Spring 2010 Issue 14

SCIENCE in SCHOOL

In this issue:

Biodiversity: a look back at 2009

Teachers and scientists face to face: the first EIROforum teacher school

Highlighting the best in science teaching and research

Welcome to the fourteenth issue of *Science in School*

In this issue, a common theme is the nature of science and how to teach it. Pierre Léna, interviewed in our feature article (page 10), believes that when teaching science "it's important to convey the idea that science is a human and collective adventure, not a lonely and national activity". For him, it is essential to exploit children's curiosity. Science teacher Jörg Gutschank agrees: "the point is not to know but to question, and to look for ways to solve problems" (online article).
This reflects the way scientists themselves work – an approach that makes them very employable, explains Yasemin Koc. "You present [scientists] with a problem, they divide it into its individual components, investigate where the problem might lie, and find an efficient solution" (online article).

Scientists are not unlike children – always asking questions. How did the Universe begin? What is matter? And how do we know? These were just some of the questions that scientists addressed at the recent EIROforum teacher school at CERN, Europe's largest particle physics laboratory (page 6).

Particle physics may sound a long way from the classroom, but even if you were not lucky enough to visit CERN, you can still introduce the topic into your lessons – visualising cosmic rays with a homemade cloud chamber (page 36). Visualising particles is also crucial to the 'Radon school survey', in which students measure radioactivity levels in their homes by literally counting holes left by α-particles (page 54).

Radioactivity is a worry as a cause of genetic mutations, yet mutations are essential for evolution. Evolutionary adaptation occurs when particular DNA sequences help us to survive in our environment. Demonstrating which sequences are beneficial and how they help us survive is challenging but not impossible – for example in bacteria (page 58).

Whereas some microbes are dangerous, others have their uses, such as yeast – which is not only used to produce bread and beer, but can convert chemical energy into electricity (page 32). Alternatively, chemical energy can also be converted into light, and vice versa, as Peter Douglas and Mike Garley explain (page 63).

Light is also at the heart of Nataša Gros and her partners' project: developing school experiments in spectrometry, such as measuring the levels of glucose in jam (page 42). Linked together, glucose units can to form starch. Although starch is so familiar, scientists are still investigating its structure, slowly, step by step, in collaborative teams (page 22) – which brings us back in a full circle to the nature of scientific research.

I hope you enjoy these and the other articles in this issue – including the online-only ones.

Eleanor Hayes
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About *Science in School*

Science in School promotes inspiring science teaching by encouraging communication between teachers, scientists and everyone else involved in European science education.
The journal addresses science teaching both across Europe and across disciplines: highlighting the best in teaching and cutting-edge scientific research. It covers not only biology, physics and chemistry, but also earth sciences, maths, engineering and medicine, focusing on interdisciplinary work. The contents include teaching materials; cutting-edge science; interviews with young scientists and inspiring teachers; reviews of books and other resources; and European events for teachers and students.
Science in School is published quarterly, both online and in print. The website is freely available, with articles in many European languages. The English-language print version is distributed free of charge within Europe.

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Additional online material

See: **www.scienceinschool.org/2010/issue14**

Events calendar: **www.scienceinschool.org/events**

Science on Stage: recent activities

As the whirl of national Science on Stage activities continues, **Eleanor Hayes** reports on some recent events from Spain, German and even Canada.

Image courtesy of Ciencia en Acción

Do you believe that fish have memories?

Spain and Portugal: Ciencia en Acción

Dancing with fire, cooking with solar energy, and adopting a star – this event offered performances, competitions and activities for everyone. From Spain, Portugal, Argentina, Colombia, Mexico, Peru, Salvador and Uruguay, 500 teachers, 250 school students and 7000 members of the public flocked to the Ciencia en Acción[w1] festival in Granada, Spain, from 25-27 September 2009.

'Science in Action' – there could not be a better name for this dizzying display of science. One hundred and forty school and university science teachers presented some of the best projects from the Spanish- and Portuguese-speaking countries, sharing their ideas for engaging young people with science. These included dramatic physics and chemistry demonstrations, practical activities for biology and geology, sustainability projects, science films and much, much more.

For the general public, two research scientists brought their subjects – the theory of evolution and the development of vaccines for Alzheimer's disease – to life. For those looking for something still more dynamic, there were three eye-catching scientific performances. In 'The Dance of Fire', visitors discovered fire, music and the characteristics of waves using the Rubens' tube[w2] (see image below). A presentation of the physics of sound conveyed some difficult physical concepts in an entertaining way: the fundamentals of aerodynamics and aviation, including Bernoulli's theorem and aerodynamic drag. Finally, participants had the opportunity to 'Cook with the Sun', assembling solar ovens and using them to prepare – and share – delicious dishes in the open air.

The Ciencia en Acción festival also hosted the final event of the 'Adopt a Star' competition – the Spanish ver-

A Ruben's tube is used to demonstrate the relationship between sound waves and air pressure

Image courtesy of Ciencia en Acción

Images courtesy of Science on Stage Canada

1 Liz Wirtanen, a science and technology teacher from Canada, displays her students' renewable energy project, built to scale

2 Erich Fock from Germany shows his model train project to Jonathon DeBooy, an outreach officer from the Australian synchrotron

3 Participants working through an inquiry-based activity

sion of the international 'Catch a Star' competition[w3] for young people. Three hundred teams from Spanish- and Portuguese-speaking countries had entered the competition, either investigating their favourite celestial object or astronomical phenomenon, or developing an astronomy outreach programme. For the final event, 17 teams with a total of 80 school students presented their projects. The two winning teams were awarded a trip to the Spanish National Research Council (Consejo Superior de Investigaciones Científicas, CSIC), and a telescope.

Science on Stage Canada

August 2009 saw the first Science on Stage event[w4] in Canada: small, but very much in the Science on Stage tradition. The Canadian Light Source at Saskatoon welcomed 12 teachers and other educators from Canada, Australia and Germany for five days of fun and hard work. In the science fair, all participants presented their teaching projects, sharing and swapping ideas with their colleagues. More formal discussions were organised to address major issues in science education, such as how to improve teacher training or motivate students to study science; state and private education; and assessment.

An important element of any Science on Stage event is direct contact between teachers and scientists: at the Canadian event, scientists from the Canadian Light Source met with the teachers, explaining how a synchrotron works and how they analyse their research results.

Image courtesy of Ciencia en Acción

Group photo in Granada

Images courtesy of Science on Stage Germany

Teachers taking part in the Science on Stage Germany teacher training workshops

Science on Stage Germany

The German Science on Stage[w5] organisers continue to be busy – not only playing an important role in the establishment of Science on Stage Europe (Hayes, 2009) but also organising smaller national and international events.

In June 2009, 52 participants from 13 countries met at the Gläsernes Labor in Berlin for the third workshop on 'Teaching Science in Europe'. Building on the previous workshops at Science on Stage 2 and the international Science on Stage festival 2008 in Berlin, the teachers continued this European exchange on three topics: science in kindergarten and primary school; the benefits of non-formal education initiatives; and moderating science lessons. The outcomes will be published in June 2010 and distributed via the Science on Stage Europe[w6] network.

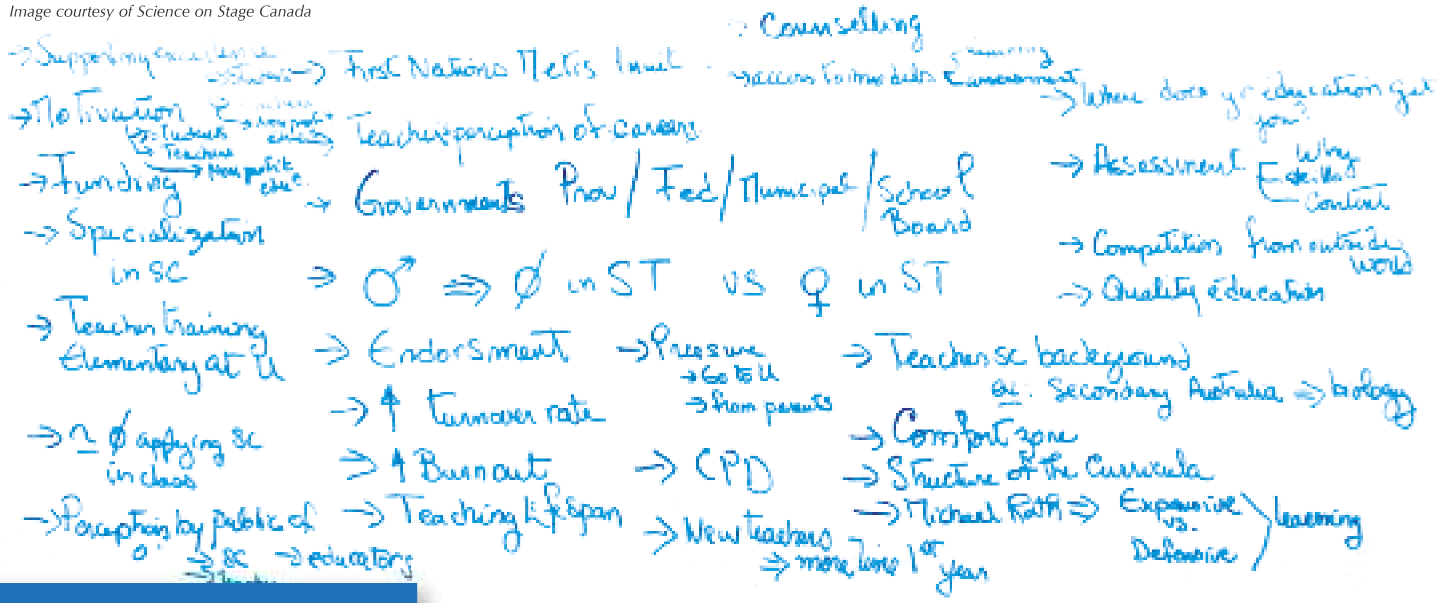
In September 2009, Science on Stage Germany, THINK ING[w7] and MINT-EC[w8] co-organised the EduNetwork fair[w9]. For the participating teachers, there were lectures and workshops on mathematics, astronomy, nanotechnology and how to support talented students, as well as an exhibition of education-related companies.

During the International Year of Astronomy, THINK ING, the journal *Life and Science*[w10] and Science on Stage Germany invited teachers from Germany and other German-speaking countries to submit ideas for teaching astronomy. The 12 best projects were published in *Life and Science*, and the award ceremony took place on 24 September in the Völklinger Hütte, the UNESCO World Heritage Site at the old Völklingen ironworks.

First prize went to Inge Theiring for her bilingual project 'Cosmological and general relativity phenomena in astrophysics', while Lutz Clausnitzer took second prize with 'Astronomy as interdisciplinary learning platform'. Christoph Noack, with his project to investigate the connection between religion and astronomy, entitled 'Creation and evolution', was awarded third prize. The Science on Stage international and national events bring together several hundred of the best teachers from across Europe to share their teaching ideas, but it is important that these ideas are spread beyond the festivals' participants. To this end, Science on Stage Germany is running a series of teacher training workshops in Berlin to present projects from previous festivals.

