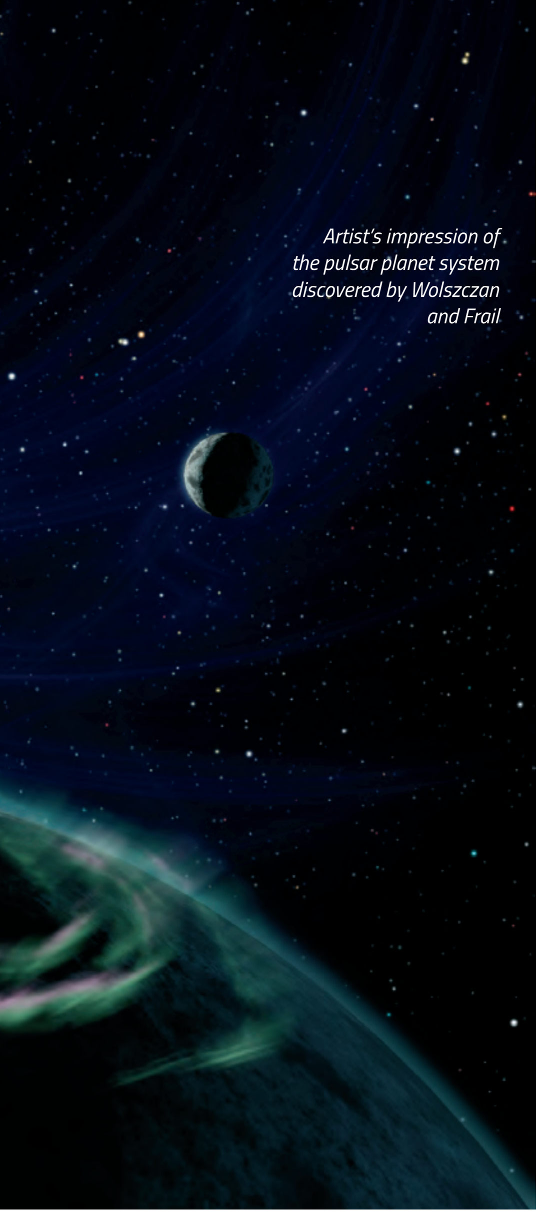
It was nearly 1000 years before the idea that Earth might not be alone was taken seriously again. In Italy in 1584, at the height of the Renaissance, the philosopher Giordano Bruno proposed that the Universe is infinite and that the stars are distant suns orbited by “innumerable worlds”. About 400 years later, in 1992, came the first confirmed detection of one of Bruno’s innumerable worlds, by radio astronomers Aleksander Wolszczan and Dale Frail (Wolszczan & Frail, 1992). Wolszczan and Frail had discovered a furiously fast-spinning pulsar in the constellation of Virgo. Rotating more than 160 times a second, this tiny collapsed star emits powerful radio beams that sweep across Earth as rapid pulsations. An irregularity in the signal led the astronomers to conclude that “the pulsar is orbited by two or more planet-sized bodies”, which became the first known ‘exoplanets’ – planets external to our own Solar System. Three years later, another exoplanet was found by Michel Mayor and Didier Queloz[w1], this time in orbit around a Sun-like star called 51 Pegasi. It was an extreme world – a ‘hot Jupiter’-type planet at least 150 times more massive than Earth and orbiting its sun even more closely than Mercury orbits ours.

Astronomers realised it was possible to detect exoplanets, and the race to find more followed. Detection methods improved, and the discoveries piled up.

We now know of more than 4000 exoplanets: most are near our Solar System, as their proximity makes them relatively easy to detect (figure 2). This suggests that there may be as many as 11 billion Earth-sized and potentially habitable planets in our Milky Way galaxy alone.

Alien worlds

The hunt for exoplanets has been far more successful than astronomers once dared hope. Alien planetary systems are ubiquitous and surprisingly diverse, with many bearing little resemblance to our Solar System. It now appears that most stars have planets, and small rocky planets are abundant, including Earth-like worlds that orbit their parent star in the ‘habitable zone’ where liquid water might exist on the planet’s surface – a condition thought essential for life. Many



Artist's impression of the pulsar planet system discovered by Wolszczan and Frail

REVIEW

- ✓ Spectroscopy
- ✓ Telescopes
- ✓ Doppler effect
- ✓ Scientific discovery
- ✓ Ages 14–19

The search for exoplanets seems to be a new discipline in astronomy. For the inhabitants of Earth, it is interesting to see if there is something out there similar to our own planet. Perhaps soon we will be able to answer the question: are we alone?

This article outlines the current methods used to discover exoplanets, which employ familiar principles of physics and chemistry. The article could be used as a comprehension exercise, and the following questions and challenges could be included:

- What is an exoplanet?
- Summarise the history of exoplanet discovery.
- Describe one of the methods used to discover exoplanets.
- What is the likely future of exoplanet discovery?

Gerd Vogt, physics and technology teacher, Higher Secondary School for Environment and Economics, Ysperal, Austria

massive, Jupiter-like exoplanets have also been found, and some have been imaged. We have detected clouds in their skies and, thanks to spectral analysis, we can even identify the elements in their atmospheres.

However, the hunt for exoplanets faces considerable challenges. Planets are much fainter and smaller than the stars they orbit, so we rely mostly on indirect methods to find them, rather than imaging them directly. There are several different approaches, each with its own advantages and disadvantages. In this article, we take a look at some of the most important methods of discovery.

Transit method

If an exoplanet happens to pass in front of its parent star while we watch from Earth – a phenomenon known in astronomy as a 'transit' – the star's brightness will briefly dip, if only by a

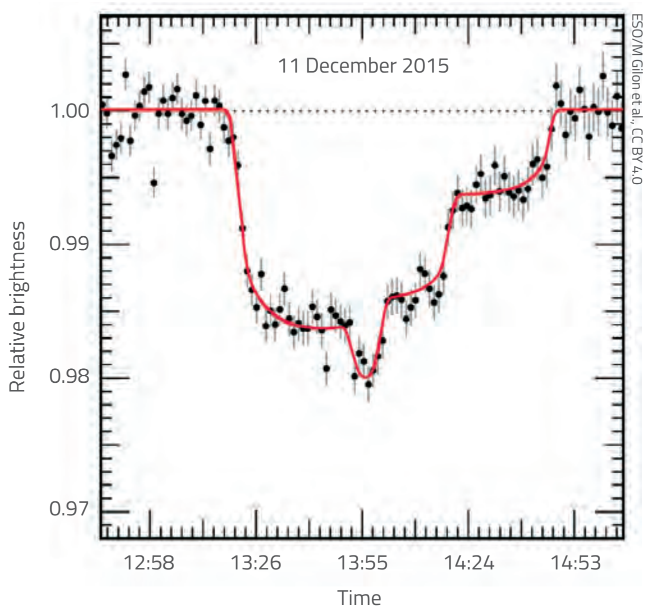
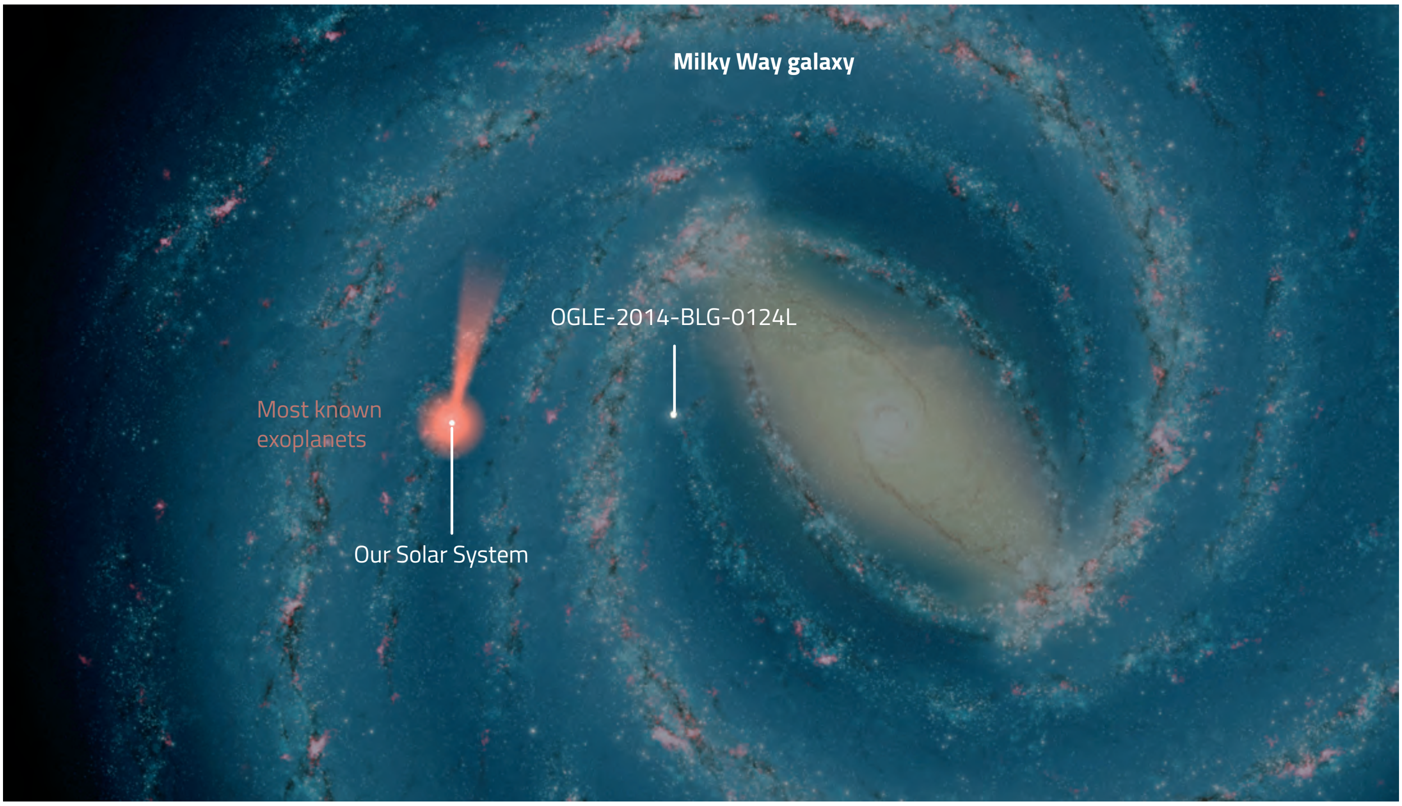


Figure 1: Graph showing the changing brightness of the red dwarf star TRAPPIST-1, which is caused by three exoplanets passing in front of the star in quick succession.



NASA/JPL-Caltech

Figure 2: Most known exoplanets are concentrated near our Solar System, but a few have been found much further away, including the gas giant OGLE-2014-BLG-0124L. The red cone is an area surveyed by the Kepler space telescope.

"There may be as many as 11 billion Earth-sized and potentially habitable planets in our Milky Way galaxy alone."

tiny fraction, as was seen with the triple transit of the star TRAPPIST-1 in 2015 (figure 1). More than three-quarters of known exoplanets were detected this way. The transit method relies on an element of luck: because the inclinations of their orbits are randomly distributed, from our viewpoint most exoplanets are never seen transiting in front of their star. To get around this problem, space telescopes such as NASA's Kepler telescope survey large numbers of stars over a long period. Stars may also show dips in brightness due to surface features such as star spots, so follow-up observations are needed to confirm a discovery.

During a transit, the star's light passes through the exoplanet's atmosphere, where certain wavelengths are selectively absorbed by elements and molecules in the atmosphere. The pattern of absorption, which we can read by carrying out a spectral analysis, serves as a chemical fingerprint, telling us which substances are present. Such studies have revealed water in exoplanet atmospheres (Tsiaras et al., 2019) and can even tell us whether atmospheric water takes the form of vapour or liquid.

Astrometric method

Planets are far less massive than stars, but they still exert a pull on them. The gravitational tug-of-war between a planet and its star causes the pair to orbit a shared centre of mass that is often within the star itself, although not right in the middle. The result is that the star appears to wobble as it moves in a tiny orbit around the shared centre of mass. The pull of Jupiter on the Sun, for example, causes the Sun to wobble with an average velocity of 12 m/s as it orbits a centre of mass close to its surface. The effect of all the planets in our Solar System on the Sun is the wobbling path shown in figure 3.

The astrometric method relies on detecting this telltale but almost imperceptibly small wobble in stars situated many light years away, which places high demands on the sensitivity of instruments. To put this into perspective, a Sun-sized star 42 light years away (ten times further than our closest neighbouring star, Proxima Centauri) would wobble by only a fifth of a millionth of a degree under the influence of a planet like Jupiter. This is equivalent to seeing the International Space Station from the Earth moving 1.5 mm in its orbit. The effect of an Earth-sized planet would be some 1600 times smaller.

Fewer than 0.02% of known exoplanets have been found using this method. However, that figure might rise, thanks to space telescopes such as the one carried by ESA's Gaia spacecraft. Gaia's equipment is unaffected by the distortion of Earth's atmosphere, and can detect movements as small as a quarter of a billionth of a degree.

Radial velocity method

Another way to detect the wobbling motion of a star is to look for shifts in its spectrum. This is called the radial velocity method, and it makes use of the Doppler effect – the compression or stretching of waves from a source that is moving towards or away from the observer. When a star is moving away from us, its light is shifted towards the red end of the spectrum; when it is moving towards us, the light is shifted towards blue.

The shift in wavelength caused by an orbiting planet is tiny. Our Sun's 12 m/s wobble, caused by Jupiter, shifts its spectral lines by a mere 0.000004%. Even so, astronomical spectroscopes can already detect stellar movements of less than 1 m/s, and work is in progress to reach the 0.1 m/s precision needed to detect Earth-like planets. For this reason, the radial velocity method is a cornerstone of exoplanetary astronomy and accounts for nearly 20% of discoveries made since 2012.

Like other techniques used to hunt for exoplanets, the radial velocity method has a distinct observational bias, favouring the planets that are easiest to find: massive, Jupiter-like worlds that orbit close to their star. Radial velocity is also biased towards stars rich in heavy elements, since the light from such stars has more spectral lines, making Doppler shifts easier to detect.

Direct imaging

The ultimate proof of an exoplanet's existence is a picture of it, but direct imaging requires telescopes with incredibly high resolution. The further away an exoplanet is, and the closer it is to its star, the wider the telescope's collecting mirror or lens needs to be to resolve the two objects as separate. An 8 m-wide telescope would be needed to separate Jupiter from our Sun when viewed from 600 light years away, while resolving Earth would require a 39 m telescope. A telescope of exactly this size – the European Southern Observatory's (ESO's) Extremely Large Telescope (ELT)[w2] – is currently under construction in the Atacama Desert of Chile and is due to start searching for exoplanets in 2026. Even greater resolutions can be achieved by combining data from several telescopes arranged over a wider area – a technique known as interferometry.

The bigger challenge to be mastered is the extreme contrast between the brightness of the exoplanet's reflected light and that of the host star, which is up to ten billion times brighter than an Earth-like exoplanet. One way to overcome this problem is by using masking techniques called coronagraphs to suppress the starlight.

More than 100 exoplanets have now been imaged directly (Chauvin et al., 2017; see figure 4). As with the transit method, direct imaging allows us to study the spectra of light from exoplanets and identify the elements in their atmospheres.