On 13 November, 30 teachers from Berlin and Brandenburg attended a half-day workshop to learn about two such projects. The German project, 'If colours become a health problem – coloured T-shirts with colours of plants', began with a newspaper article about the recall of children's clothing that contained harmful dyes. In an interdisciplinary project, the students then researched which dyes have been and continue to be important, and which harmless dyes could be used instead. The Austrian smoking prevention project uses the 'Smoking prevention lab' to discourage 14- to 18-year-old students from smoking. The affordable device – developed together with school students – helps to visualise and explain the effects of smoking on pulse rate, blood flow and blood pressure, as well as on the temperature of fingers – without the students having to smoke. The 'Smoking prevention lab' is a good example for European exchange: after the international Science on Stage festival 2008, three German participants joined the Austrian project, extending it to cover topics in biology and chemistry.

Image courtesy of Science on Stage Canada



Results of the brainstorming session

References

Hayes E (2009) Science on Stage: heading for a country near you. *Science in School* **13**: 2-3. www.sciencein-school.org/2009/issue13/sons

Web references

w1 – For more information about the Ciencia en Acción festival and details of the 'Adopt a Star' competition, see: www.cienciaenaccion.org

w2 – For instructions on how to build your own Ruben's tube, including videos and background information, see: www.instructables.com/id/The-Rubens_-Tube:-Soundwaves-in-Fire!

w3 – The 'Catch a Star' competition is organised by the European Association for Astronomy Education: www.eaae-astronomy.org

w4 – For more information about Science on Stage Canada (in both English and French), see: www.scienceonstage.ca

w5 – More information about Science on Stage Germany is available here: www.science-on-stage.de

w6 – Copies of the publication *Teaching Science in Europe 3* can be obtained from the national steering committees. To find your local contact, visit the Science on Stage Europe website: www.science-on-stage.eu

w7 – THINK ING is an initiative of the German Association of Metal and Electrical Industry Employers. To learn more, see: www.think-ing.de

w8 – Organised by employers in the fields of science, engineering and technology (SET), MINT-EC (Verein mathematisch-naturwissenschaftlicher Excellence-Center an Schulen eV) encourages more young people to enter SET careers. For more details, see: www.mint-ec.de

w9 – To learn more about the EduNetwork fair, see: www.edunetwork.de

w10 – To learn more about the German-language *Life and Science* journal, see: www.lifeandscience.de

Resources

All previous *Science in School* articles about the Science on Stage activities can be viewed here: www.sciencein-school.org/sons

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Dr Eleanor Hayes is the Editor-in-Chief of *Science in School*.

Teachers and scientists face to face: the first EIROforum teacher school

Image courtesy of Dana Jancinova

Image courtesy of Zeger-Jan Kock

Image courtesy of Paulo José Carapito

What is matter? How did the Universe begin? Are there other planets like Earth? And how do we know? **Eleanor Hayes** reports on the first EIROforum teacher school.

The first teacher school organised by EIROforum[w1], the publisher of *Science in School*, saw 35 science teachers from 17 European countries flock to CERN[w2] in Geneva, Switzerland, in November 2009. Over four days, the teachers were inspired, fascinated and challenged by the evolution of the Universe – what do we know and how do we know it?

The aim – which, to judge by the teachers' feedback, was amply achieved – was to give a flavour of the science done in four of the seven EIROforum organisations, inspiring the teachers to return home and motivate their students.

Using the same formula as CERN's long-running teacher schools (see box), the EIROforum teacher school involved lectures by EIROforum scientists on topics as varied as the structure of matter (Landua & Rau, 2008), the origin of the Solar System[w3], the search for extra-solar planets (Fridlund, 2009) and how to build a cloud chamber at school (Barradas-Solas, 2010). Other important elements were visits to research facilities including CERN's Large Hadron Collider (LHC; Landua, 2008) and the interaction both among the teachers and between teachers and scientists.

The key point was to show the teachers what we know about the beginning and the evolution of the Universe, but also – perhaps even more importantly – how this knowledge was obtained. The lectures, by scientists from CERN, EFDA-JET, ESA and ESO, demonstrated how the scientific disciplines work together to unravel nature's mysteries, how the research done in these four organisations focuses on finding answers to this common question.

"The lectures were very interesting and they will be very valuable in my teaching," reported Jens Nielsen from Norway. Svejina Dimitrova from Bulgaria and Dana Jancinova from Slovakia added: "We need to update our knowledge regularly. Such courses are very useful to us and we will be able to bring our enthusiasm to our students."

The next in the planned series of annual teacher schools will cover research from the other three EIROforum organisations: ESRF, ILL and EMBL will combine forces to bring life sciences alive at ESRF in Grenoble, France. For those European teachers lucky enough to be selected, EIROforum will cover not only the costs of their participation and accommodation but also their travel expenses to Grenoble. Teachers are selected on the basis of their motivation and enthusiasm to apply what they learn – and competition is stiff. If you're inspired to take part, keep a close eye on the *Science in School* website[w4], where details of how to apply will be published.

Image courtesy of Paulo José Carapito

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Image courtesy of Zeger-Jan Kock

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1. The Globe, CERN's exhibition centre
2. Part of an old linear accelerator at CERN
3. Model of a linear accelerator at CERN
4. Roof of Building 40 at CERN, housing scientists from the ATLAS and CMS experiments
5. Cross-section of one of the superconducting magnets of CERN's Large Hadron Collider

Image courtesy of CERN

The 35 teachers who participated in the first EIROforum school

Other education activities at the EIROforum organisations

CERN

The EIROforum teacher schools are based on CERN's long-running physics teacher programmes, more than 20 of which are organised each year. The three-day physics teacher programmes are run in English for teachers from all over Europe, and they include seminars, visits and educational activities. The national teacher programmes are similar, but are held in the national language of the participants from CERN member states. The high-school teachers programme in summer is an international three-week course held in English. Details of all courses are available on the CERN website[w2].

EFDA-JET

The Joint European Torus (JET)[w5] is Europe's largest nuclear fusion research facility, operated under the European Fusion Development Agreement (EFDA).

Both EFDA-JET and many of the other fusion research institutes in the European Fusion Development Agreement (EFDA) have their own outreach programmes, which often include lectures, as well as visits to schools and research facilities. Details of the individual research institutes are available on the EFDA website[w6].

Educational materials, including booklets, CD-ROMs, images and movies, are available via the EFDA website. The website also provides basic and more advanced information about fusion science.

EMBL

Amongst other education activities, the European Molecular Biology Laboratory (EMBL) organises 2-3 day workshops for European secondary-school teachers[w7], to introduce them to state-of-the-art molecular biology. The courses consist of lectures by EMBL scientists, practical activities suitable for schools, tours of the research facilities, and the chance to share science-teaching ideas with each other and the scientists.

ESA

The European Space Agency (ESA) offers a range of hands-on projects for schools (including a current competition to design a satellite – the ten best satellites will be launched into space[w8]). Via its European Space Education Resource Offices in several countries[w9], ESA also offers support to local teachers, developing materials appropriate for the national education systems. Many more educational resources – including teaching materials, images, DVDs and much more – can be downloaded or ordered from the ESA Education website[w10]. The ESA Kids' website[w11], available in English, Dutch, French, German, Italian and Spanish, offers quizzes, pictures, animations and space-related news for children.

ESO

In support of astronomy and astrophysics education, especially at the secondary-school level, the European Southern Observatory (ESO) produces teaching material, such as education sheets about the Atacama Large Millimeter / submillimeter Array (ALMA) telescope project, which accompany the planetarium show about ALMA, 'In search of our cosmic origins'[w12]. Another set of exercises, which use real data from telescopes such as the ESO Very Large Telescope, is produced in collaboration with ESA[w13]. ESO has also collaborated with the European Association for Astronomy Education (EAAE)[w14]. More information about ESO's education and outreach activities, as well as comprehensive galleries of astronomy-related image and video material, is available on the ESO website[w15].

ESRF and ILL

To be opened in 2013, the visitors' centre on the ESRF[w16] and ILL[w17] site in Grenoble, France will introduce the general public and school students to neutron and photon science, through hands-on activities, an exhibition and tours of the research facilities.

References

For instructions on how to build and use a cloud chamber at school, see:

Barradas-Solas F, Alameda-Meléndez P (2010) Bringing particle physics to life: build your own cloud chamber. *Science in School* **14**: 36-40. www.scienceinschool.org/2010/issue14/cloud

To learn more about the CERN teacher schools, see:

CERN (2009) Particle physics close up: CERN high-school teachers programme. *Science in School* **13**: 4-5. www.scienceinschool.org/2009/issue13/cernhst

To learn more about the CoRoT satellite's search for extra-solar planets, see:

Fridlund M (2009) The CoRoT satellite: the search for Earth-like planets. *Science in School* **13**: 15-18. www.scienceinschool.org/2009/issue13/corot

To learn more about the LHC, see:

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

To learn more about the structure of matter, see:

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

Web references

w1 – EIROforum brings together seven intergovernmental research organisations: CERN, the European Fusion Development Agreement (EFDA), the European Molecular Biology Laboratory (EMBL), the European Space Agency (ESA), the European Southern Observatory (ESO), the European Synchrotron Radiation Facility (ESRF), and the Institute Laue-Langevin (ILL). EIROforum's mission is to combine the resources, facilities and expertise of its member organisations to support European science in reaching its full potential. EIROforum also simplifies and facilitates interactions with the European Commission and other organs of the European Union, national governments, industry, science teachers, students and journalists. For more information, see: www.eiroforum.org

w2 – The CERN education website offers information about all the teacher programmes, as well as educational resources for schools. See: http://education.web.cern.ch/education/Welcome.html

w3 – Many of the topics covered in Professor Bernard Foing's lecture on the origin of the Solar System are addressed in the *Science in School* series on fusion in the Universe. See: www.scienceinschool.org/fusion

w4 – To read or download all articles from *Science in School* – and (later this year) to find out how to apply for the next EIROforum teacher school – visit: www.scienceinschool.org

w5 – The EFDA-JET website offers brochures, photos and videos about fusion research: www.jet.efda.org

w6 – To learn more about EFDA, visit: www.efda.org

w7 – For more details about courses run by EMBL's European Learning Laboratory for the Life Sciences, see: www.embl.org/ells

w8 – For details of ESA's CanSat competition to design a satellite to be sent up to an altitude of 1 km, see: www.esa.int/SPECIALS/Education/SEMR59AK73G_0.html

w9 – The ESERO website offers teaching materials to download or use online: www.esa.int/SPECIALS/ESERO_Project

w10 – For details of all ESA's education activities, visit the ESA Education website: www.esa.int/SPECIALS/Education

w11 – The ESA Kids' website can be found here: www.esa.int/esaKIDSen

w12 – Educational worksheets about the ALMA project can be downloaded here from the website 'In search of our cosmic origins': www.cosmicorigins.org/education.php

w13 – The ESO/ESA astronomy exercise series can be downloaded here: www.astroex.org

w14 – To learn more about the European Association for Astronomy Education, visit: www.eaae-astronomy.org

w15 – To learn more about ESO's education activities, see: www.eso.org/public/outreach/eduoff

w16 – To learn more about the European Synchrotron Radiation Facility (ESRF), visit: www.esrf.eu

w17 – For more information about the Institut Laue-Langevin, a European institute for neutron-based scientific research, see: www.ill.eu

Resources

Videos of all the presentations made during the first EIROforum teacher school can be downloaded here, together with the slides of the talks: http://indico.cern.ch/conferenceDisplay.py?confId=69896

To read all *Science in School* articles relating to EIROforum and its member organisations, see: www.scienceinschool.org/eiroforum

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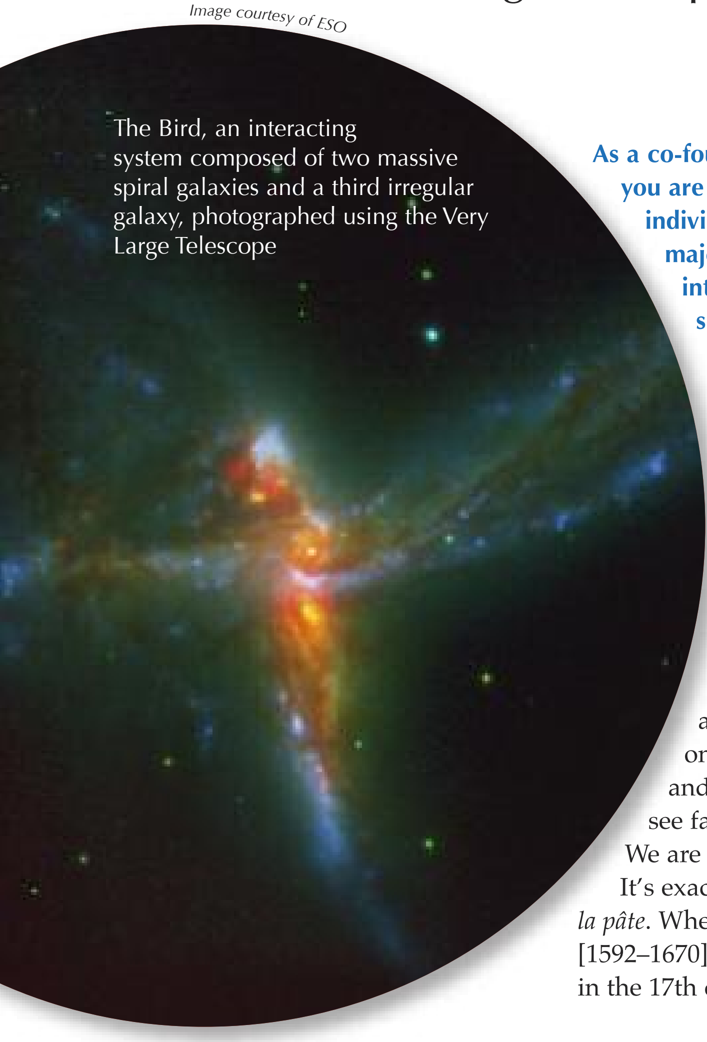
Dr Eleanor Hayes is the Editor-in-Chief of *Science in School*.

Science is a collective human adventure: interview with Pierre Léna

Image courtesy of Pierre Léna

French astrophysicist Pierre Léna talks to **Marlene Rau** about science education as a symphony, the importance of curiosity, and his commitment to spreading inquiry-based science teaching in Europe and beyond.

Image courtesy of ESO



The Bird, an interacting system composed of two massive spiral galaxies and a third irregular galaxy, photographed using the Very Large Telescope

As a co-founder of *La main à la pâte*, you are a good example of how an individual can bring about major changes – in this case introducing inquiry-based science teaching to primary schools. What would you tell people who don't believe in their power to change things?

I don't place too much importance on the role of exceptional individuals. I often quote the French 12th-century theologian Bernard de Chartres, who said: "We are like dwarves standing on the shoulders of giants, and so able to see more and see farther than the ancients." We are part of a long progression. It's exactly the same for *La main à la pâte*. When John Amos Comenius [1592–1670] invented nursery school in the 17th century, it was a revolutionary idea that children had the ability to reason: they were essentially considered to be little animals. After him, people like Maria Montessori [1870–1952] in Italy and Célestin Freinet [1896–1966] in France continued to develop the idea that children are not empty bottles to be filled with knowledge, but extremely lively organisms just waiting for a chance to develop.

When Georges Charpak [winner of the 1992 Nobel Prize in Physics] initiated *La main à la pâte*, he was drawing on a similar idea by another Nobel Prize winner, Leon Lederman, who had created a science education centre in a poor area of Chicago to train teachers and introduce inquiry-based science education into local schools. We are not individuals in a vacuum, we are just on the shoulders of predecessors, as they themselves were. It's a long chain.

Do you think that France has a special

Image courtesy of BartCo / iStockphoto

history of fostering science education?

Well, certainly Europe has a special history. France has played an important role in the history of science and education, as have Italy, Germany, Denmark and others. This is why at *La main à la pâte*, one of the very first books we published was called *L'Europe des Découvertes* [*The Europe of Discoveries*; Jasmin, 2004], in which we collected – from different European countries –discoveries such as that of the hot-air balloon, simple enough for children to understand. Primary-school teachers can use this collection to give children the feeling that science is a collective human adventure, that the children belong to Europe, and that – like musicians in an orchestra – each country has played a different instrument. So I don't think France has a unique or exceptional role, but we have certain talents.

During my career, I have contributed to the construction of a European community in astronomy, and we have built this fantastic telescope in Chile: the Very Large Telescope [see Pierce-Price, 2006]. We would never have done it without the money from the different countries, but the money was not sufficient – it also needed the diversity of talents from every country. I think it's important to convey the idea that science is a *human* and *collective* adventure, not a lonely and national activity.

And it's not just about facts, either. Say you teach interference in a physics class, using the Young experiment: you take a piece of cardboard and a needle, make two holes in the cardboard, shine a laser

REVIEW

All science teachers must have noticed the way their students change during their time at school. They generally start out excited, questioning and enthusiastic, and yet within the short space of a few years many come to find science irrelevant, dull and difficult.

Ideally, the children's enthusiasm and curiosity would be encouraged at school, in a 'proper' laboratory environment with specialist teachers who are able and willing to guide their students' learning and inquiry. However, this is seldom the case – either in primary schools or in secondary schools. Primary-school teachers often lack the detailed subject knowledge and confidence to guide student inquiry. Appreciate the teacher's dilemma – struggling with their pupils' 'what, where, why' questions, having to admit that they do not know, and not knowing if it is a shortcoming on their part or if the pupil has touched on an area where even career scientists tread very carefully!

At secondary school, the teachers have the specialist scientific knowledge, but the heavily content-drive curriculum means they often lack the time for student-centred inquiry. Thus, when children are young, teachers struggle to guide them in finding the answers they seek; when they are older, students are told that there simply isn't the time for these educational asides.

Pierre Léna encourages a loosening of the authoritarian reins and stepping away from the carefully orchestrated (and yet tedious) enquiries into the resistance of wires or the activity of enzyme solutions. Carefully managed, it could be liberating for teachers and students alike.

Ian Francis, UK

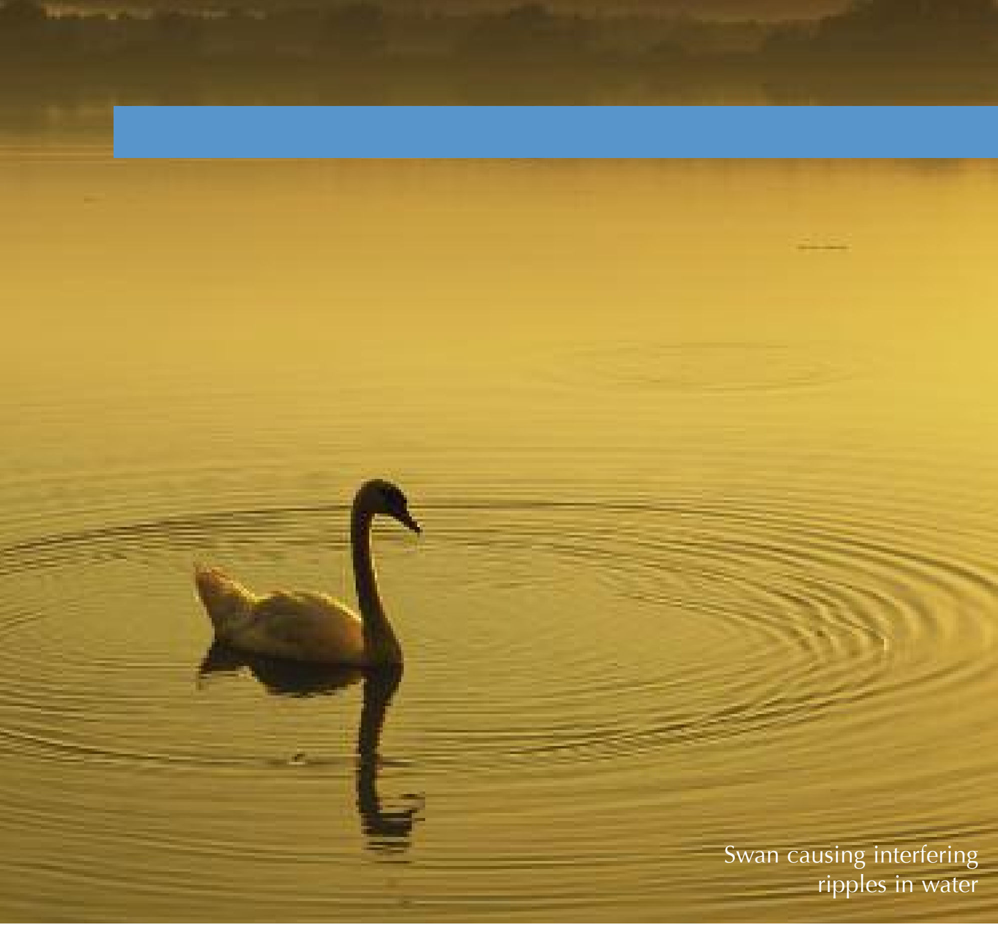


Image courtesy of mammuth / iStockphoto

onto it and you see the fringes – good. Many teachers won't even do that; they will just draw the fringes and write the formula on the board – terrible. But what if you tell the pupils that, at the age of 20, Thomas Young saw two swans swimming on a pond at a Cambridge college, making waves – and saw that these waves were interfering? And that this observation contributed to Young's idea? If you give this background to the formula on the board, it changes the students' experience completely. Science is a process of thinking, which is triggered by admiration, emotion, surprise – and we want to convey all those things to children. We must *not* extinguish them.