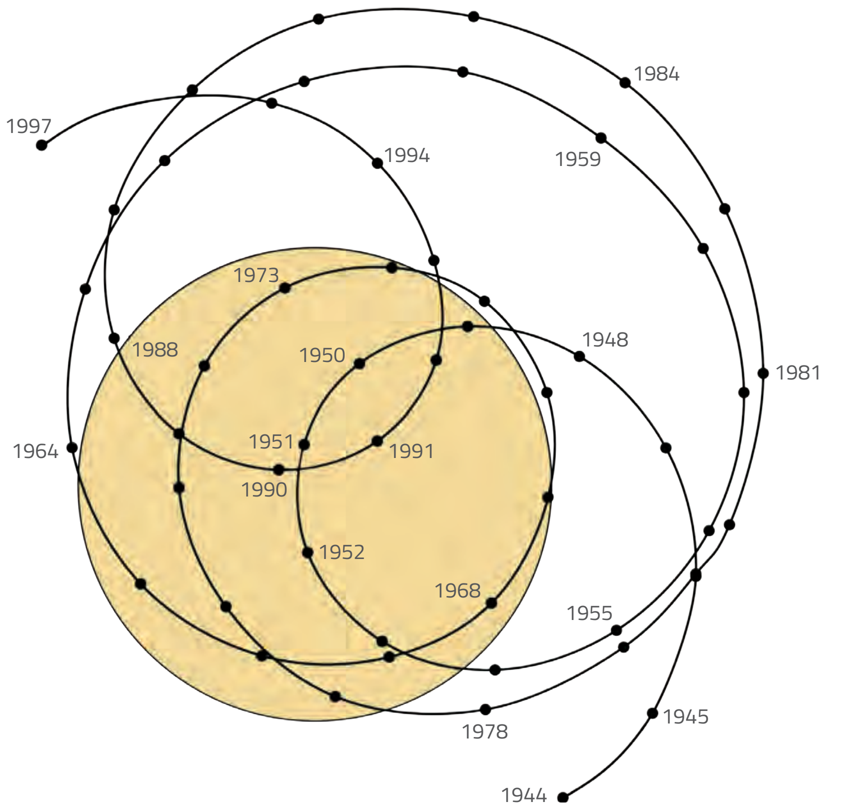


Figure 3: The black line shows the wobbling path of the Sun from 1944 to 1997 as the planets of the Solar System pull on it. The yellow circle indicates the Sun's size.

Future developments

The coming years are likely to be very exciting for exoplanet research as new telescopes become operational and detection methods improve further. One promising project in development is SPECULOOS, a set of four 1 m-wide robotic telescopes under construction in the Atacama Desert. SPECULOOS will search for Earth-like exoplanets orbiting near stars with surface temperatures below 2500 K.

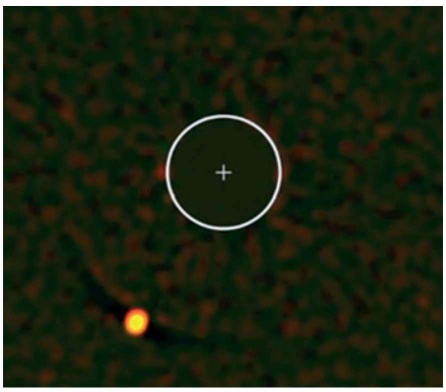


Figure 4: Actual image of the exoplanet HIP 65426b, produced by ESO's Very Large Telescope. The planet's star, shown by a cross, has been masked out. The circle indicates the orbit of Neptune on the same scale.

The four telescopes of the SPECULOOS Southern Observatory, which will search for Earth-sized exoplanets

tau-tec GmbH

In the 2020s, the James Webb Space Telescope (a partnership between NASA, ESA and the Canadian Space Agency) and large-aperture telescopes such as the ELT will provide the resolving power needed to find many more Earth-like planets in the habitable zones around Sun-like stars. Spectral analysis and other image-processing techniques will make it possible not only to identify such worlds but also to perform chemical analysis of their atmospheres – and look for the telltale signs of life as we know it.

Exoplanets for schools

The hunt for exoplanets is not just the preserve of professional astronomers with large and expensive equipment. Using the transit method, even a modest 10–20 cm telescope can reveal the eclipse of a star as an exoplanet passes in front of it. Amateur astronomers and schools might be unlikely to discover new exoplanets, but by making follow-up observations of known planets, you could provide invaluable data in our quest to learn more about these fascinating worlds. You can find links to websites describing such activities for schools in the resources section. Happy hunting!

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Wolszczan A, Frail DA (1992) A planetary system around the millisecond pulsar PSR1257 + 12. *Nature* **335**: 145-147. doi: 10.1038/355145a0

Download the *Nature* article free of charge on the *Science in School* website. See: www.scienceinschool.org/2019/issue 49/exoplanets, or subscribe to *Nature* today: www.nature.com/subscribe

Web references

w1 Michel Mayor and Didier Queloz were awarded the Nobel Prize in Physics 2019 for their discovery of an exoplanet orbiting a solar-type star. Read about their discovery on the Nobel Prize organisation's website: www.nobelprize.org/prizes/physics/2019/press-release

w2 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

Resources

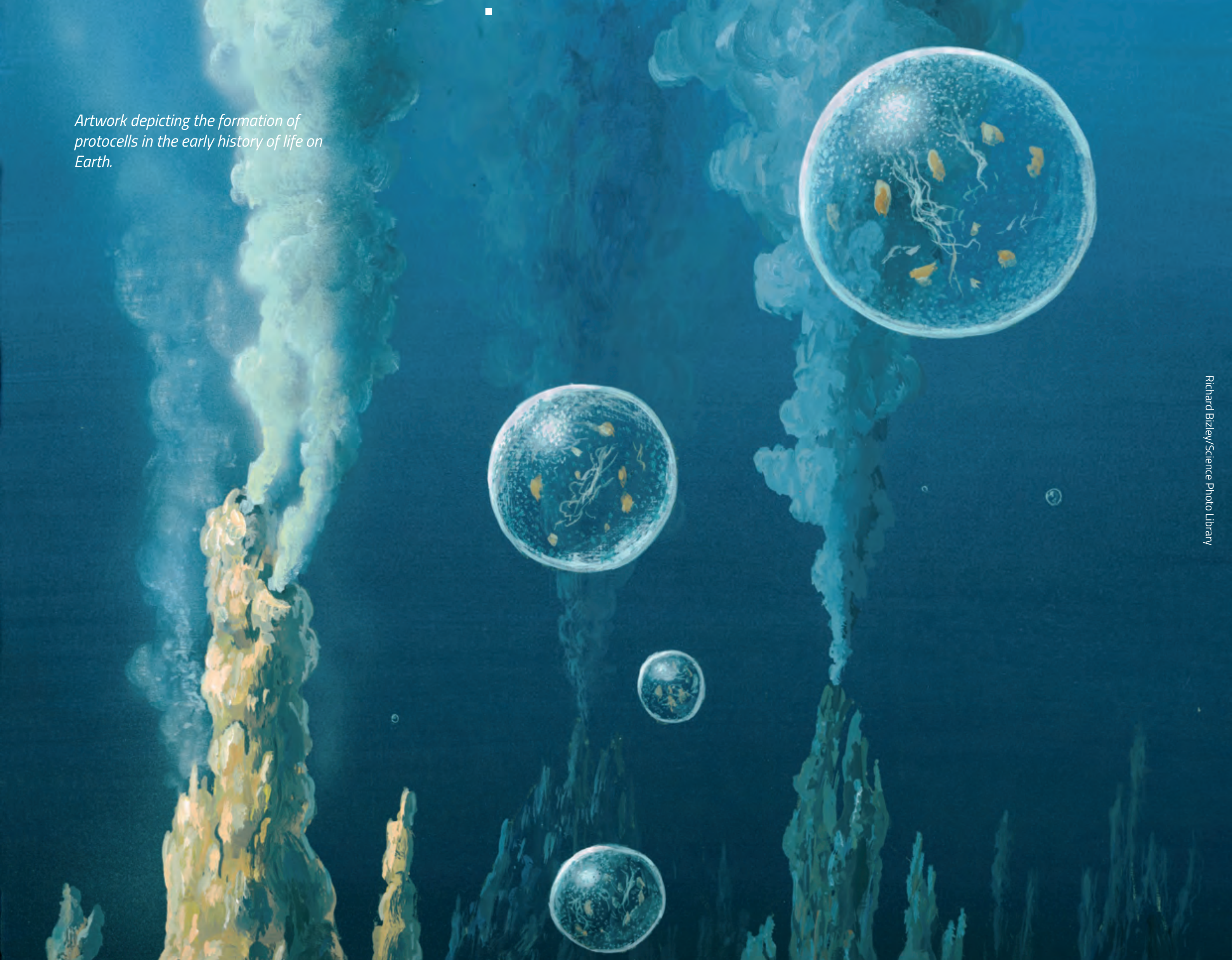
Find out how amateur astronomers can detect exoplanets. See the AstronomyOnline.org website: http://astronomyonline.org/Exoplanets/AmateurDetection.asp

Learn how amateur astronomers are helping scientists detect more exoplanets. See:

The American Association of Variable Star Observers website: www.aavso.org/exoplanet-data

The amateur astronomer page for NASA's Kepler mission: www.nasa.gov/kepler/education/amateur-astronomers

Wolfgang Vieser is an astrophysicist and physics teacher. He holds a doctorate in astrophysics and taught at secondary school for 14 years before taking up his position as ESO Education Coordinator. Bringing cutting-edge science into the classroom and supporting teachers in using astronomy as a gateway into the world of science is his main focus.



Artwork depicting the formation of protocells in the early history of life on Earth.

Richard Bizley/Science Photo Library

Finding the recipe for life on Earth

Three key factors were required for life to develop on Earth – but which factor came first? Recent research could help settle the debate.

By Andy Extance

Stop for a moment to consider yourself: think about your eyes reading this, your brain absorbing it, and your body containing and powering these organs. Ask yourself: how did this complex, living biochemical machinery come to be? It's a profound question that has driven scientists for centuries. Charles Darwin partially answered it with his theory of evolution, detailing how each species emerged from a previous one.

If you trace evolution back far enough, there must have been a time when cells themselves first came to exist – the origin of life, which happened over 4 billion years ago. Today, researchers are trying to solve the puzzle of exactly how this happened, but as it was so long ago, that's very hard. Comparing modern life forms on Earth provides a powerful argument for how life originated. We humans are more similar to trees, insects, bacteria and all other life than it may seem at first, in three important ways. First, all species use similar molecules to pass on genetic information: ribonucleic acid (RNA) and deoxyribonucleic acid (DNA). Second, different species' cells look roughly similar – even single-celled organisms share characteristics with the cells of larger organisms. And third, the way all cells get the energy they need for their biochemical processes through metabolism is very similar. This argument leads to the idea that three key factors were required for life to develop on Earth: nucleic acids (RNA and/or DNA); a membrane, compartment or some way to contain the cell's contents; and metabolism.

Researchers continually offer new ideas on how life might have originated, but a big cause of arguments among them has been the question of which of the three key factors emerged first. More recently, however, a new idea has emerged that could settle that argument: what if all three appeared at the same time?

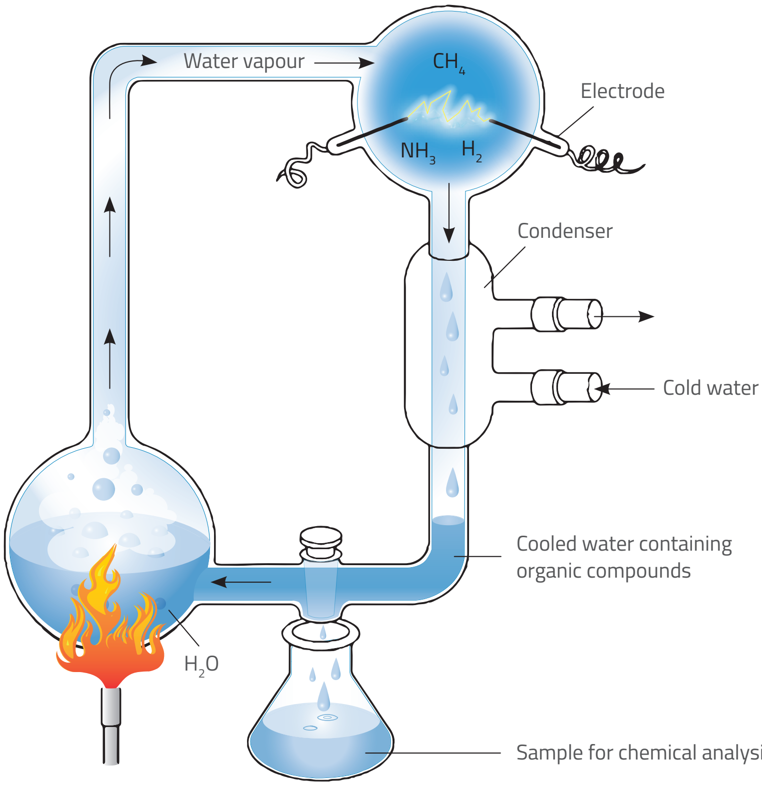


Illustration of Miller and Urey's 1952 experimental setup

Early Earth experiments

We have known for a while that organic molecules can be produced under the type of conditions that might have been found on the early Earth. The most famous first step in understanding how life emerged is Stanley Miller and Harold Urey's 1952 experiment (Miller, 1953). Firing electrical sparks into flasks containing water, ammonia, methane and hydrogen produced some organic substances, including amino acids. However, this failed to explain many aspects of life's emergence, because it didn't produce other important biological molecules, such as nucleic acids.

In the early 1980s, Tom Cech and Sidney Altman made the Nobel prize-winning discovery of enzymes made of RNA, called ribozymes. Because RNA can encode genetic information and ribozymes can manipulate it, scientists suggested that RNA enabled life by itself, before the other factors were in place. This idea is known as the 'RNA-first' hypothesis.

John Sutherland, who now works at the Medical Research Council (MRC)

REVIEW

- ✓ Evolution
- ✓ Biochemistry
- ✓ Geology
- ✓ Earth science
- ✓ Cell biology
- ✓ Macromolecules
- ✓ Ages 11–18

In almost all school textbooks, within the section that deals with the origins of life, references are limited to the famous experiment of Stanley Miller and Harold Urey in 1952. Since then, more experiments have been made, and it is certain that the question of the origin of life will always concern the scientific community.

This article, which explores several theories of the origin of life, can be used in a variety of ways – either as an example of the ways science evolves while basic research questions remain, or for the scientific theories related to living matter. It will be a journey through time, space and the world of great research questions.

Comprehension questions could include:

- When is life thought to have originated on Earth?
- What are the three factors that are believed to be fundamental for the emergence of life?

Panagiotis K Stasinakis, biology teacher and head of Ampelokipoi Laboratory Centre for Natural Sciences (EKFE), Greece

Laboratory of Molecular Biology in Cambridge, UK, is among those who found evidence apparently supporting an RNA-first case. In 2009, his team showed how a ribonucleotide could form under conditions that might have existed on the early Earth (Powner et al., 2009).