It can be difficult to change a firmly established idea of how science should be taught, though, can't it?

Yes. That's true, and it has not been easy to introduce inquiry-based science teaching in the classroom. However we have one good ally in this battle – the child. Many teachers change their minds when they see a colleague teaching a science lesson like this. Because what do they see? They see children who don't want to have a break and play football – they want to continue the lesson, because it's interesting. They see children for whom school is taught in their second language, or who never express themselves in the classroom, or with poor grades, low self-confidence or learning difficulties – they see these children changing their attitude. The children turn into good speakers, willing to explain to others, gradually improving. It is a little miracle. I have seen it happening so often that I can't believe it's a coincidence. Often teachers say: "Teaching inquiry-based learning is difficult, but it's wonderful when I see the result, so maybe it's worth trying."

Inquiry-based learning can be a way to develop children's curiosity, but is the importance of curiosity unique to science teaching? Basically, you need curiosity to gain any kind of knowledge.

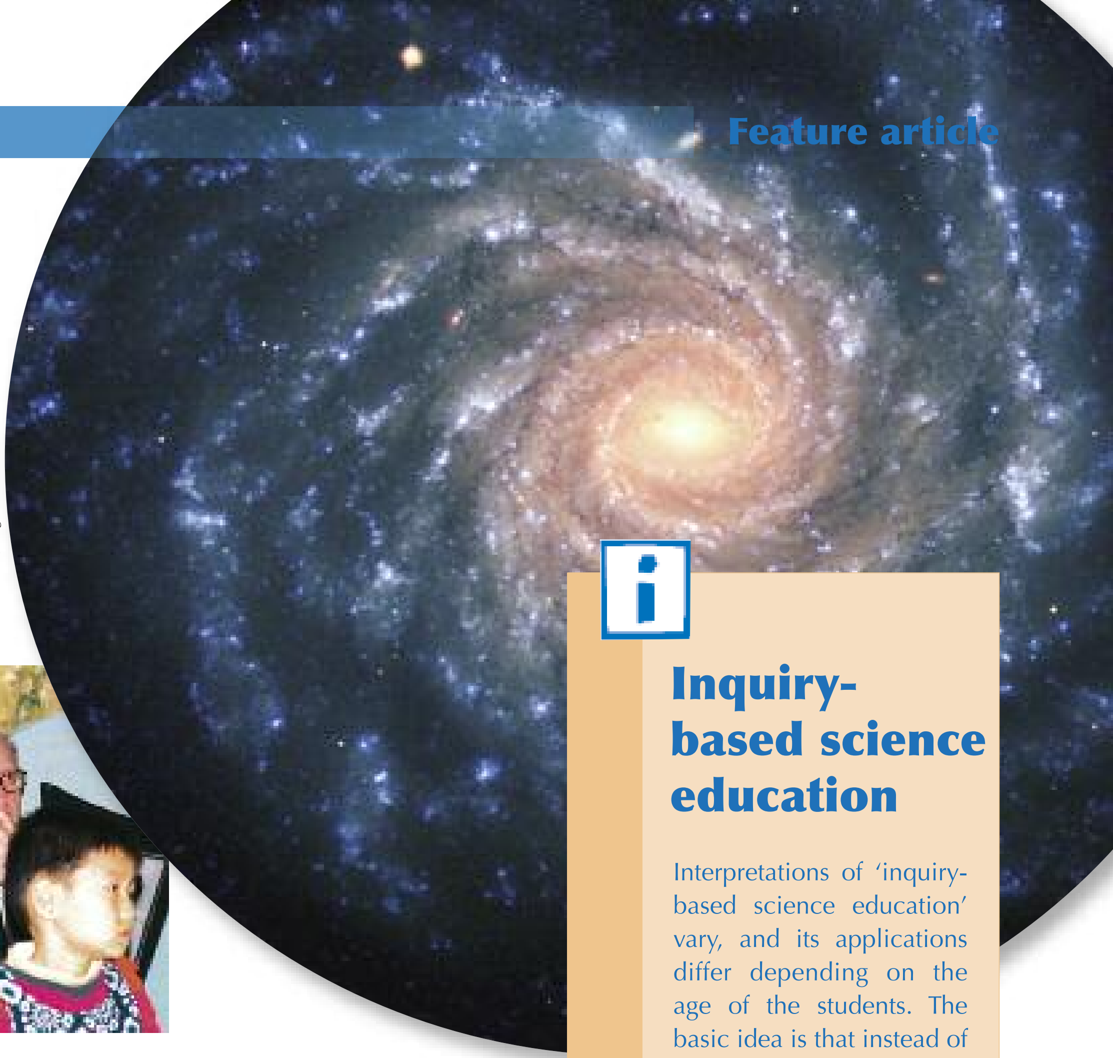
It's true that you need curiosity for any kind of knowledge acquisition, but science is something special, and this is why scientists are special people in a sense. Scientists ask "why?" a lot, but you can also ask "Why does this person love me?" or "Why does this man dislike me?" Questioning is universal; you can question absolutely anything. But what makes science special is how we go about finding the answer to "why?": the scientific method.

BACKGROUND

Pierre Léna

Pierre Léna, born in 1937 in Paris, France, is an astrophysicist who most notably contributed to the development of infrared astronomy, to the conception of ESO's Very Large Telescope[w1] in Chile, and to novel methods of astronomical imaging at high resolution.

Pierre Léna is very involved in reforming school science education, especially through the *La main à la pâte* initiative to introduce inquiry-based science learning into primary schools, which he launched in 1996 together with fellow physicists and members of the French Academy of Sciences, Yves Quéré and Georges Charpak (Lellouch & Jasmin, 2009). From 1991 to 1997, Pierre Léna was president of the French national institute of education research. He often visits schools and tests ways to teach science to children. In November 2009, for instance, he visited the international French school in Beijing, China.



Spiral galaxy NGC 1232 located in the constellation Eridanus (the river), photographed using the Very Large Telescope

Image courtesy of ESO

Pierre Léna and Yves Quéré visit the international French school in Beijing, China

Image courtesy of La main à la pâte

Children and adults often have very different approaches to asking questions, don't they?

Yes, and that is what sometimes destabilises the teacher because children go to the heart of the question: "Why does an atom have a mass? What is mass?" The teachers are sometimes completely baffled. They reply: "You have to wait until you grow up", or "Oh, I don't know, I never understood this myself" – which is honest, but not very satisfactory. Or, worst of all: "You shouldn't ask this kind of question". One should take the children's questions seriously though, and that's why so many teachers are afraid of teaching inquiry-based science lessons. Once you open Pandora's Box….

The reactions from teachers in primary and middle school [for pupils aged 12 to 15] are different, though. In primary schools in France, we have teachers who usually have little science background, so they are worried about teaching the subject in the first place. In middle school, however, science teachers have four or five years of university training in physics or biology, so they are well prepared. Now we're introducing inquiry-based science teaching in French middle schools, and some teachers tell us: "You are getting us into trouble because children might ask all kinds of questions to which we don't know the answers. So we'll do inquiry-based science teaching in a special way: we'll guide them to the right answer. Of course we'll have many questions coming from the class, but we'll keep only those that will lead us exactly where we want to go."

It is difficult to accept a new attitude that might destabilise your authority. Children can ask many questions, and in the inquiry process they make hypotheses. Some hypotheses are very interesting, but can be destabilising for the teacher.

Most teachers, especially in primary school, are very aware of their responsibility to educate children, helping them to grow as people – which is magnificent, of course. But they don't see that science can help them in this task: building on chil-

BACKGROUND

Inquiry-based science education

Interpretations of 'inquiry-based science education' vary, and its applications differ depending on the age of the students. The basic idea is that instead of a teacher presenting concepts, their logical implications and examples of applications, children are involved to make their own observations and experiments and are guided by the teacher in developing their own knowledge. Children are encouraged to be curious and to tackle problems by observing and experimenting, and by reflecting and thinking critically about the meaning of the evidence they have gathered.

This works very well in primary school, by taking advantage of children's natural curiosity at this age. Inquiry-based science education also encourages children to develop complementary skills including working in groups, written and verbal expression, and solving open-ended problems.

Image courtesy of ESO

Three of the telescope domes of the Very Large Telescope

dren's curiosity to engage them with the world around them. And that is something that – as part of the *La main à la pâte* project – we are able to help with (see box below).

One last question: do you have a dream?

Yes, but my dream is not only for Europe: we are wealthy in Europe, but I have visited schools in Africa and in Latin America and seen the poverty. There are more than a hundred million children today who never go to school, and there are African schools with 120 children in one class. This is a very big problem. So if we succeed in building this European community of science education, we really have to share it with those countries; we have to help them, and also learn from them. The situation is bad, and climate change and overpopulation will make it worse. In a globalised world, we cannot just care for our own children. So my dream is that we build something for Europe, but that we then share it. It's not simple, but we can do it.

Take Abdus Salam: he was a physicist from Pakistan who won the 1979 Nobel Prize in Physics. His dream was to foster research in developing countries. He convinced UNESCO, the Italian government, scientists and Nobel Prize winners to build a centre in Trieste, Italy, in 1964: the International Centre for Theoretical Physics[w2]. It was to be a place to train scientists from developing countries to a high international standard. The role this centre has played in changing research in those countries is incredible; it's a simple idea and a remarkable model.

La main à la pâte ideas have been extended to the Pollen project, in which 12 'seed cities' throughout Europe encouraged inquiry-based science learning in primary schools (Lellouch & Jasmin, 2009). With the follow-up Fibonacci project, started in 2010, the model will be extended to even more countries, involving not only primary but also secondary schools, and not only science but also mathematics (see Léna, 2009). I think we should convince the European Commission that we should also run a similar, dual project with, say, 12 cities in Europe and 12 small towns in Africa. I know it's possible, because *La main à la pâte* is working with a school in Cameroon – and science education has blossomed there. Nobody would have thought it possible, but we coached the teachers there, and it worked. Don't forget – we're dwarves standing on the shoulders of giants.

BACKGROUND

Coaching teachers in *La main à la pâte*

As part of the *La main à la pâte* project[w3], between 1500 and 2000 science or engineering students in France volunteer to help teachers use an inquiry-based approach in the classroom. For at least seven consecutive weeks, they spend half a day per week at a primary school, helping the teacher prepare the lessons – finding materials, preparing handouts, and setting up the experiments, as well as helping with the scientific concepts and knowledge. The teacher remains in charge of the lesson, and the student supports both the teacher and the children throughout the inquiry process. Once the lesson is over, the student and teacher analyse it together. For more information, see Lellouch & Jasmin (2009).

The famous 'Sombrero' early-type spiral galaxy Messier 104 in the constellation Virgo (the virgin), photographed using the Very Large Telescope

Images courtesy of ESO

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Lellouch S, Jasmin D (2009) Catch them young: university meets primary school. *Science in School* **11**: 44-51. www.scienceinschool.org/2009/issue11/pollen

Léna P (2009) Europe rethinks education. *Science* **326**: 501. doi: 10.1126/science.1175130

Pierce-Price D (2006) Running one of the world's largest telescopes. *Science in School* **1**: 56-60. www.scienceinschool.org/2006/issue1/telescope

Web references

w1 – ESO, the European Southern Observatory, is the foremost intergovernmental astronomy organisation in Europe and the world's most productive astronomical observatory. ESO's Very Large Telescope is the world's most advanced visible-light astronomical observatory, located high in the Chilean mountains. To learn more about ESO, see: www.eso.org

As a member of EIROforum, ESO is one of the partners that fund and publish *Science in School*. For more information about EIROforum, see: www.eiroforum.org

w2 – To learn more about the Abdus Salam International Centre for Theoretical Physics, visit: www.ictp.trieste.it

w3 – *La main à la pâte*, the French programme for inquiry-based science education, is coordinated by the French Academy of Sciences (Académie des sciences) with the support of the national institute of education research (*Institut National de Recherche Pédagogique*, INRP) and the *École normale supérieure* (Paris), in partnership with the ministry of education. For more information (in French) about *La main à la pâte*, see: www.lamap.fr

For more information about the French Academy of Sciences, visit: www.academie-sciences.fr

To learn more about the French national institute of education research, see: www.inrp.fr

For more information about the *École normale supérieure* (Paris), see: www.ens.fr

Resources

Instructions for repeating Young's light interference experiment are available here: http://cavendish-science.org/phys/tyoung/tyoung.htm

If you enjoyed reading this article, why not take a look at other feature articles published in *Science in School*? See: www.scienceinschool.org/features

Dr Marlene Rau was born in Germany and grew up in Spain. After obtaining a PhD in developmental biology at the European Molecular Biology laboratory in Heidelberg, Germany, she studied journalism and went into science communication. Since 2008, she has been the editor of *Science in School*.

"We are like dwarves standing on the shoulders of giants (...)"

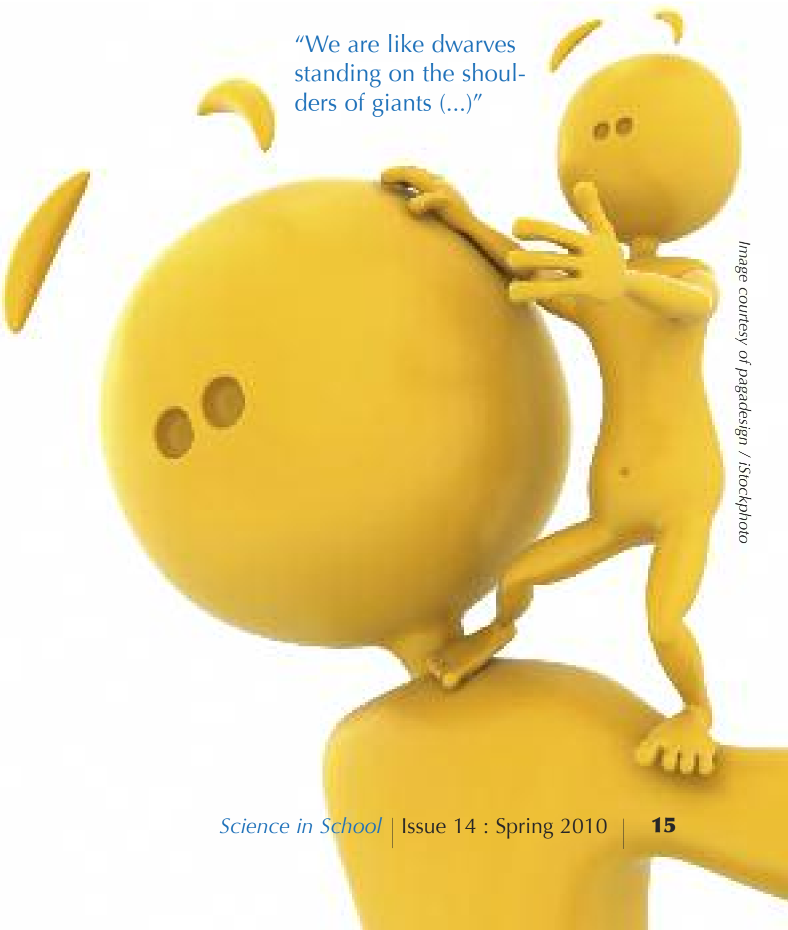


Image courtesy of pagadesign / iStockphoto

Getting ahead in evolution

Lucy Patterson talks to Èlia Benito Gutierrez, from the European Molecular Biology Laboratory in Heidelberg, Germany, about how Èlia's favourite animal, amphioxus, could be the key to understanding the evolution of vertebrates.

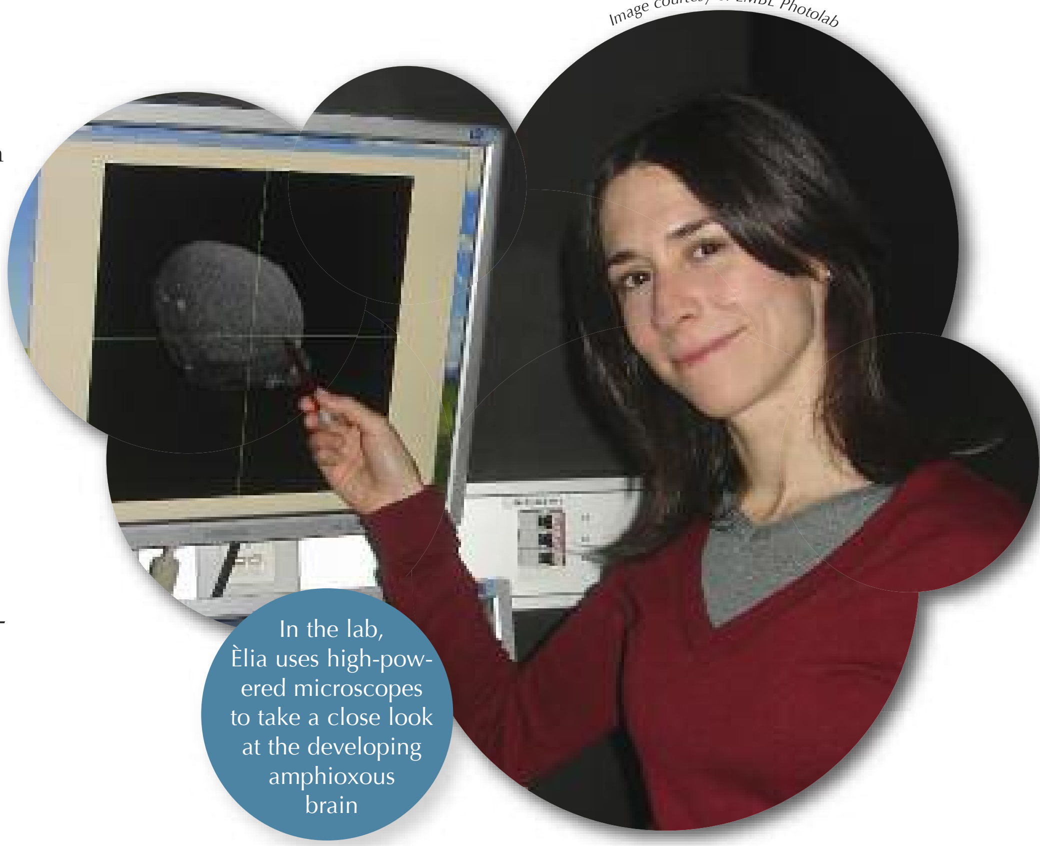


Image courtesy of EMBL Photolab

In the lab, Èlia uses high-powered microscopes to take a close look at the developing amphioxous brain

In coastal seabeds around the world, buried up to the gills, the worm-like amphioxus filters plankton from the waves. This has been going on for a *very* long time. Day in and day out, for more than 520 million years, amphioxus – or something very like it – has filter-fed as the world changed around it. Fish heaved themselves onto land, dinosaurs rumbled across the plains, early man struck flints together to make fire, and all the while, amphioxus sat there. If you have the chance to go snorkelling, look out for them. They might not sound very dynamic, but these creatures have fascinated natural historians and scientists since the mid-19th century, including Èlia Benito Gutierrez.

Her interest in amphioxus was sparked in her first-year zoology course at the Universitat de Barcelona[w1], Spain. "Amphioxus was this strange worm-like animal mentioned at the end of the list of invertebrates, before the vertebrates," she remembers. Since Charles Darwin's great revelation 150 years ago, many have considered amphioxus to be the key to understanding the origin of the vertebrates – the group of backboned animals including fish, amphibians, reptiles, birds and mammals, among them, of course, us. Èlia's own niggling curiosity brought her, after a PhD in Barcelona and a research position in London, Uk to the European Molecular Biology Laboratory (EMBL)[w2] in Heidelberg, Germany and a pioneering new amphioxus project.

Èlia's project falls under the still rather new science of 'evo-devo' – the combined study of evolution and development. Scientists are increasingly realising that the intricacies of development – how a single fertilised egg gives rise to the incredible diversity of cells and tissues in an adult – have had a major impact on the course of evolution.

Rather than re-inventing the wheel every time, new species arise through tweaks and adjustments to pre-exist-

Image courtesy of NaluPhoto / iStockphoto ing developmental plans. The earlier the tweaks, the more dramatic the resulting changes. Later tweaks, producing subtler changes, were less likely to cause major disadvantages, and thus were favoured. This has mind-boggling implications: the further back in development we look, the more similar we are to our evolutionary ancestors. For instance, did you know that as embryos, we pass through a stage in which we start to develop gills like our fishy predecessors? Just like fish embryos, we develop 'pharyngeal arches', six fleshy pouches on either side of the neck, each containing a rod of cartilage. Evolutionary adaptations since our aquatic past caused these to be re-assimilated into the developing jaw and tiny bones of the middle ear.

Amphioxus is one of a very select group of creatures that Darwin termed 'living fossils' – species alive today but still remarkably similar to their ancient fossilised ancestors – which are of great value to scientists studying evo-devo. Other examples include crocodiles and the coelacanth, a large ancient-looking fish thought to be extinct until a living specimen was discovered in 1938. Over millennia, Earth has witnessed huge environmental changes, stimulating the evolution of new species, and bringing about the extinction of others. In fact, it is calculated that 99.9% of all species that ever lived are now extinct. Nonetheless, these fossil species have survived and appear relatively unchanged. Although it may seem that these creatures have been stuck in an evolutionary time warp, in fact their DNA has been subject to as many mutations as that of other species. However, for some reason, mutations that caused changes to body shape were never particularly advantageous. For amphioxus – a versatile creature that is comfortable in many kinds of sandy or gravelly seabed, in warm or even rather chilly water – perhaps the filter-feeding lifestyle it shares with its ancestors was, even over 520 million years, never really under threat.