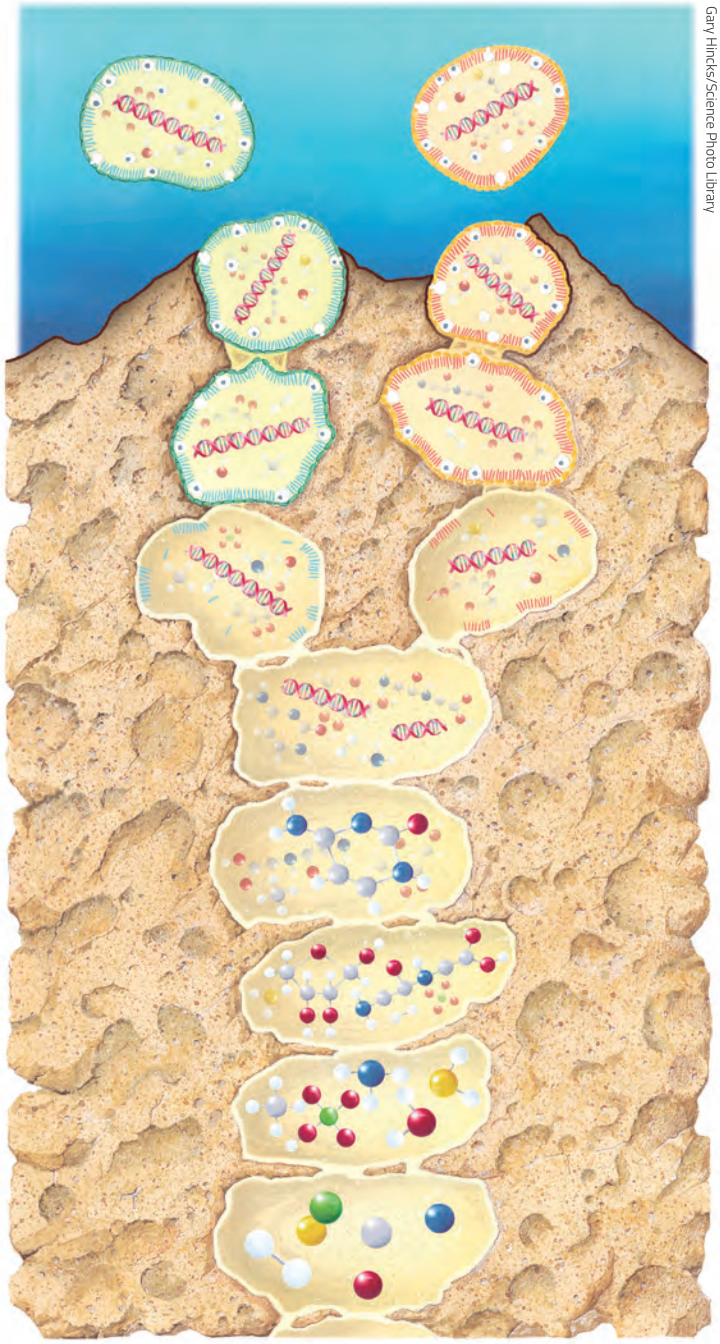
Sutherland's team then sought a better way to make ribose sugars. Researchers had shown that they could be made

> "Making sugars and amino acids together is an important advance, as today's cells break down sugars in metabolism to get the energy they need."

from formaldehyde, but this route was "really messy and difficult", Sutherland observes. His team explored an alternative route using just hydrogen cyanide, hydrogen sulfide and ultraviolet light. As well as making the ribose sugars, they produced over 50 different molecules, including some that could help make amino acids – which could assemble to make the proteins that form the physical structure and enzyme machinery of living cells. Making sugars and amino acids together is an important advance, as today's cells break down sugars in metabolism to get the energy they need (Ritson & Sutherland, 2013).

In 2015, the MRC team showed that the same chemical system leads to fatty molecules that can form cells' outer walls, defining their shape (Patel et al., 2015). And the system also has similarities to metabolism itself. "It's consuming small molecules and making bigger molecules", Sutherland says. "It does suggest that all the subsystems could have emerged at the same time."

Following on from this, Sutherland and his colleagues published a study in 2019 suggesting that RNA and DNA might have appeared at the same time, thus further challenging the RNA-first hypothesis (Xu et al., 2019).



Gary Hincks/Science Photo Library

Artwork illustrating the theory that life on Earth originated around underwater volcanic vents. Nine stages are shown, from the atomic level to the cellular level. From bottom: prebiotic chemistry; amino acids, sugars and bases; more complex carbon compounds; formation of RNA; formation of DNA. The evolutionary tree splits at this point into the routes that will form bacteria (left) and archaea (right).

Places of origin

Like Sutherland, Frances Westall, from the Centre for Molecular Biophysics in Orléans, France, sees the three key factors for life as having emerged by luck at the same time. Her view is that the reactions responsible would have happened on the surfaces of minerals. Chemists in her group talk about a 'protocell', with metabolic machinery and RNA contained in a tiny mineral pocket. Eventually, fatty lipid molecules would have formed an outer wall inside the pocket, giving cells the

> **“Westall and others are looking for the location where life emerged, studying mineral pores in deep-sea vents that spew out hot alkaline fluid.”**

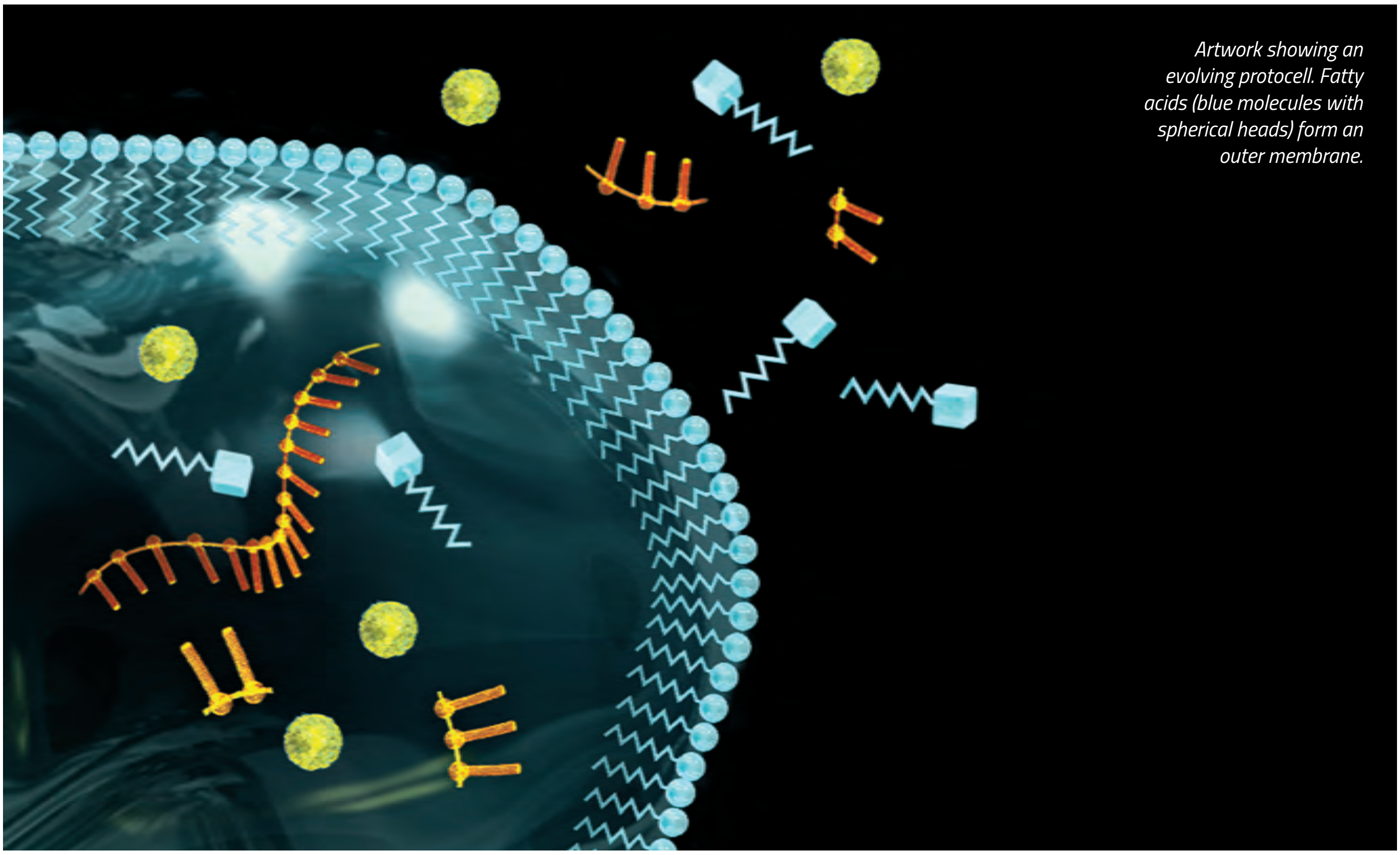
form we recognise today. “Depending upon the environment,” Westall says, “concentrations of lipids, proteins and RNA in porous mineral matrices would assemble to form a cell with a membrane.”

Westall and others are looking for the location where life emerged, studying mineral pores in deep-sea vents that spew out hot alkaline fluid. Her team has found possible examples in South African rocks (Westall et al., 2018). “Although temperatures at the vent may be greater than 300°C, far too hot to preserve proteins and other essential molecules, the external seawater is 2°C”, Westall says. The temperature gradient drives a flow of water that helps move compounds around, and may also help provide a driving force for metabolism. As Westall explains, “The vent edifices are full of reduced minerals that can be oxidised to provide energy for prebiotic reactions and surfaces for concentrating the organics, as well as various structural combinations and formations.” Other researchers have also suggested that, in such environments, cellular ion pumps – proteins that regulate the flow of ions across cell membranes – might have evolved (Lane & Martin, 2012).

Yet the search for places with the right chemistry and the energy to drive metabolism and enable cells to form also includes such locations as coastal volcanic areas, pumice rafts floating on the ocean, and geysers. A more speculative idea adds meteorites to this list: in 2014, rocks from the 24 km-wide Ries crater in southern Germany, which formed from a meteorite impact about 14.6 million years ago, were found to contain microscopic tubule-like formations, which have been linked to biological activity (Sapers et al., 2014). The tubules are similar to fossil traces of microbes found in volcanic glass, suggesting that water circulating within the rocks could have enabled microbes to colonise them. Some researchers have therefore suggested that similar tubules, formed billions of years earlier by meteorite impacts, could have offered a viable habitat for the earliest life forms.

NOAA/Wikimedia Commons, public domain

Evidence of Earth’s earliest life forms has been found in hydrothermal vents.



Artwork showing an evolving protocell. Fatty acids (blue molecules with spherical heads) form an outer membrane.

Henning Dalhoff/Science Photo Library

Fyre Mael/Flickr, CC BY 2.0

Westall's team examined volcanic sediments ranging from 3.46 to 3.33 billion years in age from the Barberton Greenstone Belt in South Africa (pictured here) and the Pilbara in Australia.

Unusual science

Westall compares combining the different elements needed for the origin of life to developing cooking recipes. "If you want to get the perfect cake, you have to use exactly the right amount of specific ingredients and the right cooking temperature and time", she says. "On the other hand, if you feel like experimenting, you change the ingredients, the quantities, temperature and time – and see what comes out."

The idea of the three critical factors for life emerging all at once calls for something more like the second approach, Westall believes, and it's an unusual kind of science. "Trying to do the experiments in a realistic scenario where you just stick in all the ingredients in a context that cannot be controlled, it just runs by itself, is really scary for chemists", she says. "If something interesting happens, it's more difficult to work out what and why. But that is the way to go now."

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Resources

- Read more about scientific research on the origin of life in an article from *Education in Chemistry*. See: https://edu.rsc.org/feature/the-origin-of-life/2000129.article
- Listen to an episode of Sean Carroll's 'Mindscape' podcast about how designing cells from scratch can help us understand how life arose. See: www.preposterousuniverse.com/podcast/2019/07/22/56-kate-adamala-on-creating-synthetic-life or use the direct link: https://tinyurl.com/y48hwvvq
- Read a feature from *Current Biology* to find out more about research relating to the origin of life. See: www.sciencedirect.com/science/article/pii/S0960982216314476

Andy Extance is a science writer based in Exeter, UK. His writing explores everything related to chemistry, from Earth's environment to space, from food to nuclear fusion, and from solar cells to how we smell.

Saami man with reindeer

The social science of climate change

In Arctic regions, landscapes are changing fast. This has profound effects on their biological systems, but how are communities and their traditional lifestyles affected?

By Holly Unwin

I first visited Arctic Norway in 2016 as a geology student, spending two months exploring a remote valley to learn about its geology and to produce a geological map of the area. It was so exciting to climb out of my tent every morning and spend the day hunting for outcrops of rock that very few, if any, geologists had ever seen before. Although this idyllic landscape was hardly ever visited by other people, the effects of humankind were clear: climate change was making its mark. In 2018, I had the chance to return to document the effects of climate change on this landscape, so we could share with others how rapidly our world is changing.

How can we see the effects of climate change?

Today, climate change can be seen around the world. Changes are occurring most rapidly at high latitudes, such as towards Arctic regions. People living in these remote places are already noticing the changes happening around them and are being forced to adapt. This inspired my team to investigate climate change from a social science perspective, discovering the effects on remote communities and what this might mean for their future.

We are all constantly taking photographs of people and landscapes, and such images can be used as a tool to look back into the past. By returning to the location of an old photograph and taking a photograph of the same landscape today, from exactly the same viewpoint, it is possible to identify small-scale changes. This technique, called rephotography, has been widely used to capture how cities are changing through time. But it can also be used to examine how landscapes are changing due to climate change – for example, the melting of Arctic glaciers is making landscapes almost unrecognisable (figure 1).

We chose to visit the Varanger Peninsula in Finnmark, Norway, to capture how rapidly the landscape is changing, even below the tundra line. I collected old photographs showing the landscapes of the Varanger Peninsula from previous expeditions to the area between 1959 and 2016. Once the location of each photograph was pinpointed, we visited it in 2018 to retake a modern version of the photograph. We also spoke to local people about their opinions of climate change and its effects.

> **“By returning to the location of an old photograph and taking a photograph from exactly the same viewpoint, it is possible to identify small-scale changes.”**

REVIEW

- ✓ Climate
- ✓ Weather
- ✓ Biodiversity
- ✓ Globalisation
- ✓ Arctic regions
- ✓ Ages 11–19

Climate change might still be an abstract idea for many students. We read a lot about future changes and global goals – but this article describes several consequences that are already happening. We find out about the changes that communities are facing and some of the mechanisms of change, which show how everything is connected.

The article could be used for guided discussions in class about what we can do about the negative effects of climate change, how communities can deal with the effects of climate change – and how we can learn from past mistakes and manage further changes. Comprehension questions could include:

- Why have the birch trees in the Finnmark region died?
- What happens to different species in a region when the climate changes?

The content is also interesting for teachers in social sciences, for discussions on how human culture is changing due to globalisation.

Finally, the article can serve as an environmental wake-up call: it’s time to act!

Ingela Bursjöö, science teacher and researcher, Montessori School Elyseum, Gothenburg, Sweden

Figure 1: The Nordenskiöld Glacier, Svalbard in 1919 (top) and 2016 (bottom). The glacier has retreated over this time.

Trees in changing environments

Some of the northernmost trees in the world are small silver birch, and as the climate warms these trees are likely to flourish and become bigger. More trees should also be able to survive at higher latitudes, allowing the treeline to move further north. This trend can be seen in our rephotography: over time, the trees have become larger and the landscape has become greener overall (figure 2). In this image pair, the distant hillsides are visibly greener today (2018) than they were in 1974.

The warming climate also allows other species to live at higher latitudes. In this area of Norway, rising temperatures are increasing the survival rates of some moths of the family Geometridae: the autumnal moth, the winter moth and the scarce umber moth. In the autumn, these moths lay eggs on the branches of the silver birch, where they remain over the winter until they hatch the following spring. The eggs can tolerate temperatures down to around -37°C, and with warmer winters more of these eggs hatch, producing greater numbers of caterpillars. Once hatched, the caterpillars strip the new silver birch leaves from the trees, killing large numbers of trees and leaving piles of fallen tree trunks where there once was forest.

The number of caterpillars varies each year. There are massive outbreaks in some years, and recently these very damaging outbreaks have become more frequent, preventing the silver birch trees from fully recovering in between. The result is that, where there were once valleys with healthy forests, there are now just leafless trees, many of them dead (figure 3). This effect is also very visible in figure 2, where the forest in the foreground has been destroyed by moth damage.

Figure 2: Gulgo, one of the world's northernmost birch forests. Climate warming means the distant hillsides are greener today than in 1974, but the foreground forest shows moth damage.

Effects on local communities

Many people living in areas like the remote Varanger Peninsula are dependent on the land, and their livelihoods are threatened by climate change. Living lives so connected to the land, these people notice small changes that are overlooked by others.