However, what most excites amphioxus fans is the position of its ancient ancestor in the evolutionary tree. As Èlia explains, "what's really

REVIEW

- **Biology**
- **Earth sciences**
- **Information and communications technology**
- **Evolution**
- **Development**
- **Geology**

This fascinating article emphasises the importance of the science of evo-devo and how the invertebrate amphioxus has evolutionary links with vertebrates, ranging from the development of the head to an explanation for a slipped disc. The breadth of information covered in the article makes it an invaluable resource for teachers and for students aged 16-18.

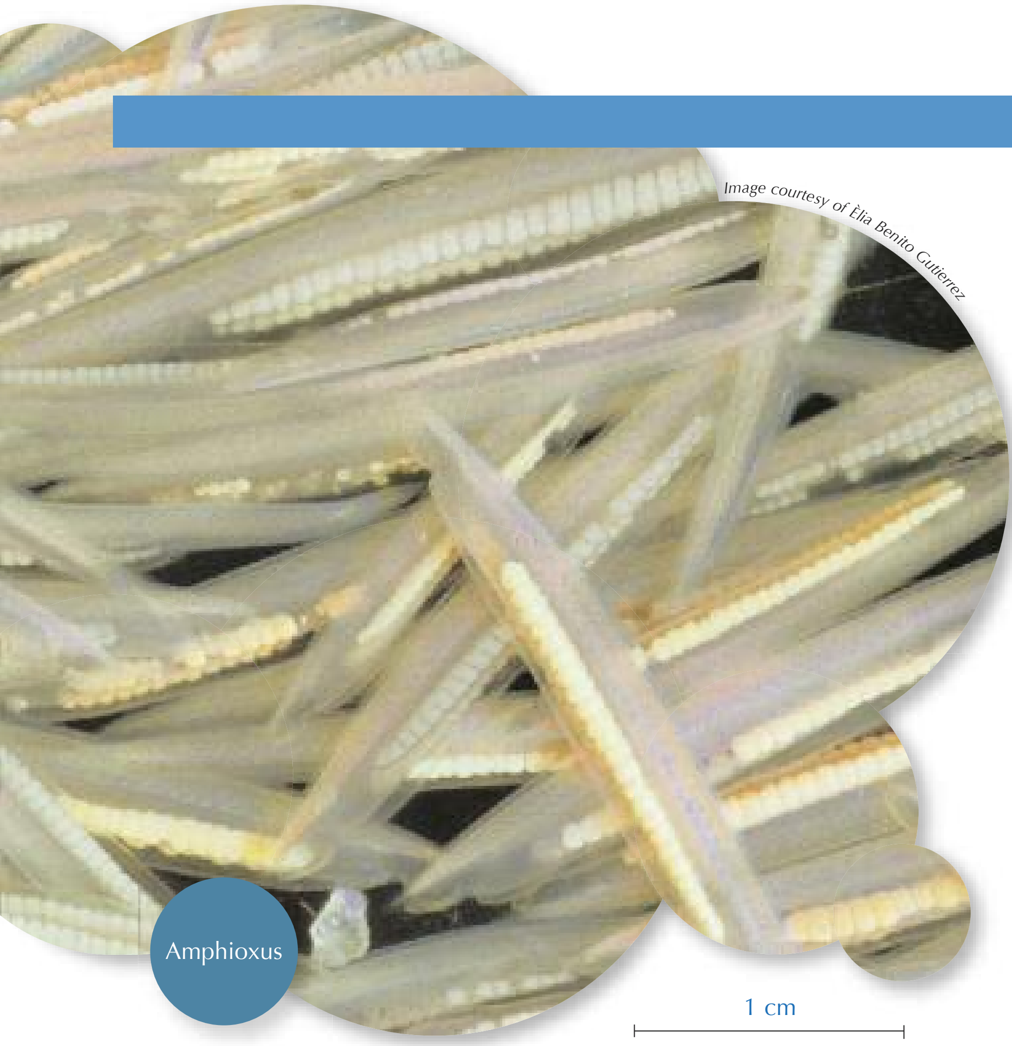
The information could be used for teaching vertebrate evolution, in particular the development of the nervous system and sensory organs, and for group discussion to address why amphioxus provides a valuable model for vertebrate development. There are interdisciplinary opportunities with geology (the fossil record), and with information and communications technology (the construction of phylogenetic trees).

The article would make an excellent comprehension exercise, using, for example, the following questions.

1. Why is evo-devo an important science?
2. What is meant by a living fossil?
3. What do you understand by the terms stem vertebrate and stem genome?
4. What were the selection pressures that led to the development of the head?
5. What do you understand by the term gene duplication and why was it crucial to vertebrate development?

For the more adventurous, there is the potential for DNA sequence alignment and phylogenetic analyses between amphioxus and human genes.

Mary Brenan, UK



evolution of a jaw with teeth to bite and chew food before it reaches the gut.

Key to both the development and evolution of the head is a tissue called 'neural crest' – special cells originating from the same tissue that makes our brain and spinal cord. Once formed, these cells begin to migrate all over the body. The final destination of many is the head, where they make connective tissue, muscle, skin, facial nerves, bones and cartilage, providing support crucial to the development of the eyes and the taste and smell receptors of the mouth and nose. Neural crest cells also contribute (via the pharyngeal arches) to the jawbones, teeth, and the tiny bones of the middle ear, essential for the evolution of hearing.

As its name suggests ('amphis' means 'both' and 'oxys' means 'sharp'; so 'sharp at both ends'),

interesting is that the ancient ancestor that amphioxus represents was a kind of minimalist or 'stem' vertebrate." Although officially an invertebrate, that amphioxus has a lot in common with backboned vertebrates. It has a hollow nerve cord running down its back, like our spinal cord, and next to this a notochord, a stiff but flexible rod that supports the body, serving as a kind of primitive backbone. As embryos, we also have a notochord, a remnant from our invertebrate past, but just like the pharyngeal arches, ours is broken up and re-used – to make the disks that lie between the vertebrae. "As the closest living relative of the ancestor of all vertebrates, amphioxus gives us a rare glimpse of how our evolutionary ancestors are likely to have looked," Èlia says. And really, the chances of such an evolutionarily important fossil species being alive today must be phenomenally slim.

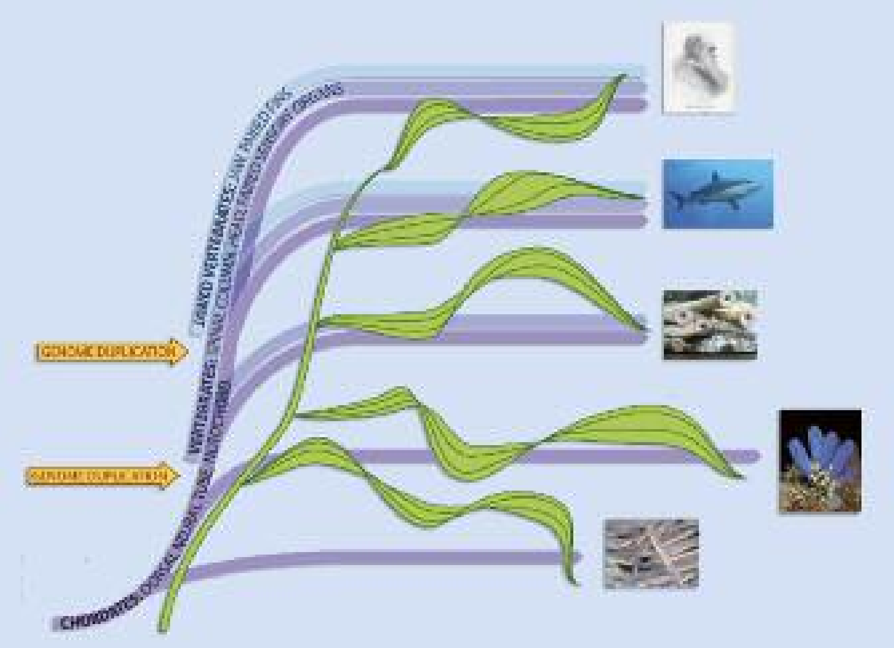
So how did the vertebrates evolve from these amphioxus-like ancestors? Of course, cartilage and bone evolution was very important, but the transition from invertebrate to vertebrate involved more than a backbone. It was also a matter of lifestyle choice, particularly feeding. Whereas creatures like amphioxus sat on the seabed, waiting for food to come to them, the early vertebrates evolved a new strategy: predation. They started to evolve the means to actively find food, requiring a whole raft of novel innovations, body parts and skills. Key to these was the evolution of a new head.

It might seem obvious, but to actively feed yourself, you first have to find your food. For this, you need sophisticated sensory organs to see, smell, taste and hear it (although our invertebrate ancestors had sensory cells or organs, the early vertebrates evolved *paired* organs, like our eyes, allowing them to sense the world in three dimensions). Where better to evolve these new, food-finding tools and the brain they're wired up to than next to your mouth? These innovations, in turn, broadened the menu, and, for most vertebrates, the pursuit of less digestible diets resulted in the

amphioxus doesn't have much of a head. Crucially, neither does it have neural crest, whereas all vertebrates do. There is some evidence though that migrating cells a little like primitive neural crest exist in amphioxus and in tunicates (sea squirts), another invertebrate group related to the ancestral vertebrate. By studying these cells, Èlia hopes to understand how neural crest, and by extension, the head, evolved.