Saami people

Inland, the indigenous Saami people use the vast wilderness for reindeer herding. As the climate warms, the number of days with snow cover is decreasing, and more frequent winter

> **"Routes that have traditionally been safe are now more dangerous, as ice cover is thinner and melting occurs earlier."**

thaws followed by refreezing are making it more difficult for reindeer to dig through the snow to reach the lichen beneath. The northward movement of the treeline will increase the amount of vegetation available for reindeer, but the changing environment may decrease its nutritional value and threaten the lichen ecosystems. The snow is now

Figure 3: Moth-damaged forest in Gulgo

less predictable and is arriving later. Routes that have traditionally been safe are now more dangerous, as ice cover is thinner and melting occurs earlier. Conditions are less suitable for travel by snowmobile, and there is an increased avalanche risk in mountainous regions (Jaakkola et al., 2018). All of these changes are increasing the risk of accidents among the Saami people. The introduction of modern technologies and additional foodstuffs may help these people adapt to the changes, but there is a real risk that their traditional culture may be lost.

Fishing

Along the coastline of the Varanger Peninsula, the Norwegian people are fishers. Many live in small, remote villages accessible only on foot or by boat. However, the population is now decreasing as young people find more career opportunities elsewhere. In Gulgo, formerly a thriving fishing community, a jetty that once served large boats has been left to decay (figure 4), with the area now visited only by locals enjoying a peaceful weekend in their cabins. As the climate changes, so too does the weather. With rougher seas, it has become harder to fish further away, so the remaining fishermen are no longer sailing the few extra hours from the main town (Berlevaag) to reach Gulgo.

In Stappogiede, a former small fishing community accessible only by boat, we met a man and his mother who were visiting a remote cabin that had once been the family home, but which is now used only for leisure. With no permanent residents, there is less fishing here now than in 1973. Comparing images from 1973 and 2018 (figure 5) shows an increase in the surrounding vegetation over time: the man could remember his father having to walk a long way to collect firewood, but today it is on their doorstep. In fact, isolated Stappogiede is one of the few places relatively unaffected by moth outbreaks so far.

Tourism

A lot of the concerns that the local people have about climate change focus on the effects that the moth damage may have on tourism. One local described the moth damage nearby as “like a nuclear bomb has gone off”, as there are so many dead and fallen trees. The Varanger Peninsula is now visited by many tourists driving the length of the beautiful Norwegian coastline, providing much-needed income for this remote area. Most visitors are unaware of the moth damage in the area, as the effects are not visible from the road. However, for an area attracting tourists with its rugged beauty, the next moth outbreak could be disastrous for this growing industry, which benefits the area’s economy.

One of the ways this economic change can be seen is in the variety of foods available in local supermarkets: in Berlevaag, the northernmost fishing town on the Varanger Peninsula, there

Figure 4: Jetty in Gulgo. In 1974 there was lots of fishing in the area, but today it is visited only for recreation.

Figure 5: Cabin in Stappogiede (centre left). This was the family home, but it is now visited only occasionally.

were no expensive luxuries such as cake available to buy in 2016, but in 2018 it was possible to buy not only cake but also exotic fruits such as kiwis. With globalisation, the diet of local people is shifting from being completely seasonal to being supplemented by imports. As people are less reliant on food from their local environment, the culture of eating elk in the autumn and winter, cod in the spring, and halibut and salmon in the summer may be lost.

Local culture

As people of working age move to areas with better job prospects, the local population becomes more elderly and there are fewer young people to learn traditions. Children at the school in Berlevaag are still taught how to skin a reindeer, but this is now more a piece of their culture than a practical skill. Globalisation also brings positive effects: there is now a larger market for local foods considered unusual elsewhere, such as reindeer. Traditional items crafted by local Saami people also now have a larger market, with both tourists and online shoppers from around the world buying decorative items and traditional knives.

Future prospects

Climate change is not just a problem of the future: its effects can already be seen today. In remote areas largely forgotten by the rest of the connected world, communities are being forced to adapt their livelihoods and cultures to the reality of climate change. If international efforts succeed in limiting global warming as much as possible, protecting traditional ways of life will be another likely benefit.

Acknowledgements

The author would like to thank the members of the expedition team, as well as the Royal Geographical Society, the University of Oxford, Gilchrist Education Trust, the Andrew Scott Memorial Fund, and the Scottish Arctic Club for funding the expedition.

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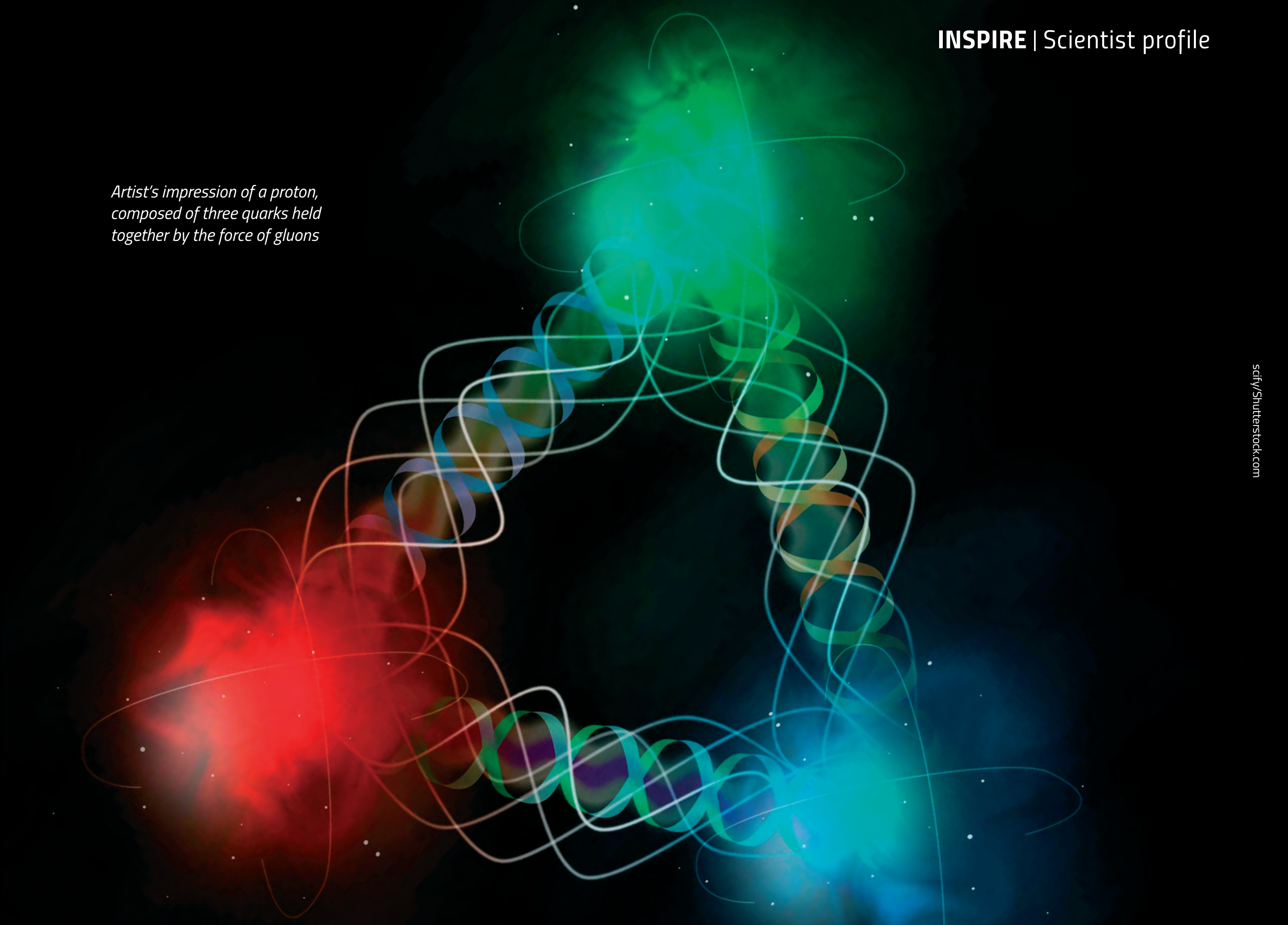
Resources

Learn more about moth damage on the Varanger Peninsula by visiting the Birch Moth website. See: www.birchmoth.no/project-at-a-glance

Read about the author's adventures on the Finnmark expedition in Norway by visiting the expedition website. See: www.finnmarkexpedition.co.uk

Holly Unwin is a PhD student at Lancaster University, UK, researching how fluid flows inside volcanoes. She is also Science Officer for the expedition Finnmark: Past Present Future. She spends her free time exploring the natural world or organising the next expedition to another remote place.



Artist's impression of a proton, composed of three quarks held together by the force of gluons

scify/Shutterstock.com

Phenomenal physics

Theoretical physicist Maria Ubiali reflects on her role as a particle phenomenologist working at the interface between theory and experiment.

By Rachel Thomas

Historically, the job of physicists was to explain the things we observe in the world around us. In modern physics, however, explanation often comes before observation. The famous Higgs boson is an example. Physicists realised that something like the Higgs must exist for their theory of elementary particles to make sense; they went looking for it and, a few decades later, finally discovered it[w1].

When a theory is written in the language of maths, it's not always clear what kind of experiments you should perform to confirm or debunk it. This is where phenomenologists come in. Dr Maria Ubiali, from the University of Cambridge, UK, is one of them. Her job is to work out what observable consequences our theories of nature might have. In particular, she focuses on the Standard Model of particle physics, which describes the fundamental particles of nature.

"What I really do is to formulate theoretical predictions, to give numbers to the experimentalists", says Ubiali. "They verify what I give them to see if the Standard Model is the law that correctly describes nature, or if there is something more than that."

What can we predict?

A good example of the interplay between theory and experiment is the evolution of our understanding of the proton. When protons were discovered a century ago,

Varsity Newspaper, www.varsity.co.uk/Evelina Polyakov

Maria Ubiali at the University of Cambridge, UK

scientists thought they were elementary, indivisible particles. In the 1960s, scientists realised that protons were actually built from three smaller particles, which we now call quarks, bound together by some force-carrying particles called gluons. Today, our picture of protons is even more complicated. As Ubiali explains, "There is an interesting life inside the proton. Inside this tiny radius of the proton, quarks keep creating and annihilating in pairs – quarks and antiquarks – with gluons radiating all the time off the quarks and antiquarks."

At high energies (when quark/antiquark pairs are more likely to pop in and out of existence), you might think of a proton as more like a swarm of particles: three quarks, and a crowd of gluons and quark/antiquark pairs. The structure of the proton is then described in statistical terms that capture how the properties of the proton, such as its momentum, are distributed across the swarm.

Machine learning

Theoretical predictions for processes involving elementary particles, such as electrons or photons, can be determined from the Standard Model by solving the relevant equations. "What is interesting about the structure of the proton is that it can't be determined using first principles", says Ubiali. For the mathematical description of protons, called quantum chromodynamics, the equations cannot be completely solved. "That's why we need experimental data to infer the structure of the proton in terms of its elementary constituents."

Experiments such as those at the Large Hadron Collider (LHC) at CERN[w2] produce a huge amount of data, so sorting through this data to see what it might teach us about the structure of the proton is a near-impossible task. This is why Ubiali and her colleagues harness the power of computers. In particular, they use machine learning[w3] to find patterns in these large data sets, which they can then use to fine-tune their mathematical description of the proton.

"That's how we apply machine learning, so we have a much better determination of the proton's structure", says Ubiali. This data-driven description gives not only the best prediction of the structure, but also the uncertainty associated with this prediction. "We have more realistic estimates of the uncertainty, of what we still don't know."

Beyond the Standard Model

"The success of the Standard Model is extraordinary", says Ubiali. Recent comparisons of the model's predictions to experimental data show an unprecedented agreement over a wide range of scales (from 10^{-4} to 10^{11} picobarns – a measurement of area). However, the Standard Model cannot describe nature completely, as there are many mysteries – such as why neutrinos have mass, and the nature of dark matter – that it cannot solve.

Ubiali says that part of her work involves stretching the Standard Model

REVIEW

- ✓ Nuclear physics
- ✓ Mathematics
- ✓ Careers
- ✓ Ages 14–19

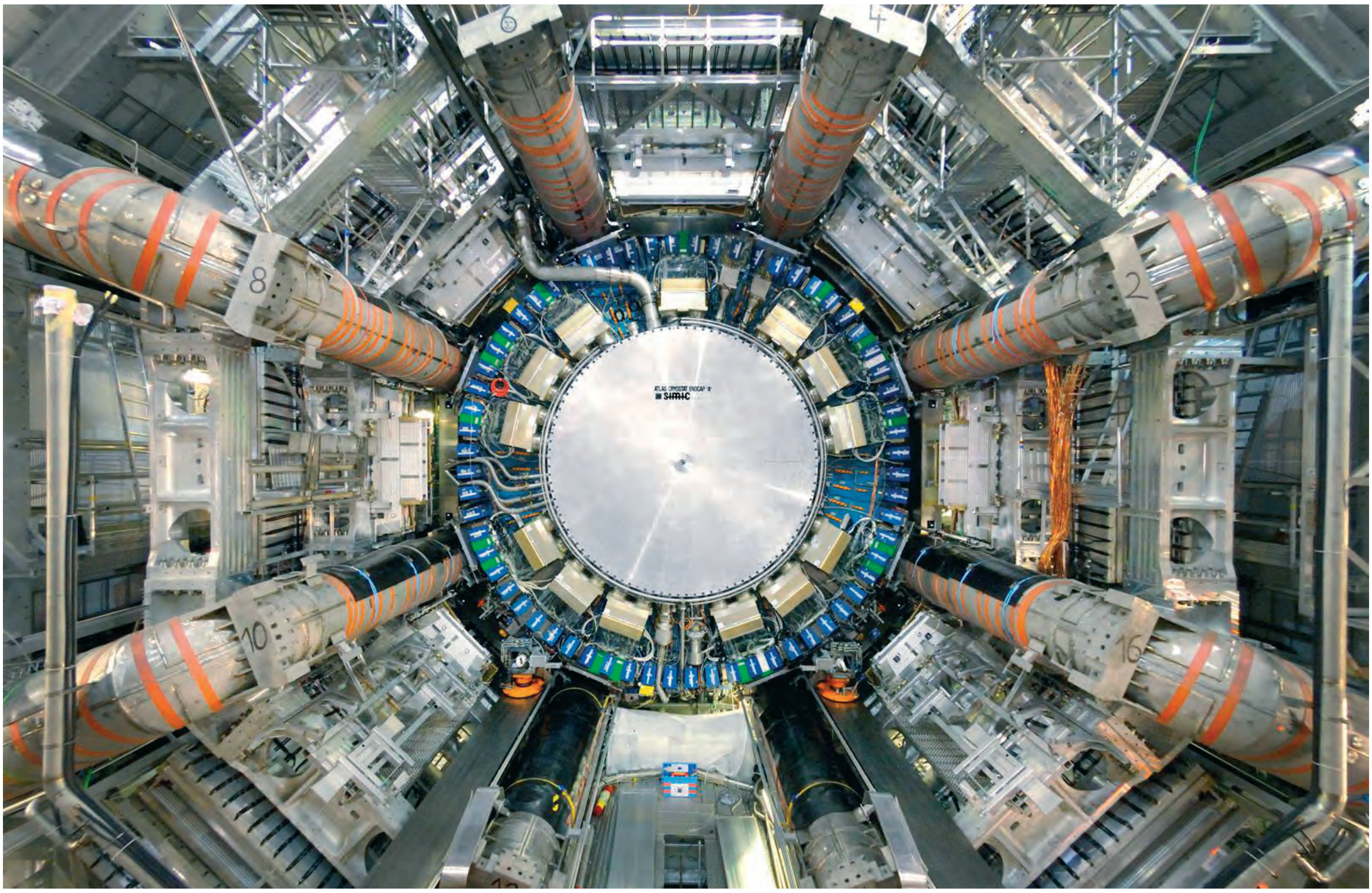
Have you ever wondered how mathematical models are used in physics research? Or how scientists use computers to analyse data from large-scale experiments such as those at the LHC? This article explores these topics and more by considering the interplay between physics and maths through the eyes of a theoretical physicist.

The article could be used to promote careers in STEM, to highlight the importance of mathematics as a tool in modern scientific research, and to illustrate the benefits of working in a team of researchers with complementary skills.

If the article is used as a comprehension exercise, discussion questions could include:

- Does Maria Ubiali's work rely on mathematical or scientific information?
- What is the role of a particle phenomenologist?
- What is the Standard Model of particle physics?
- How is machine learning used in particle physics?

Stephanie Maggi-Pulis, head of department for physics, Secretariat for Catholic Education, Malta



CERN

The ATLAS experiment (pictured here) was one of two experiments at CERN that provided the first evidence of a Higgs boson particle in 2012.

CERN

Section of the 27-km tunnel that houses the LHC particle accelerator at CERN

to the maximum possible precision in order to experimentally observe any deviations from predictions. She also works on models that go beyond the Standard Model.

"As a theorist, I'm really interested to see what is beyond the Standard Model. I'm particularly interested in the paradigm shift we are living in. When the LHC was turned on, we were all expecting to see some spectacular deviation from our predictions, because we would reach the energy of the collisions when something would break down. But that didn't happen.

"This could be a source of disappointment, or a source of excitement. For me, it is a source of excitement – it means that nature will give us some more subtle hints about deviations."

Acknowledgement

This article was originally published in Plus[w4], a free online magazine that aims to introduce readers to the beauty and the practical applications of mathematics.

Web references

w1 Visit the *Science in School* website to read the story behind the Higgs boson in an interview with Rolf Heuer, formerly director general at CERN. See:
Hayes E (2012) Accelerating the pace of science: interview with CERN's Rolf Heuer. *Science in School* **25:** 6-12. www.scienceinschool.org/2012/issue25/heuer

w2 The CERN laboratory sits astride the Franco-Swiss border near Geneva, Switzerland. It is the world's largest particle physics laboratory. See: www.cern.ch

w3 Learn more about machine learning in an article on the *Plus* website. See: https://plus.maths.org/content/what-machine-learning

w4 The original version of this article, published in *Plus*, is available on their website. See: https://plus.maths.org/content/theory-practice

Rachel Thomas is an editor of *Plus* magazine and has written and edited a number of popular maths books, including *Numericon: A Journey through the Hidden Lives of Numbers*, *50: Visions of Mathematics*, and *Understanding Numbers*.

Lars Hallstrom/Shutterstock.com

Nicola Graf

Science crosswords

Try these crossword puzzles as an entertaining way for your students to brush up on their science general knowledge.

By Randal Henly

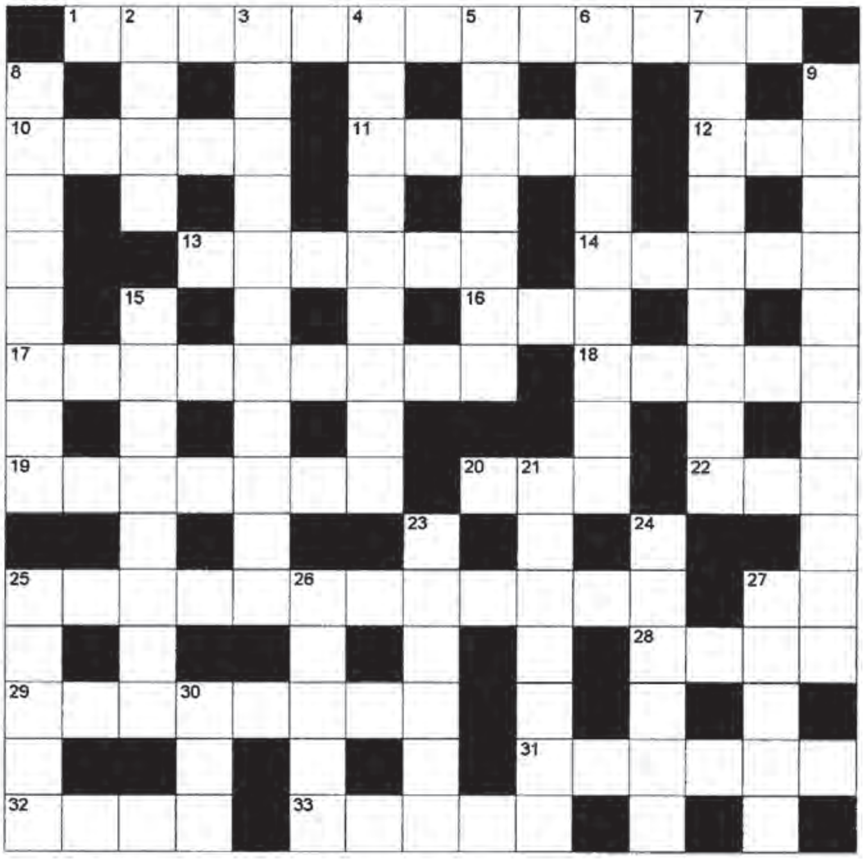
To get back into the swing of the new term, why not jog your brain – and your students' – with a pair of scientific crossword puzzles? The topics covered here span multiple disciplines, both pure and applied, so it's an effective way to get everyone thinking outside the curriculum box.

Both crossword puzzles are aimed at students aged around 16 and older. They might also provide an interesting challenge for you (and your colleagues) in the staff room.

If students find some clues too hard or are making slow progress, offer them some helpful hints along the way: you'll find the solutions on page 43.

Randal Henly is a retired science teacher, author of school science textbooks, retired editor of science and music magazines, presenter of science road shows, and a church organist.

Crossword 1



Clues

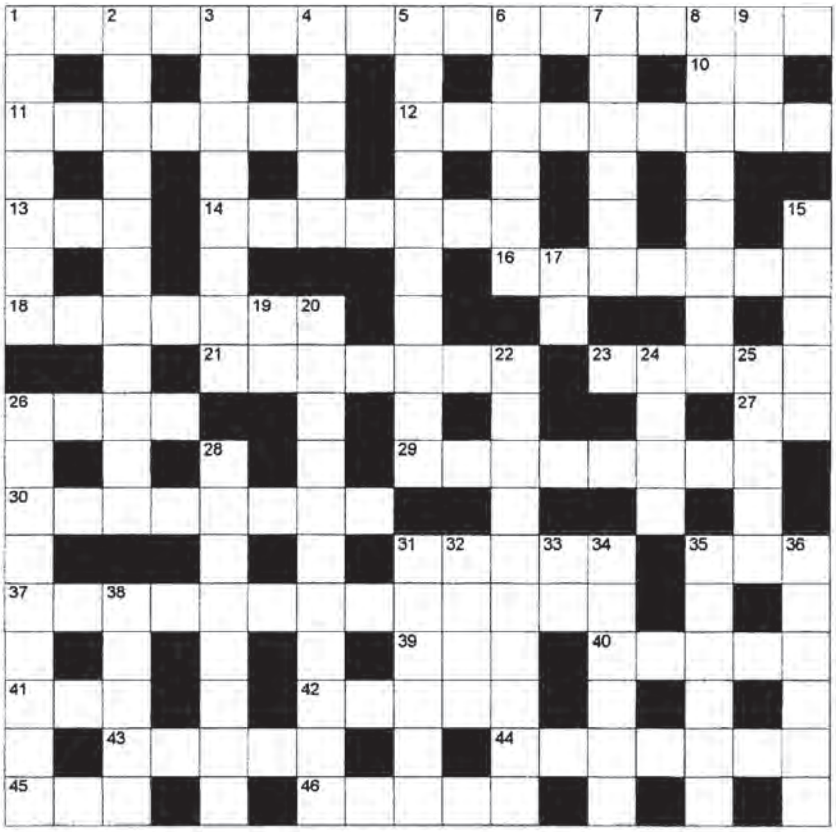
Across

1. The scale on which wind speeds are given (8,5)
10. The path of a planet (5)
11. Scientist James and the unit of energy (5)
12. State in which molecules are very widely dispersed (3)
13. Smelling or tasting like oxidised fat (6)
14. Prefix meaning 'between' (5)
16. Abbreviation for 'and the rest' (3)
17. Electrical device that converts alternating current to direct current (9)
18. A negatively charged particle in electrolysis (5)
19. Bright and misty areas in the sky caused by very distant groups of stars (7)
20. The short name for the mammal *Equus asinus* (3)
22. Substance that exudes from certain plants and hardens on its surface (3)
25. The region of the atmosphere from about 7 km to 16 km above the Earth's surface (12)
27. Symbol for element 38 (2)
28. Narrow beams of radiation (4)
29. Prevent the passage of energy such as heat (8)
31. An outer planet of the Solar System (6)
32. Prefix meaning 10^9 (4)
33. Form of water above its boiling point (5)

Down

2. Flows out, like the tide (4)
3. Electromagnetic waves of wavelength less than 380 nm (11)
4. The lens in a microscope that is furthest from the eye (9)
5. Sound accompanying 7 down (7)
6. Substances in the laboratory and in all other places (9)
7. Electrical discharge from clouds to Earth (9)
8. Positive electron (8)
9. Scientists who study stars (11)
15. Huge floating blocks of solid H_2O (8)
21. The breast bone (7)
23. Its volume is given by $4/3\ \pi r^3$ (6)
24. Pertaining to spring (6)
25. Wasp's defence weapon (5)
26. Elongated circles, the shape of eggs (5)
27. Saturated sugar solution (5)
30. The home country of Thomas Edison (1,1,1)

Crossword 2



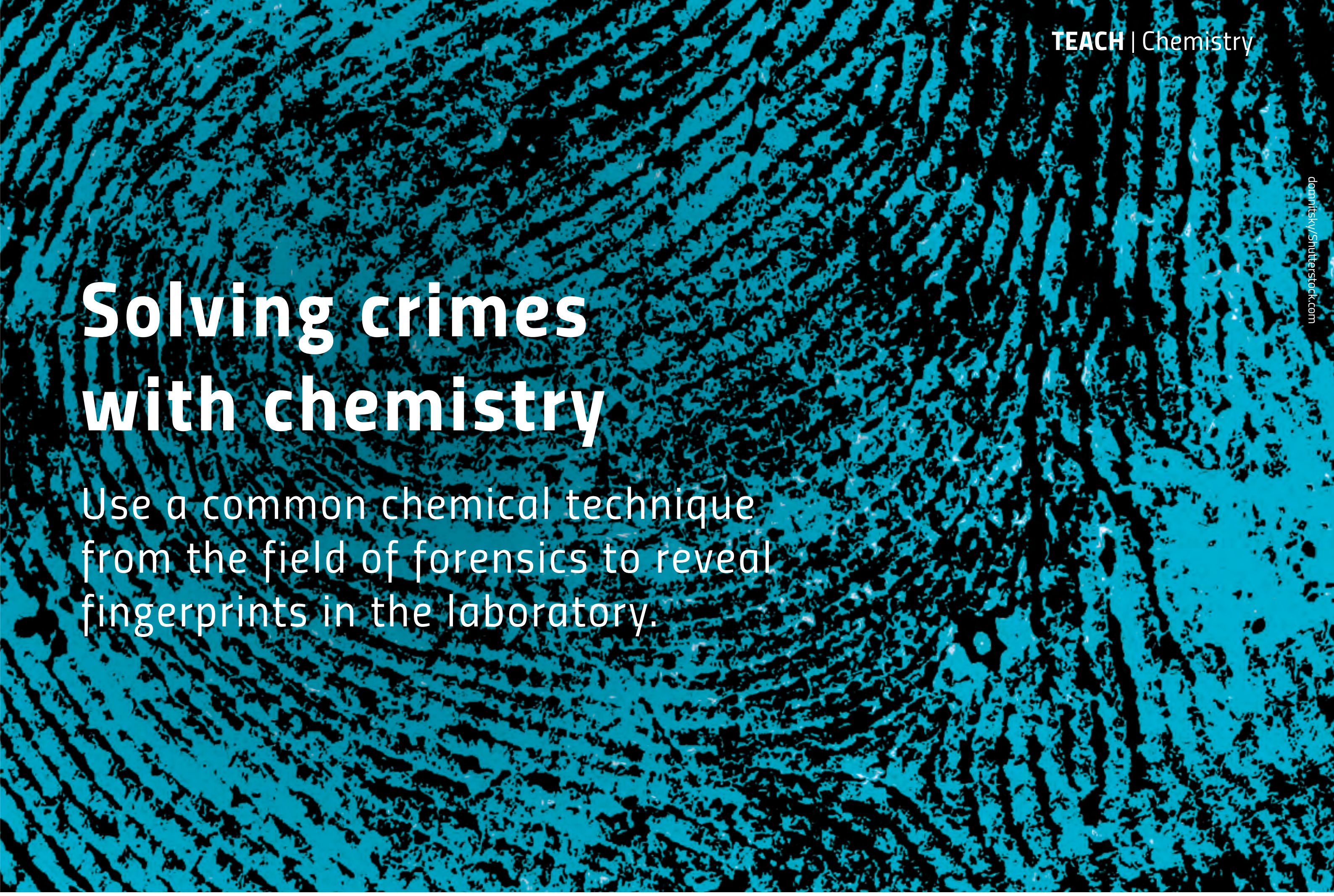
Clues

Across

1. 'Science' was originally called this (7,10)
10. Symbol for the first member of the lanthanide elements (2)
11. One that goes up, like a mountaineer or a rose (7)
12. Emissions from cobalt-60 (5,4)
13. Long, slippery fish (3)
14. Crystalline carbon (7)
16. Poisonous Group 5 element (7)
18. Planet and legendary god of the sea (7)
21. Computer screen (7)
23. Astronomical body with tail (5)
26. Solenoid (4)
27. Symbol for semiconductor element (2)
29. Sodium chloride from the earth (4,4)
30. Dissolve as much as possible in (8)
31. Hoard or accumulate (5)
35. Part of a circle (3)
37. White hotness (13)
39. Ovum or female gamete (3)
40. The relation of one number to another (5)
41. The 17th Greek letter; symbol for resistivity (3)
42. Type of element that loses electrons on ionisation (5)
43. Galvani's first name (5)
44. Bright green gemstone (7)
45. It's not 'no' (3)
46. Male birds (5)

Down

1. General name for a nuclear particle (7)
2. The temperature at which ice, water and water vapour can exist together (6,5)
3. Very reactive Group 1 element (8)
4. It hatches from the egg of an arthropod undergoing complete metamorphosis (5)
5. Instrument for measuring atmospheric moisture (10)
6. Greek letter, symbol for wavelength (6)
7. Visible discharges of electricity (6)
8. Noble metal (8)
9. Dried grass for animals (3)
15. Angle of less than 90° (5)
17. Symbol for 3 down (2)
19. It's not 'yes' (2)
20. Type of reaction in which ΔH is positive (11)
22. Plane figures with straight sides at right angles to each other (10)
24. Iridescent gemstone (4)
25. Compound formed by the reaction of an organic acid and an alcohol (5)
26. Electromagnetic radiation from space (6,3)
28. Benjamin, the American who invented the lightning conductor (8)
31. Traditional name for the acid in vinegar (6)
32. Prefix meaning 10^6 (4)
33. Symbol for first transition element (2)
34. One of two ways of arranging electrical components in a circuit (6)
35. Pertaining to the stars (6)
36. Stores of water vapour in the atmosphere (6)
38. Reduces in temperature (5)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Solving crimes with chemistry

Use a common chemical technique from the field of forensics to reveal fingerprints in the laboratory.

By Rachel Fischer and Marco Oetken

Detecting fingerprints has been a key aspect of criminal investigations for over 100 years. It is an important forensic tool for two reasons: first, fingerprints are unique (even identical twins have different patterns), and second, fingerprints do not change over time: if you burn or cut your fingertip, the pattern will re-form as it was before. At a crime scene, 'patent' fingerprints are easy to detect. These are visible prints left behind by blood-covered fingers, for example. 'Latent' fingerprints, however, pose more of a problem. These are invisible prints left by the natural oils and sweat on our skin.