Since the completion of the amphioxus genome sequence in 2008, amphioxus research has really come of age. Scientists like Èlia can now work out how the stem vertebrate genome would have looked. Comparisons with vertebrate genomes, including human, show remarkable similarity. "We now know that amphioxus has all the same important gene families that vertebrates have," explains Èlia. "All the basic building blocks needed to make a vertebrate are present. So you could ask: why doesn't amphioxus develop like a vertebrate?" The likely answer to this also lies in the genome. Unlike

Image courtesy of Lucy Patterson. Constituent images courtesy of Lycaon (amphioxus), Nhobgood (sea squirt), Drow_male (lampreys), Albert Kok (shark), Robbot (Darwin), Lmozero (hagfish); image source: Wikimedia Commons



You might have noticed that the evolutionary tree depicted in textbooks looks a little different to this one. It was traditionally assumed, based on physical similarity, that vertebrates were more closely related to amphioxus than to the rather bizarre tunicates. As larvae, tunicates look like free-swimming tadpoles with a notochord and nerve cord. However, as they mature, they attach themselves to the sea floor and metamorphose into sack-like sedentary filter feeders. Their notochord and neural tube degenerate – some say it's almost as though they eat their own brains!
However, in 2006, by looking at DNA, scientists discovered that, in fact, vertebrates share a more recent common ancestor with tunicates than with amphioxus. This common ancestor would probably also have looked similar to amphioxus, but since our lineages split, our evolution has taken a very different path: vertebrates evolved neural crest, a head and predation, while the tunicates specialised even further to become (as adults) sedentary filter feeders

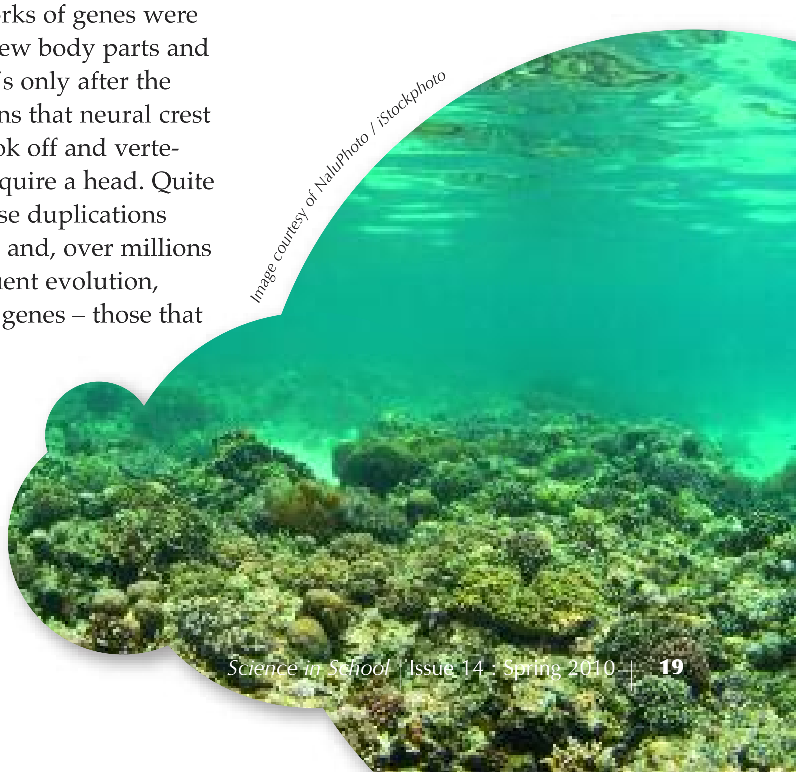
in vertebrates, where many genes are duplicated, all amphioxus gene families are present as single copies. This confirms suspicions of a major difference between vertebrates and their ancient ancestor: early in the evolution of vertebrates, the entire ancestral genome was duplicated, twice.

Strange events in our evolutionary history at once vastly increased the number of genes available for natural selection to act on, and therefore the potential to evolve. With the original genes taking care of the usual business of building an animal, there was much greater freedom for natural selection to play around with the new copies. Through this activity, whole families and networks of genes were recycled to make new body parts and systems. Indeed, it's only after the genome duplications that neural crest evolution really took off and vertebrates started to acquire a head. Quite when and how these duplications occurred is unclear and, over millions of years of subsequent evolution, most of the copied genes – those that didn't give rise to new features – have been lost.

So, rather than just sitting in the sand, with no real pressure to change, perhaps amphioxus has simply evolved as far as it could with the genes it has; without the influx of freshly copied genes, it has reached a dead end. Whereas for many other species, such a dead end would mean extinction, there is always a part of the coastline somewhere where amphioxus can bury itself.

Researchers like Èlia are more than happy that amphioxus is still around today because it provides a unique opportunity to study how the early vertebrates evolved. Her particular interest is in the evolution of the brain, and she plans to construct a detailed map of the amphioxus brain as it develops, showing the positions of the different neurons and which genes they express. "By comparing amphioxus to vertebrate species we can learn how the basic machinery already present in the stem vertebrate was recruited and redeployed, eventually creating complex characteristics like memory or our ability to learn." So by getting left behind for all those years, amphioxus might provide the key to our evolutionary past, helping us to understand the creatures we are today.

Image courtesy of NaluPhoto / iStockphoto



Sitting in coastal seabeds around the world, buried in the sand: this is how amphioxus views the world

Web references

w1 – For more information on the Universitat de Barcelona, see: www.ub.edu

w2 – Find out more about the European Molecular Biology Laboratory here: www.embl.org

Resources

To read more about the research group at EMBL where Èlia works and the story of her supervisor, Detlev Arendt, see:

Hodge R (2006) A search for the origins of the brain. *Science in School* **2**: 68-71. www.scienceinschool.org/2006/issue2/brain

To learn about how a new tree of life – tracing the course of evolution – was established, see:

Hodge R (2006) A new tree of life. *Science in School* **2**: 17-19. www.scienceinschool.org/2006/issue2/tree

The Understanding Evolution website from the University of California, Berkeley (USA), provides authoritative, up-to-date information about evolutionary mechanisms, theory, evidence and modern research. The site includes numerous resources for teaching about evolution, including evo-devo (aimed at a US audience). See: Berkeley's evolution website (http://evolution.berkeley.edu) or use the direct link: http://tinyurl.com/yc27f4n

A great feature article on evo-devo from *The New York Times*:

Yoon CK (2007) From a Few Genes, Life's Myriad Shapes. *The New York Times* 26 June. See the New York Times website (www.nytimes.com) or use the direct link: http://tinyurl.com/34h675

Two popular science books about evo-devo research:

Shubin N (2008) *Your Inner Fish. A Journey into the 3.5 Billion-Year History of the Human Body.* London, UK: Allen Lane. ISBN: 9780713999358

Carroll SB (2005) *Endless Forms Most Beautiful: The New Science of Evo Devo and the Making of the Animal Kingdom.* New York, NY, USA: Norton. ISBN: 9780393060164

A comment on the importance of the publication of the amphioxus genome, including some more information about amphioxus, from *Nature*:

Gee H (2008) Evolutionary biology: The amphioxus unleashed. *Nature* **453**: 999-1000. doi: 10.1038/453999a. Download the article free of charge from the *Science in School* website (www.scienceinschool.org/repository/docs/issue14_nature_gee2008.pdf), or subscribe to *Nature* today: www.nature.com/subscribe

The amphioxus song: www.molecularevolution.org/mbl/resources/amphioxus

A video of a coelacanth: www.youtube.com/watch?v=NzzxOlFJtzg

Watch this incredible talk from paleontologist Paul Sereno. In just over 20 minutes he explains his research – digging for fossils in brand new territories – how his encounters with living crocodiles have revealed how huge ancient fossilised crocodiles would have looked, and how he hopes this kind of research will help to inspire future generations of scientists. See: www.ted.com/talks/view/id/428

Read more about natural selection and molecular evolution in:

Bryk J (2010) Natural selection at the molecular level. *Science in School* **14**: 58-62. www.scienceinschool.org/2010/issue14/evolution

For a review of a book on evolution that is suitable for beginners, see:

Haubold B (2010) Review of *Why Evolution is True. Science in School* **14**. www.scienceinschool.org/2010/issue14/evotrue

For a complete list of all biology-related articles that have been published in *Science in School*, see: www.scienceinschool.org/biology

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Lucy Patterson finished her PhD at the University of Nottingham, UK, in 2005, and has since been working as a postdoctoral researcher, first in Oxford, UK, then in Freiburg and Cologne, Germany. During this time she has worked on answering several different questions in developmental biology, the study of how organisms grow and develop from a fertilised egg into a mature adult, using zebrafish embryos. She has a broad interest and enthusiasm for science, and is currently developing her own embryonic career as a science communicator.

→ FEEDING OUR FUTURE

Nutrition on Earth and in Space

There are of course many technical challenges when planning missions to the International Space Station, Mars and beyond, but there is another important question: what should the astronauts have for dinner?

Order or download for free the new multilanguage ESA video 'Feeding our Future - Nutrition on Earth and in Space', and related exercises, for your students.

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Image courtesy of Dietmar Klement / iStockphoto

Starch: a structural mystery

A string of glucose molecules: starch. It sounds simple, but it isn't. **Dominique Cornuéjols** and **Serge Pérez** explore the intricacies of its structure – and show that the mystery is by no means solved.

Take a handful of spaghetti and throw it into boiling water. The stiff sticks will quickly become softer and gently curve while swelling. We take this behaviour of noodles in hot water for granted, but what exactly is happening to the fine structure of spaghetti to result in such a dramatic metamorphosis?

The beginning of the answer is that pasta – like rice, potatoes or bread – contains a large amount of starch. But what is starch? Produced in plants by the photosynthesis of carbon dioxide, starch granules are made out of glucose polymers and serve as energy stores. Towards the end of the growing season, starch accumulates in twigs of trees, close to the buds. It is also found in fruits, seeds, rhizomes and tubers. Starch granules are very suitable for such long-term storage, because of their compactness, relative dryness and high stability.

However, this essential source of energy only became accessible to humans once they had tamed fire, because raw starch granules are so compact that they are hardly digestible. In order to increase its digestibility, starch needs to be cooked: it is only once it has been heated that it becomes water-soluble and edible.

The transformation of raw starch in hot water is called gelatinisation: the granules swell and burst, forming a paste. During cooling or prolonged storage, the starch paste often thickens due to a phenomenon called retrogradation. Gelatinisation and retrogradation, which correspond to structural modifications in the granules, affect the behaviour of starch-containing systems.

Consequently, starch is excellent for modifying the texture of many processed and home-cooked foods (for example, as flour or corn flour to thicken sauces), and has also been used for centuries for other purposes, including the manufacture of paper (sizing), glues or fabric stiffener. Today, new applications of starch are emerging, including low-calorie dietary fibres, biodegradable packaging materials, thin films and thermoplastic materials.

Science: one small step at a time

Starch, therefore, is widely used in industry – and has been for thousands of years. The scientific study of starch started in 1833 when the French chemist Anselme Payen identified starch as being composed of glucose units. However, even today, its biochemistry and detailed structure are not yet well understood. At a molecular level, we know that *native* starch (as it occurs naturally) is made of two distinct components, amylose and amylopectin, which can be isolated by fractionation and studied independently.