Over time, forensic scientists have developed ways to visualise latent fingerprints. The oldest technique is the powder method, whereby the fingerprint is carefully dusted with dry powder using a fine brush. The powder adheres to the moisture and oil in the fingerprint, making it visible. There are now hundreds of powders with different compositions depending on the surface they are used for. In general, the powders contain pigments to provide contrast, and binders to help them adhere to the fingerprint. The powder method is still used today because it works on almost all non-absorbent surfaces, such as glass.

Another common visualisation technique is cyanoacrylate fuming. This method is used by the police not on site but in the laboratory. Cyanoacrylates are the molecules found in superglue, so the technique is also referred to as the superglue method. Like the powder method, cyanoacrylate fuming is suitable for detecting fingerprints on non-absorbent surfaces. The fuming is carried out in a developing chamber. The cyanoacrylate forms a vapour that adheres to the fingerprint after polymerisation reactions, creating a visible white print.

After development with cyanoacrylate, powders or stains can be applied to the fingerprint to improve the contrast and make it more visible. Fingerprints are often stained with crystal violet solution, which turns them purple.

The activity outlined in this article enables students to detect their own fingerprints using the superglue method. After making their fingerprints visible, students add fluorescent dye to the prints to add contrast. This procedure allows students to experience a safe alternative to staining fingerprints, since crystal violet cannot be used in the classroom due to its toxic and carcinogenic effects. We recommend that students work in small groups of three. Each part of the activity takes approximately 30 minutes.

Part 1: Visualising latent fingerprints

In this procedure, students detect latent fingerprints using the superglue method to learn about polymerisation reactions. The superglue method involves evaporating superglue in a closed chamber. We used a Tic Tac® box for the chamber and replaced the lid with a reinforced plastic lid to ensure that the vapour could not escape. Alternatively, you could use a Tic Tac® box with a Petri dish for the lid, or exchange the box for a drinking glass, and again use a Petri dish for the lid[w1]. Note that this equipment should not be used for other purposes after the experiment, so it needs to be disposed of.

Safety note: Wear a lab coat, gloves and safety glasses. Be careful when handling superglue as it can glue skin – such as fingers and eyelids – together in a few seconds. Cyanoacrylate vapour is a respiratory tract irritant, so the activity must be carried out in a well-ventilated room. If your school laboratory has access to a fume hood, it is advised to carry out step 6 onwards inside the fume hood.

Materials

- Large Tic Tac® box (8 cm x 4 cm x 1.5 cm)
- Reinforced plastic lid[w1]
- Heating plate
- Tweezers
- Scissors
- Kitchen roll
- Cellulose fleece (e.g. disposable nappy liners)
- Aluminium foil
- Ethanol
- Superglue (liquid glue works best)

Procedure

1. Using scissors, cut a piece of fleece measuring approximately 10 cm x 15 cm and place it inside the Tic Tac® box.
2. Cut a piece of aluminium foil measuring approximately 4 cm x 4 cm. Add some ethanol to a piece of kitchen roll, and use it to rub the surface of the foil to remove any dirt.
3. Choose one person in the group to create a fingerprint on the aluminium foil. The person should rub one finger on his or her forehead or nose to pick up oil and sweat, then carefully place the fingertip on the piece of foil for two seconds.
4. Using tweezers, place the aluminium foil inside the box.
5. Add ten drops of superglue to the fleece. The fleece increases the surface area for evaporation and prevents the superglue from reaching the bottom of the box and hardening.
6. Close the lid of the box and place the box on the heating plate.
7. Set the heating plate to 75°C. If the temperature rises above 100°C the box will melt, so ensure that the temperature remains at around 75°C (see figure 1). Note that using glassware rather than the Tic Tac® box would eliminate this risk.
8. As soon as the fingerprint is visible, remove the box from the heating plate. Wait ten seconds, and then remove the aluminium foil with the tweezers. To prevent the superglue from escaping, open the lid only briefly.
9. If the fingerprint is not yet fully developed, apply another ten drops of superglue to the fleece and repeat the procedure.
10. Repeat the procedure for each student in your group, and compare your fingerprints. Note that after five repetitions, you will need to replace the fleece.
11. Once you have completed the procedure for all group members, place the box under a fume hood with the lid open. After a few minutes, the box can be disposed of in the domestic waste.

Discussion

Discuss some of the following questions as a class:

- What did you see when you turned on the heating plate?
- What does the fingerprint look like after the experiment?
- Why does the fingerprint turn white, while the rest of the aluminium foil remains the same?
- What type of reaction occurs when the superglue adheres to the fingerprint?

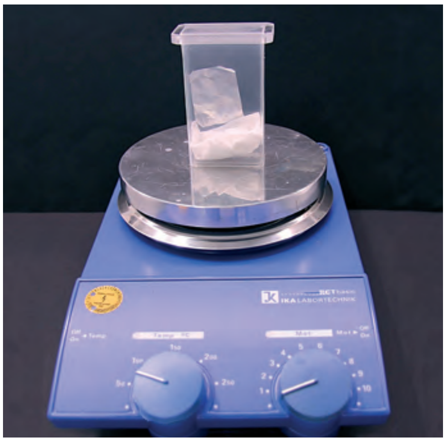
REVIEW

✓ Organic chemistry
✓ Polymerisation
✓ Esters
✓ Alkenes
✓ Nitriles
✓ Polar and non-polar solvents
✓ Ages 16–19

The article describes a simple method that utilises easily sourced equipment to illustrate a contemporary method for visualising latent fingerprints. Most suitable for 16–19-year-old chemists, the technique allows students to consider an alternative take on polymerisation as a valuable tool in forensic detection, rather than focusing on its role in the manufacturing of materials.

I trialled the method with two classes of students (aged 16–17) who commented on how much they enjoyed that the method used common, everyday equipment to illustrate an interesting scientific technique. The method is easy to follow, gives good results and is reproducible. This activity is definitely going to be incorporated in my chemistry teaching, as it is a novel task, will allow me to provide my students with the stretch and challenge of considering an anionic mechanism for polymerisation, and will encourage discussion around science careers in forensics and criminology.

Caryn Harward, head of chemistry, St Mary's Calne, UK



Rachel Fischer

Figure 1: Experimental setup for the superglue method

Rachel Fischer

Figure 2: Fingerprints on aluminium foil visualised with superglue

- What are the reactants and products in this chemical reaction?
- How can superglue glue your hands and eyelids together within seconds?

Explanation

A few minutes after the heating plate is switched on, gaseous superglue rises from the fleece. This superglue vapour adheres to the fingerprint, leaving behind a white trace (see figure 2). This reaction occurs because the cyanoacrylate esters in superglue polymerise on contact with molecules in the fingerprint (e.g. water, fatty acid, amino acids). In this process, a cyanoacrylate ester (most commonly an ethyl cyanoacrylate monomer) becomes a molecular chain (an ethyl cyanoacrylate polymer; see figure 3). At room temperature, an ethyl cyanoacrylate polymer is solid and white, and it is produced in the area where you left your fingerprint. This method works only on dry objects. If the entire piece of aluminium foil were wet, the water would make polymerisation take place on the whole surface of the foil.

Part 2: Making fingerprints fluoresce

In this part of the activity, students stain the fingerprints from part 1 using a handmade dye. To create the dye, students dissolve ink from highlighter pens in ethanol. Students learn about the electromagnetic spectrum and fluorescence, as well as polar and non-polar molecules.

Safety note: Wear a lab coat, gloves and safety glasses – ideally UV protection glasses. Do not look directly towards the UV lamp or shine the light into someone's eyes.

Materials

- UV lamp (λ = 395 nanometres)
- Tweezers
- Three Petri dishes
- Three pieces of filter paper
- Stabilo Boss® highlighter pens in yellow, orange and pink
- Aluminium foil with superglue fingerprints from part 1
- Ethanol
- Cardboard box
- Hair dryer (optional)

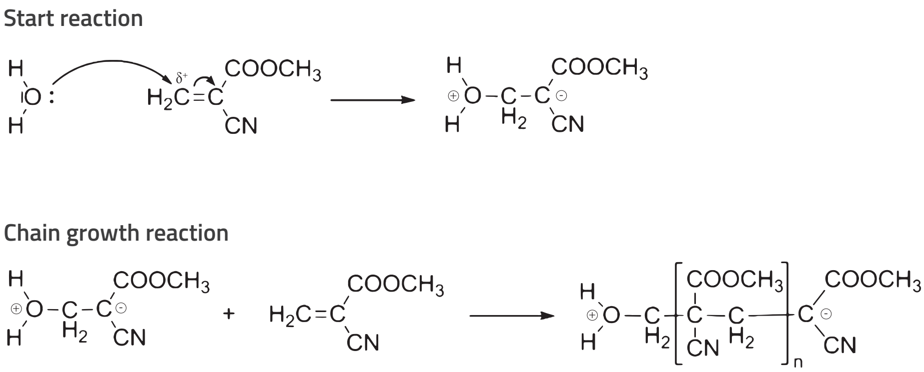
Procedure

1. Take a piece of filter paper and colour the surface with the yellow highlighter. Repeat the process with the other two pieces of filter paper and two highlighters (see figure 4).
2. Place each piece of paper in a separate Petri dish. Add ethanol to each dish until the paper is completely covered (see figure 5).
3. After ten minutes, remove the filter papers from the Petri dishes using tweezers and dispose of them in your domestic waste.
4. Choose three of the aluminium foil fingerprints from part 1, and place one in each of the solutions in the Petri dishes (see figure 6).
5. Wait five minutes and then remove the aluminium foil from the solutions using tweezers. Leave the foil to dry (the ethanol will evaporate) or use a hair dryer to speed up the process.
6. Observe the dyed fingerprints in a dark cardboard box or in a darkened room under UV light (see figure 7).

Discussion

Discuss some of the following questions as a class:

- What happens when you pour ethanol over the coloured filter paper?



Rachel Fischer

Figure 3: Polymerisation reaction of the ethyl cyanoacrylate monomer with water

Rachel Fischer

Figure 4: Filter papers coloured with highlighter pens

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Figure 5: Highlighted filter papers covered with ethanol

Rachel Fischer

Figure 6: Superglue fingerprints on aluminium foil in highlighter solutions

Rachel Fischer

Figure 7: Fluorescent superglue fingerprints under UV light

- For this experiment to work, the dye must contain both polar and non-polar components. Why?
- What does the fingerprint look like under UV light?
- Why does the fingerprint fluoresce under UV light?

Explanation

When the highlighted filter paper comes into contact with ethanol, the fluorescent dye from the highlighter pen diffuses out from the paper into the solution. To dissolve in ethanol (a polar molecule), the dye must contain some polar components. To stain the superglue fingerprint (comprising non-polar ethyl cyanoacrylate polymers), the dye needs to have non-polar components, too. A highlighter from Herlitz®, for example, would not stain the fingerprints, because the dye (pyranine) is polar (Ducci & Oetken, 2018).

Once the ethanol evaporates off the aluminium foil and the fingerprint is stained with the dye, the fingerprint will fluoresce when irradiated with UV light. This is because the dye contains fluorescent molecules that absorb light of a certain wavelength (such as UV light) and re-emit it at a longer wavelength, such as yellow, orange or pink in the visible spectrum. This isn't particularly noticeable in daylight, but is more obvious under UV light.

Reference

Ducci M, Oetken M (2018) Fluoreszierende Farbenspiele. *Spektrum der Wissenschaft* **3:** 56-59.

Web reference

w1 If you wish to purchase reinforced plastic lids for the Tic Tac® boxes, you can contact Bernd Mößner (info@experimente-zur-energiewende.de) for more information and to place an order.

Resource

For more information about fingerprint analysis, visit the 'Forensic science simplified' website. See: www.forensicsciencesimplified.org/prints

Rachel Fischer is a PhD student in the team of Professor Marco Oetken at the Freiburg University of Education, Germany. Her research focuses on the visualisation of latent fingerprints in school teaching.

Marco Oetken is a professor of chemistry and didactics at the Freiburg University of Education, Germany. His research focuses on the development of model experiments for energy storage systems.

Astrofarmer: how to grow plants in space

Investigate the factors affecting plant growth and devise a plan for growing plants on the Moon.

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The extreme conditions of space pose many challenges for cultivating plants on the Moon.

By Keith Hardie and Cátia Cardoso

When we think about space exploration, farming and agriculture are not often the first things that come to mind. Although they have been commonplace in human civilisation for millennia, these essential activities are fast becoming an integral part of research for enabling space exploration. Currently, the only human outpost in space is the International Space Station (ISS), which is supplied with air, food and water from Earth. Each astronaut needs approximately 1 kg of oxygen, 1 kg of dehydrated food and 3 litres of water per day. Providing these supplies for all astronauts on board the ISS is costly and impractical for long space missions. If humanity is to explore further into the cosmos, plants will have to be grown in flight – as a food source and more.

Growing plants in space

In space, the conditions required for plants to grow (such as water, light, nutrients and suitable temperature) are difficult to meet. This makes growing plants in space a challenging

REVIEW

- ✓ Plant growth
- ✓ Conditions in space
- ✓ Experimental variables
- ✓ Ages 11–14 and under

This enlightening article combines two areas of science to create an interesting project for young students. In the set of activities, students understand the factors that affect plant growth and relate these to growing plants in space. All activities are easy to conduct and could be a good basis for understanding control variables in experimental design. The article is very useful and can be used for both upper elementary and lower secondary levels.

Dr Christiana Nicolaou, elementary teacher, Makedonitissa 3rd primary school, Cyprus

– but not impossible – task. In 2015, crew members of the ISS Expedition 44 had their first taste of space-grown food when they harvested a red romaine lettuce grown as part of NASA's Veg-01 plant experiment. Since then, scientists have been researching novel ways of growing other plants in space.

When choosing which plants to grow, a variety of factors are considered – such as dietary value and yield. Two prime candidates are potatoes and dwarf wheat. Both are carbohydrate-rich foods with high calorific content, so they can help provide astronauts with enough energy to sustain them throughout a long mission. They are also robust plants that are adaptable to most conditions on Earth and provide a high yield without taking too much space to grow.

A self-sustaining system

Plants are useful in space not only as a food source: astronauts are also hoping to use plants to create a self-sustaining circuit to supply astronauts with all the oxygen, water and food they need – without any resupply from Earth. For over 25 years, the European Space Agency (ESA) has been working towards this goal with its Micro-Ecological Life Support System Alternative programme (MELiSSA). The project seeks to perfect a life support system that could be flown to space. Human waste products (such as urine and exhaled carbon dioxide) would supply plants with the essential ingredients for growth, and in turn the plants would provide oxygen and food for humans, as well as filtering waste water. This area of research also has the potential to create methods for more sustainable food production on Earth.

Conditions for plant growth

In the following activities, students learn about the basic elements that plants need to grow. After completing activities 1–3, students apply what they have learned about plant growth to activity 4, in which they explore how to grow plants in space – a real-life challenge facing scientists today.

The activities use simple household materials and are suitable for students aged 8–12. The procedures require a number of small pots or containers: we created these from old plastic bottles by cutting off the bottom third of the bottle and using this as a pot.

Activity 1: Do plants need light?

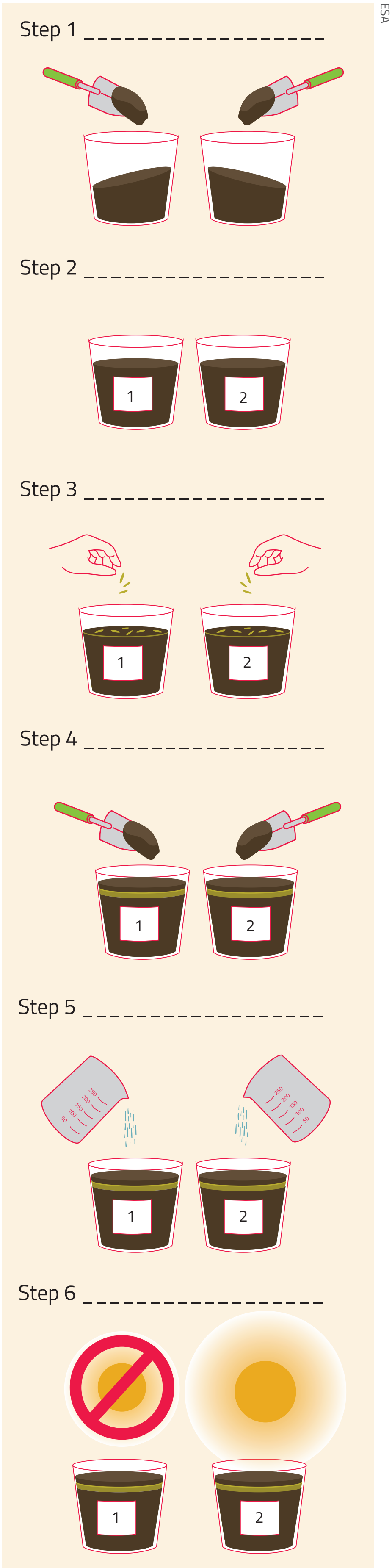
Working in groups of two to four, students investigate how cress grows in different light conditions: constant darkness and the normal day-night cycle. It takes 30 minutes to complete the hands-on part of this activity and approximately one week for the cress to grow after planting.

Materials

Each group needs:
- Cress seeds
- Two identical pots or containers
- Potting soil
- Small trowel or spoon
- Beaker or measuring cup
- Cardboard box or a dark cupboard
- Self-adhesive labels
- Marker pen

Procedure

Instruct the groups as follows:
1. Using a small trowel or spoon, fill the two pots with potting soil, leaving about 1 cm of space at the top of each pot.
2. Number the pots 1 and 2 using self-adhesive labels and a marker pen. Label the pots with your names so that you can distinguish them from other pots later.
3. Scatter 10–20 cress seeds over the soil in each pot, ensuring that you add roughly the same number of seeds to each pot.
4. Cover the cress seeds with some extra soil.
5. Fill a beaker or measuring cup with water. Add roughly the same amount of water to each pot, ensuring that the soil is damp.
6. Place pot number 1 in a cardboard box or dark cupboard, and place pot number 2 near a window where it will be exposed to sunlight.



Procedure for activity 1, which explores whether plants need light

ESA

Two pots of cress, planted in the same type of soil and with equal amounts of water. The pot on the left was placed in darkness, while the pot on the right was placed in sunlight.

7. What do your students predict will happen, and why? What will happen if a plant doesn't receive sunlight? Ask them to write and/or draw their predictions in a workbook.
8. Leave the cress to grow for approximately one week. It should not need more water during this time. After this time, students can retrieve their pots. What differences do they observe between the two pots in each group?

Discussion

Students will observe that cress grown in the dark has white stems and yellow leaves, in contrast to cress grown with a normal day-night cycle, which has light green stems and bright green leaves. This is because in the absence of light, plants do not develop any chlorophyll – the pigment that gives plants their healthy green colour. The cress grown in the dark should also be noticeably taller, having used the energy stored in the seeds to accelerate their growth in search of light.

Compare your students' predictions with their results, and discuss some of the following questions:

- Which plant is healthier, and why?
- How important is light for the healthy growth of plants?
- Do plants need light to germinate?
- Do plants need light to grow after germination?

Activity 2: Do plants need soil?

As a whole class, students plant radish seeds in different materials to determine which are best for growing plants. The hands-on part of this activity takes approximately 30 minutes, and there is a waiting period of one week.

Materials

- 16 radish seeds
- Eight clear pots or containers
- Small trowel or spoon
- Beaker or measuring cup
- Liquid plant food
- Cling film
- Self-adhesive labels
- Marker pen

The following materials, each to fill two pots:

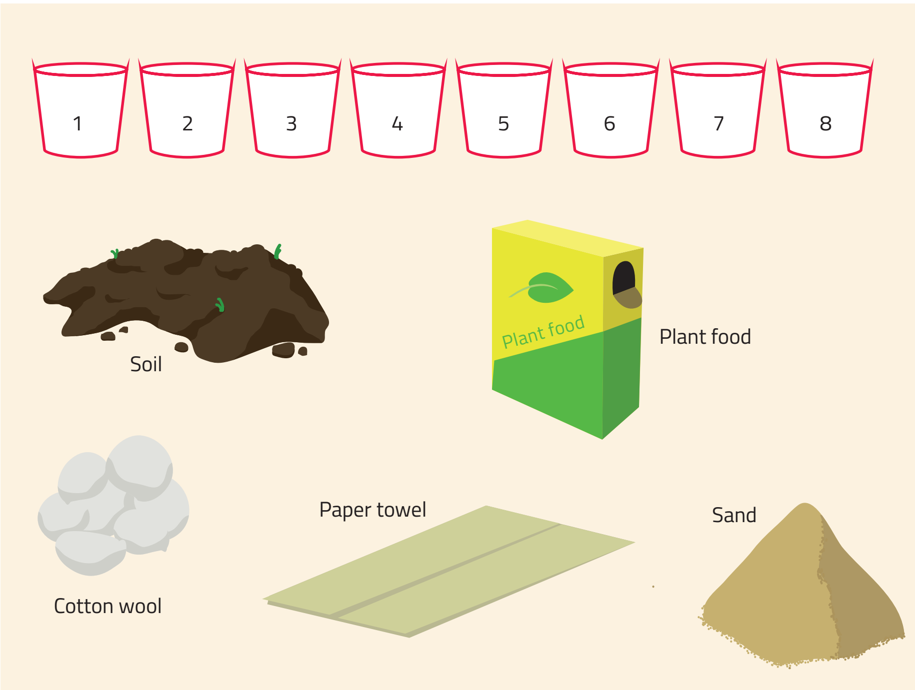
- Soil
- Sand
- Cotton wool
- Paper towels

Procedure

Ask individual students to carry out different steps in the following procedure:

1. Number the pots 1–8 using self-adhesive labels and a marker pen.
2. Using a small trowel or spoon, add soil to pots 1 and 2.
3. Add sand to pots 3 and 4.
4. Place cotton wool in pots 5 and 6.
5. Scrunch up the paper towels into balls and add them to pots 7 and 8.
6. Fill a beaker or measuring cup with water. Add roughly the same amount of water to pots 1, 3, 5 and 7, ensuring that the material is damp.
7. Fill the beaker again with water, and add the liquid plant food. Add the solution to pots 2, 4, 6 and 8. Ensure that you add roughly the same amount of liquid as you added to the pots in the previous step.
8. Add two radish seeds to each pot and place cling film over the top.
9. Place all the pots near a window, i.e. in identical conditions.
10. What do your students predict will happen? Will the plants grow in all four materials? In which pot will the plants grow best? How might liquid

ESA



Materials for activity 2, which investigates whether plants need soil

Astronauts plan to grow food on future spacecraft and other planets to enable self-sufficient space exploration.

plant food affect plant growth? Ask them to write and/or draw their predictions in a workbook.

11. Leave the plants to grow for one week before presenting the pots to your students. How has each plant developed?

Discussion

Students may be surprised to find that the seeds germinate in all eight pots. This is because seeds already contain some nutrients that allow the plant to begin growing. If the substrate contains nutrients, the plant will continue to grow. Nutrients are naturally present in soil, but for other materials (such as sand, cotton wool and paper towel) they can be added, for example in the form of liquid plant food. In the absence of added nutrients, the plant grows more slowly and eventually stops growing when the nutrient supply stored in the seed is depleted. This is why the radish seeds do not grow well in the pots with sand, cotton wool or paper towel without plant food.

The radish seeds usually grow best in cotton wool with the plant food mix. This is because cotton wool is more effective at holding water than soil or the other substrates, and because the plant food provides all the necessary nutrients for the plant's initial development. If the plants were grown for a longer period, soil would provide the best base for their roots to expand, giving support and stability to the plant shoots.

Compare your students' predictions with the results and discuss some of the following questions:

- What are the advantages and disadvantages of growing plants without soil?
- Which pot was best for growing plants and why?
- Do plants need soil to germinate?
- Do plants need soil to grow?

Activity 3: How do plants transport water?

To investigate how water is transported within plants, students observe how flower petals change colour when dye is added to plant water. The procedure can be completed by small groups of 2–4 students or as a classroom demonstration. It takes approximately 15 minutes to complete the hands-on part of the activity and one day for the effects of the experiment to become visible.

Materials

Each group needs:

- Two white flowers without roots (cut at the stem)
- One white flower with roots intact
- Three clear pots or containers
- Red or blue food colouring
- Spoon

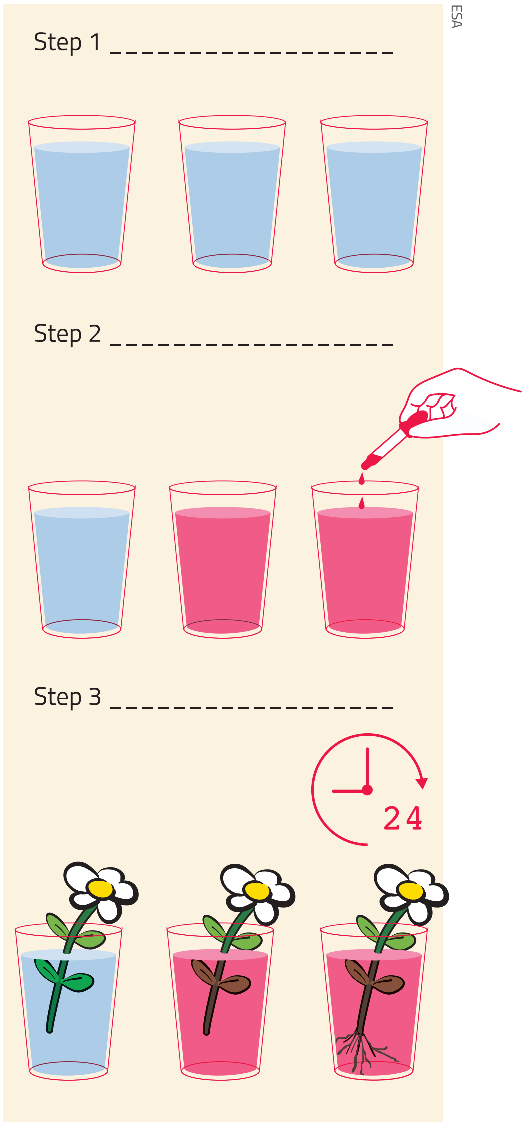
Procedure

Instruct the groups as follows:

1. Fill the three pots with water.
2. Add food colouring to two of the pots and stir using a spoon.
3. Place one of the two flowers without roots in a pot with food colouring, and the other in the pot without food colouring. Place the flower with roots in the other pot containing food colouring.
4. What do your students predict will happen, and why? Will both flowers placed in coloured water change colour? Ask them to write and/or draw their predictions in a workbook.
5. Leave the flowers for one day before presenting the results to your students. What has happened to each flower?

Discussion

Students will observe that the flower without roots changes colour from the



Procedure for activity 3, which looks at how water is transported in plants food colouring, especially along the edges of the petals. This is because plants transport water through their stem to other parts of the plant. The flower with roots, however, does not change colour from the food colouring. The roots act as a filter, preventing the food colouring from being transported to the rest of the plant. As a result, there is no colour change.

ESA

Moon fact card, used in activity 4 to devise a plan for growing plants in space

Compare your students' predictions with the results, and discuss some of the following questions:

- Why did the flower with intact roots not change colour?
- What was the purpose of adding one flower to a cup containing only water?
- Is water essential for plants?

Activity 4: What do plants need to grow in space?

In teams of three or four, students apply their knowledge from the previous activities to devise a strategy for growing plants on the Moon. Students are provided with a fact card about the Moon to help them consider the particular space environment.

Materials

Each group will need:

- Moon fact card[w1]

Procedure

Instruct the groups as follows:

1. Read the fact card to learn about the conditions on the Moon, such as its day-night cycle and temperature.
2. Consider the factors that plants need to grow. How will the plants access light, water and nutrients on the Moon?
3. Devise a plan for growing plants on the Moon, such as building a greenhouse. Can the system be self-sustaining? What type of plants would grow best, and why?
4. Select one person from the group to explain the strategy to the rest of the class.

Discussion

One of the first challenges to growing plants on the Moon is the lack of liquid water and nutrients. Water is not readily available in rivers and oceans as it is on Earth, and lunar soil does not contain the nutrients required for growing plants. Students could suggest using a hydroponic system to overcome this challenge: plants are grown in a water-based, nutrient-rich solution without the need for soil. Water could potentially be sourced from surface ice near the Moon's north and south poles, which under certain conditions could be converted to liquid water.

Another challenge is the Moon's day-night cycle. One day on the Moon lasts approximately the same time as four weeks on Earth, so plants would need to adapt to two weeks of daylight and two weeks of darkness, or be placed in a light-controlled environment. This environment would need to be temperature-controlled to counteract extreme temperature variations. What's more, there is virtually no atmosphere on the Moon so plants would need to be kept in a pressurised container filled with gases. Without an atmosphere for protection, the container would also help safeguard plants from space radiation.

To be sustainable, the container should have a system for recycling gases and water.

Acknowledgements

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Web reference

w1 The Moon fact card is available to download from the *Science in School* website. See: www.scienceinschool.org/2020/issue49/spaceplants

Resources

Further resources for learning about plants in space are available on the ESA website:

'Astrofarmer' explores the factors that affect plant growth. See: www.esa.int/Education/Teachers_Corner/Astrofarmer_-_Learning_about_conditions_for_plant_growth_Teach_with_space_PR42 or use the direct link: https://tinyurl.com/y5e6v733

'Astrofood' investigates the different components of plants and potential future space foods. See: www.esa.int/Education/Teachers_Corner/Astrofood_-_Learning_about_edible_plants_in_Space_Teach_with_space_PR41 or use the direct link: https://tinyurl.com/y4vnxyoz

'Astrocrops' studies one full growth cycle for different plant species to understand germination and plant growth. See: www.esa.int/Education/Teachers_Corner/Astro_crops_-_Growing_plants_for_future_space_missions_Teach_with_space_PR43 or use the direct link: https://tinyurl.com/y48znwrl

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Are 'superfoods' really so super?

Are you tempted to buy 'superfoods' for health reasons, despite the higher prices? These activities encourage students to explore some of the claims made for these celebrity foods.

Marco Verch/Flickr, CC BY 2.0

Quinoa, goji berries and chia seeds

By Nadja Frerichs and Sosin Ahmad

When you look for a lunchtime snack or ingredients for a family meal, do you choose to include 'superfoods'? In the past few years, relentless marketing has helped to make exotic products such as chia seeds, goji berries and avocados very popular. Superfoods are presented in the media as extremely nutritious and having a positive impact on health – but what exactly are 'superfoods', and is the hype justified? In fact, there is no clear definition of the term, and such foods often command very high prices while lacking scientific evidence for any real health benefit (Van den Driessche, Plat & Mensin, 2018).

We wanted to encourage students to reflect on the idea of superfoods, as young people play a significant role in influencing the food-buying choices of the whole family. We developed some simple experiments to allow students to analyse the nutritional content of selected superfoods for themselves, and to compare these foods to conventional, less expensive alternatives. In this way, we hope also to empower students to be media-literate citizens and critical consumers who understand the effect of advertising claims.

In this article, we focus on the 'superfoods' goji berry juice and chia seeds, which are analysed with regard to specific nutrients using qualitative and quantitative methods.

REVIEW

- ✓ Nutrition
- ✓ Health
- ✓ Chemical analysis
- ✓ Ages 14–19

This article and its experiments will provide teachers and students with the skills to analyse and compare some important components within different kinds of foods. Analysing food items through laboratory experiments allows students to assess their nutritional value for themselves, and to investigate whether the description 'superfood' is deserved. However, the experiments can be used for many different foods, not just 'superfoods'.

The article also encourages students to combine nutritional information with laboratory experiments, which helps to develop their skills of scientific analysis and critical thinking more broadly.

Dr Bartolomé Pizà Mir, science teacher, Sant Vicenç de Paül, Sóller, Spain

Berries	Blueberries Cranberries Goji berries
Seeds	Chia seeds Hemp seeds Quinoa
Other	Garlic Ginger Chillies Bee pollen Spirulina Wheat grass

Table 1: List of some foods commonly described as 'superfoods'

The activities are suitable for students from around age 16, although the quantitative analysis may require some more advanced knowledge of chemistry.

Safety note: For all the experiments, students should wear safety glasses and follow the usual safety rules for chemistry classes.

Activity 1: Comparing goji berry juice and orange juice

Goji berries and their juice are often associated with an extremely high vitamin C content. But is drinking goji berry juice better than the good old habit of a glass of orange juice for breakfast, given that the goji juice is much more expensive? In this activity, the ascorbic acid (vitamin C) content of the two juices is compared in a qualitative way using ascorbic acid test strips.

This activity takes about 10 minutes.

Materials

- Orange juice
- Goji berry juice
- Two beakers (50 ml)
- Ascorbic acid test strips (we used the Quantofix® strips by Macherey-Nagel)

Nadja Frerichs

Goji berry juice (left) and orange juice (right)

Nadja Frerichs

Vitamin C test strip and scale after immersion in orange juice

Nadja Frerichs

Vitamin C test strip and scale after immersion in goji berry juice

Procedure

1. Put about 20 ml of the orange juice into one beaker, and a similar amount of goji juice into the other beaker.
2. Take an ascorbic acid test strip and hold it in the orange juice for about 10 seconds. Make sure that the test field is completely submerged in the liquid.
3. Take out the test strip and wait for another 30 seconds.
4. Now compare the colour of the test field with the scale on the packaging. What can you conclude?
5. Carry out the test with the goji juice in the same way.

Results

The test strip results show the approximate concentration of vitamin C in each juice. In the orange juice, the test strip turns green, showing that this juice contains quite a high concentration of vitamin C, so it is a good source of this vitamin. Goji juice makes the test strip turn a darker green, showing that this juice contains more vitamin C than orange juice.

In the next activity, students use a titration method to measure the vitamin C concentration in each juice accurately and compare this to the recommended daily requirement.

Activity 2: Quantitative analysis of vitamin C in juice

From activity 1 we know that both goji berry juice and orange juice contain vitamin C – but which juice is a better choice to meet our daily need for vitamin C?

Titration with 2,6-dichlorphenolin-dophenol sodium solution is a common procedure to detect the amount of ascorbic acid. One mole of (anhydrous) 2,6-dichlorphenolindophenol sodium reacts with one mole of ascorbic acid, and the solution changes initially from light blue to colourless, and then from colourless back to light blue at the end point (once all the ascorbic acid has reacted). As the ascorbic acid is constantly oxidised by oxygen in the air, oxalic acid is added to prevent this.

This activity takes about 45 minutes (plus 15 minutes of preparation time for the solutions).

Materials

- Orange juice
- Goji berry juice
- Oxalic acid solution (2% w/w)
- 2,6 dichlorophenolindophenol sodium solution (0.001 mol/l)
- Measuring cylinders (two 10 ml and one 20 ml)
- Beakers (100 ml)
- Burette (secured with a clamp stand)
- Funnel
- Magnetic plate with a stirrer

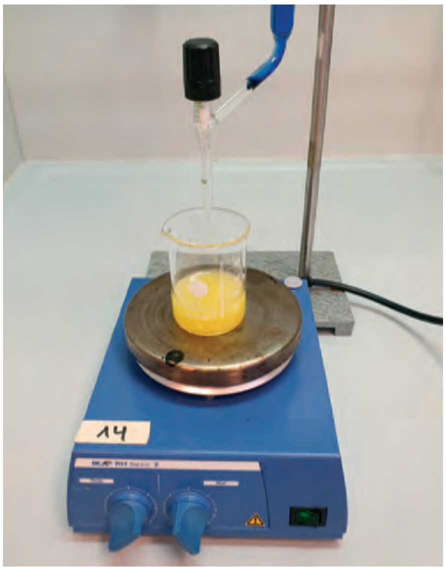
Procedure

1. Place 50 ml of the 2,6-dichlorophenolindophenol sodium solution in the burette.
2. Use the funnel and measuring cylinders to pour 10 ml of orange juice, 20 ml of oxalic acid solution and the stirrer into a beaker.
3. Place the flask and contents on the magnetic plate, so that the burette opening is just above the beaker. Switch on the stirrer.
4. Note the volume of the solution in the burette (V_1), then slowly and carefully open the burette and start the titration.
5. As soon as you see a colour change in the flask, stop the titration and note the volume of solution in the burette again; this is V_2.
6. Carry out the same steps with the goji berry juice. You may need to refill the burette before the end point is reached.
7. After the experiment, the solutions should be disposed of in a sealed container for solutions containing organic compounds.

Calculation

In this calculation, we work out how much vitamin C is in 100 ml of each juice (enough for a small glass).

In our experiments, we found that 28 ml of 2,6-dichlorophenolindophenol sodium solution was needed to react with 10 ml



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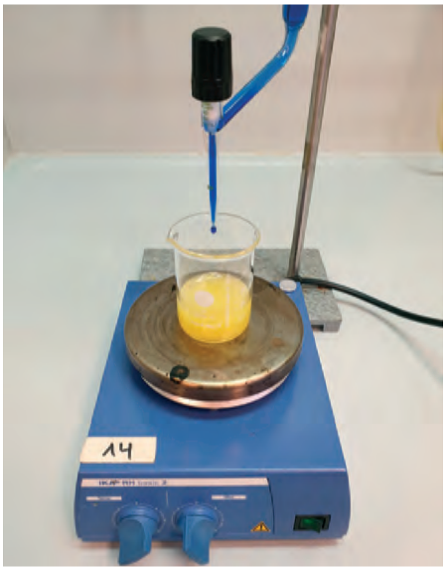
The burette set up for the titration with orange juice



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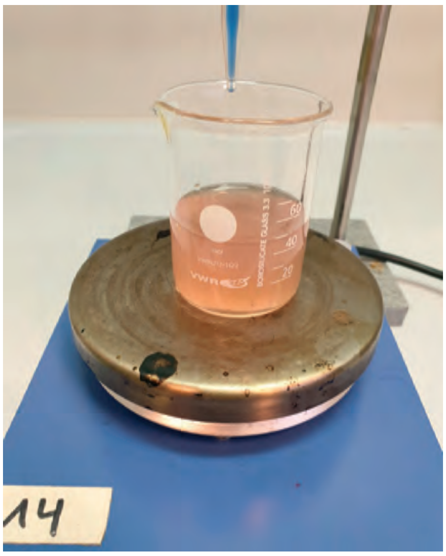
Carrying out the titration with orange juice



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Colour change at the end point of the orange juice titration

of orange juice, and 58 ml was needed to react with 10 ml of goji berry juice. In the calculation below, we use these figures as examples, but students should replace these figures with those from their own experimental results.

Calculation for orange juice:

$$V_{total} = V_1 - V_2$$
$$= 50 \text{ ml} - 22 \text{ ml} = 28 \text{ ml}$$

Here, one mole of 2,6 dichlorophenolindophenol sodium reacts with one mole of ascorbic acid.

Thus, 1 ml of the 0.001M 2,6-dichlorophenolindophenol sodium solution reacts with 0.176 mg of ascorbic acid (relative molecular mass of ascorbic acid = 176).

So 28 ml of the 0.001M 2,6-dichlorophenolindophenol sodium solution reacts with 0.176 mg x 28 of ascorbic acid

$$= 4.93 \text{ mg}$$

This is for 10 ml of juice, so 100 ml of orange juice contains 49.3 mg of vitamin C.

Calculation for goji berry juice:

$$V_{total} = V_1 - V_2$$
$$= 70 \text{ ml} - 12 \text{ ml} = 58 \text{ ml}$$

Thus, 1 ml of the 0.001M 2,6-dichlorophenolindophenol sodium solution reacts with 0.176 mg of ascorbic acid.

So 58 ml of the 0.001M 2,6-dichlorophenolindophenol sodium solution reacts with 0.176 mg x 58 of ascorbic acid

$$= 10.21 \text{ mg}$$

This is for 10 ml of juice, so 100 ml of goji berry juice contains 102.1 mg of vitamin C.

For a large glass (300 ml) of each juice, the amount of vitamin C is:

Orange: 49.3 x 3 = 147.9 mg

Goji berry: 102.1 x 3 = 306.3 mg

Discussion

In Germany, one litre of goji berry juice costs around €15, while orange juice is available for less than €1 per litre. The daily need for vitamin C is about 75–100 mg (depending on age, weight, and other factors). A large glass (300 ml) of orange juice has about 150 mg of vitamin C, which is already some 30% more than the daily requirement. So, it is not necessary to drink goji berry juice for its even greater amount of vitamin C.

Of course, other positive effects of goji berry juice have been suggested, such as the antioxidative effect, but so far these benefits have not been established in humans (Kulczyński & Gramza-Michałowska, 2016).

Activity 3: Detecting proteins in seeds

This activity compares the protein content of linseeds (flax seeds) with 'superfood' chia seeds.

Proteins are an important part of a balanced diet, especially for people with an active lifestyle. There are many 'high-protein' products on the market – for example, breakfast cereals enriched with linseeds or the much more expensive chia seeds. Do these products really contribute to a protein-rich diet?

This activity uses the biuret reaction to test for the presence of protein. In the reaction, a purple colour is seen when protein is present, due to copper ions forming a coloured complex with proteins.

The activity takes about 30 minutes, plus 15 minutes of preparation time for the solutions.

Materials

- Chia seeds
- Linseeds (flax seeds)
- Milk (as control)
- Distilled water
- Sodium hydroxide solution (1 mol/l)
- Copper(II) sulfate solution (7% w/w)
- Weighing scales
- Test tube stand and 4 test tubes with stoppers
- 2 pipettes (5 ml)
- Dripping pipette
- 2 x mortar and pestle

Procedure

1. Weigh out 0.5 g each of chia seeds and flax seeds, and grind these up separately using the mortars and pestles.

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Chia seeds (left) and linseeds (right) after grinding

2. Put the crushed seeds into separate test tubes and add 5 ml of distilled water to each.
3. Seal the test tubes with the stoppers and shake them well.
4. Pour 5 ml of milk into the third test tube and 5 ml of distilled water into the fourth test tube.
5. Add 10 drops of the copper(II) sulfate solution to each of the four test tubes.
6. Pipette 1 ml of sodium hydroxide solution into each test tube.
7. Shake the test tubes to mix the contents well.
8. Note your observations: you should see some colour changes.
9. After the experiment, dispose of the solutions in a sealed container for solutions containing heavy metals.

Results and discussion

The expected results are shown in table 2.

Test tube contents	Colour change
Milk (control)	Purple
Water (control)	Light blue
Chia seeds	Purple
Linseeds, flax seeds	Purple

Table 2: Expected results of the biuret test with chia seeds and flax seeds

Milk contains protein, so the milk solution turns purple. The chia seed

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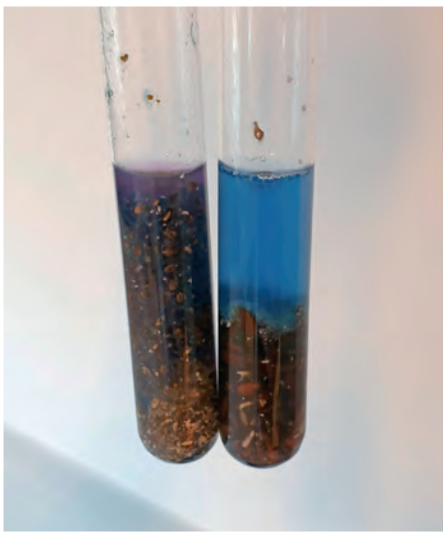
Test tubes with (from left) chia seeds, linseeds, milk, water



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Colour change after adding copper(II) sulfate solution to chia seeds (left) and linseeds (right)

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Chia seeds (left) and linseeds (right) on sale in a German supermarket, showing the price difference

"For most superfoods, no studies on humans confirm the potential health benefits."

and linseed mixtures also turn purple, so both types of seed must also contain protein. Students may notice that the purple coloration is more intense in the chia sample, showing that these seeds contain a higher concentration of protein.

Proteins can improve muscle growth and contribute to a balanced diet, but is it necessary to pay more for chia seeds? Note that the recommended daily amount of protein for an adult is around 0.8–1 g per kg of body weight (Rodriguez, 2015) – that is, around 48 g per day for a 60 kg person. So, at these quantities, it is quite easy for anyone to consume enough protein just by eating a balanced diet including normal foods that are rich in protein.

Chia seeds are also thought to be extremely healthy due to other nutrients, especially unsaturated fats. In addition, in the media you can find advice that eating chia seeds produces a feeling of being full for longer, and therefore potentially helps weight loss, because the seeds expand when put into liquid, producing a gelatinous 'chia pudding'. However, so far, no studies confirm either the nutritional benefits or the weight loss effects of chia seeds (Ulbricht et al., 2009; Egras et al., 2011).

Conclusions

From the results of these experiments the students can conclude that, in many cases, non-exotic, less expensive, perhaps locally sourced alternatives may be quite sufficient to meet the daily needs for nutrients and maintain a healthy diet. For most superfoods, no studies on humans confirm the potential health benefits. Rather, a diet that is balanced overall is the key to healthy nutritional habits.

The activities could be followed up by a classroom discussion on the ethical and ecological aspects of superfoods. For example, the excessive cultivation of avocados leads to huge amounts of pesticides being released to the environment, and long transportation routes from South America impact the environment. A social aspect is that the popularity of certain products (e.g. quinoa) in developed countries leads to rising prices in their countries of origin (in this case mostly Chile and Bolivia), where people are no longer able to afford their staple foods. Such discussions could lead to the question of sustainable nutrition, and to education for sustainable development.

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Resources

A comprehensive and accessible overview of superfoods from the Harvard T H Chan School of Public Health can help spark classroom discussion. See: www.hsph.harvard.edu/nutritionsource/superfoods/

An article from the Harvard Medical School highlights some less exotic foods that can provide some important nutrients to enhance a healthy diet. See: www.health.harvard.edu/blog/10-superfoods-to-boost-a-healthy-diet-2018082914463

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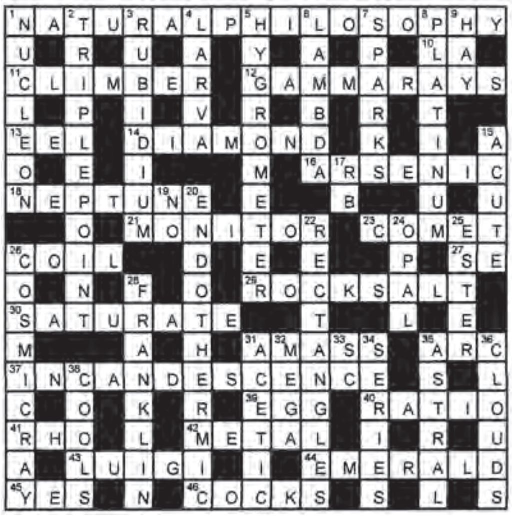
Sosin Ahmad is a Master of Education student of chemistry and mathematics at the University of Bremen. Her bachelor thesis dealt with the chemistry of selected superfoods.

Solutions to science crosswords

Crossword 1

Crossword 2



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Therefore, before undertaking any activity, readers should always carry out their own risk assessment. In particular, any local rules issued by employers or education authorities MUST be obeyed, whatever is suggested in the *Science in School* articles.

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- Practical work is carried out in a properly equipped and maintained science laboratory
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- Good laboratory practice is observed when chemicals or living organisms are used
- Eye protection is worn whenever there is any recognised risk to the eyes
- Pupils and students are taught safe techniques for activities such as handling living organisms, hazardous materials and equipment.

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