Both components contain polymer chains of glucose units, but the chains are linked differently. Amylose is mainly linear (with glucose units linked by (1-4) bonds (Figure 1a), whereas amylopectin has a highly

REVIEW

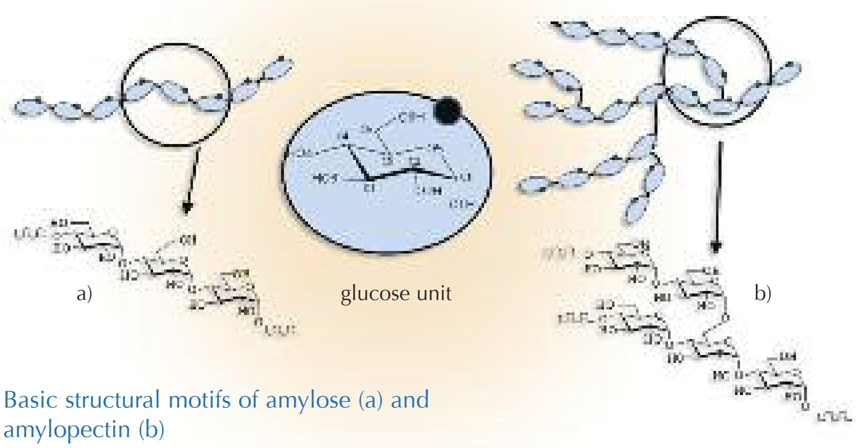
The ultra structure of starch is not often considered, but this article describes how the components of starch – amylose and amylopectin – form the complicated levels of structure within the polymer. The article could be used as extension work in a lesson on starch digestion or measurement. It could also be used as an example of the use of the technique of X-ray diffraction or polarising light microscopy. Posters could be made (or homework set) on the uses of starch in industry, with each group taking a different use. Methods for producing and / or assaying starch in industry could be investigated. Comprehension questions could be set; for example:

1. Starch is made up of 2 components that are:
   a) Amylase and amylopectin
   b) Amylose and amylopectin
   c) Glucose and amylase
   d) Glucose and amylose
2. Describe what gelatinisation is.
3. What are growth rings in starch?
4. What is the difference between amylose and amylase?
5. Convert the sizes of the different structural levels from 10^{-9} m into smaller units, e.g. micrometres or nanometres.
6. X-ray diffraction was used in the 1950s to determine the structure of a well known molecule. Which molecule?

Shelley Goodman, UK

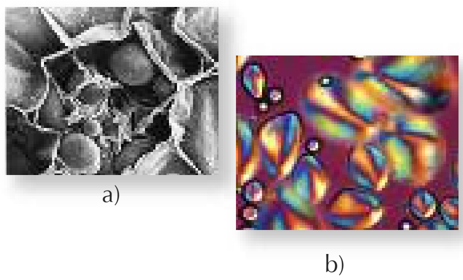
Figure 1

Image courtesy of Serge Pérez, ESRF



Basic structural motifs of amylose (a) and amylopectin (b)

Figure 2



Images courtesy of Serge Pérez, ESRF

a) Raw starch granule observed by scanning electron microscopy
b) The corresponding granule under polarised light

branched, very dense structure, due to (1-6) linkage (Figure 1b). Amylopectin can contain up to a hundred thousand glucose residues and is the largest known biomacromolecule.

Native starch granules vary enormously in shape and size (from 0.1 to 200 µm), but they all have a common characteristic: under the microscope and illuminated with polarised light, starch grains stained with iodine exhibit a distinctive 'Maltese cross' (shown in orange in Figure 2b), indicating the existence of some common internal ordering. When granules are heated in excess water (as when spaghetti is cooked), the polarisation cross begins to disappear, demonstrating that this molecular order is being disrupted.

The physical properties of starch – its stability and phase transformations, for example from starch granules to gels, or from brittle, raw pasta to soft, cooked pasta – are directly linked to this molecular order. However, understanding the detailed structure of starch requires very advanced research tools and techniques, such as X-ray crystallography, electron microscopy, nuclear magnetic resonance and computer modelling.

With the help of these tools, scientists are slowly beginning to build up a picture of how starch – something we are so familiar with – is constructed.

Starting from the nanoscale: double helices, lamellae and superhelices

X-ray diffraction investigations at the nanoscopic level indicate that:

- Starch is composed of thin lamellar domains (about 4.5 nm thick);
- Each lamella is made up of about 100 double-stranded helices, each consisting of about 20 glucose units (Figure 3);
- The double helices are very densely packed, with a high degree of regularity, like in a *crystal* (see glossary for italicised terms).

(For an explanation of how X-ray diffraction is used to analyse crystalline structures, see Cornuéjols, 2009.)

These X-ray results corroborate biochemical studies of the amylopectin molecule which show that this huge molecule is organised in *crystalline* clusters of double helices (Figure 4a): the lamellae revealed in the X-ray diffraction research consist of the clusters of double helices demonstrated in the biochemical studies. In this model, the branch points (the (1-6) links) in the amylopectin molecules are located in the less organised (or more *amorphous*) regions between the clusters. Amylose is entangled with amylopectin (Figure 4b), but so far nobody knows exactly how.

Additional X-ray studies, using the techniques of small-angle and wide-angle scattering (SAXS and WAXS) to analyse hydrated starch, show that the lamellae of double helices are probably organised in a helical superstructure, or superhelix (Figure 5). (For an explanation of SAXS, see Stanley, 2009.)

Down from the microscale: growth rings and blocklets

The lamellar and superhelix structures of amylopectin are only a small part of the whole picture, however. On a larger (microscopic) scale, it is known that starch granules are made up of alternating amorphous and *semi-crystalline* shells, between 100 and 800 nm thick. These structures are termed growth rings (Figure 6).

We know almost nothing about the amorphous parts of the growth rings. The more crystalline regions, however, can be studied by X-ray diffraction. Recently experiments using extremely focused X-ray beams at a synchrotron (see box on page 25) have demon-

BACKGROUND

Glossary

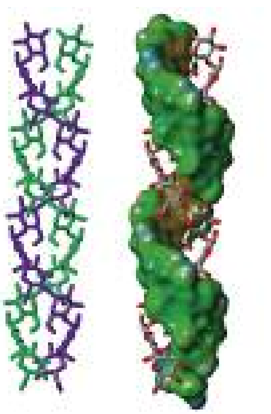
Amorphous: Describes a material (or part of material) that has no organisation and no order.

Crystal: A perfect crystal is a solid material whose constituent atoms, molecules or ions are arranged in an orderly repeating pattern extending in all three spatial dimensions.

Crystalline: Having the properties of a crystal; by extension, characterises parts of a material that are ordered (for example, a cluster of double helices all packed with the same orientation of the helix axis).

Semi-crystalline: Describes a material (typically a biopolymer) with both amorphous and crystalline parts.

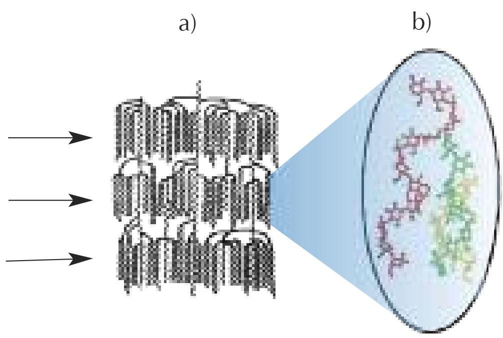
Figure 3



Images courtesy of Serge Pérez, ESRF

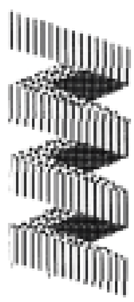
Double-helix structure in amylopectin

Figure 4



a) The cluster model of amylopectin showing three lamellae (marked with arrows)
b) Possible entanglement between an amylose chain (red) and amylopectin double helices (green and yellow)

Figure 5



Possible model of a superhelix structure strated that within the semi-crystalline regions, the nanoscopic lamellae are parallel to the surface of the starch granule (Figure 7, Chanzy et al., 2006). This enabled scientists to make the link between the small (microscale, e.g. the starch granules) and the very, very small (nanoscale, e.g. lamellae) – a link that is difficult to obtain in such structural investigations.

Another recent study, using atomic force microscopy to look at the starch granule's surface, showed the presence of blocklets within the growth rings. These blocklets are more or less spherical and have a size of 20–100 nm. So far, however, nothing more is known about these blocklets.

Taking all the studies together, we can be fairly sure about nanoscale structure (double helices forming lamellae) and the growth rings (alternating amorphous and semi-crystalline shells); however, the evidence for the intermediate structures (the superhelices and the blocklets) is less solid. Furthermore, it is still unclear how the superhelices, blocklets and growth rings relate to each other. Figure 8 on pages 26-27, summarises the different structural levels (glucose units, helices, lamellae, superhelices, blocklets and growth rings), from the molecular (10^{-9} m) to the microscopic (10^{-5} m) level.

As early as 1858, the Swiss botanist Carl von Nägeli had a brilliant intuition, stating that "The starch grain... opens the door to the establishment of a new discipline... the molecular mechanics of organised bodies." He would no doubt be astonished that, more than 150 years later, we are still struggling to understand the complex architecture of starch granules.

BACKGROUND

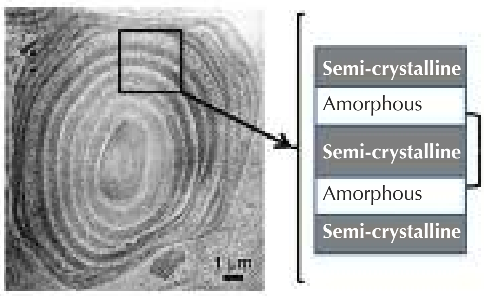
ESRF

The European Synchrotron Radiation Facility (ESRF) in Grenoble, France, is a good example of a large facility operating day and night for the benefit of thousands of users from all over the world. A 'user' is a scientist, usually part of a larger team, who occasionally needs a powerful tool to obtain information on a sample of interest (a polymer, a protein crystal, a fossil or a catalytic reaction, for instance).

ESRF produces extremely intense X-rays, called synchrotron radiation. These X-ray beams are emitted by high-energy electrons, which circulate in a large storage ring, 844 m in circumference. The X-ray beams are directed towards the beamlines, which surround the storage ring in the experimental hall. Each of the 42 beamlines at the ESRF is specialised in a specific technique or type of research. For around half a dozen of them, this speciality is polymers.

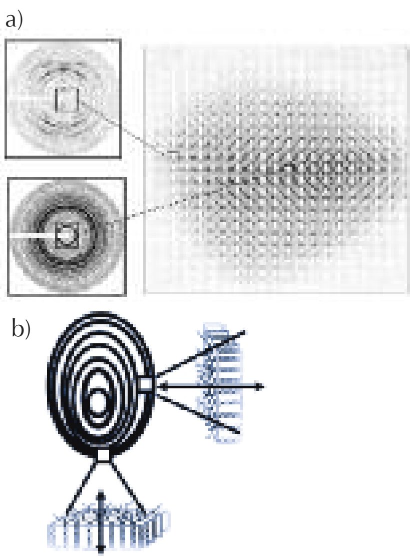
In the future, polymer research will benefit from the newly created Partnership for Soft-Condensed Matter (which includes polymers). The introduction of nanobeams (even more focused, nano-sized X-ray beams) will soon allow even finer structural analysis and yet more progress in the study of polymers, including starch.

Figure 6



Growth rings consisting of alternate layers of amorphous and semi-crystalline regions

Figure 7



a) A series of diffraction images taken at different places in the granule ('mapping' of the granule)

b) Orientation of the lamellae vis-à-vis the surface of the granule

Figure 8: The levels of starch organisation

a **Glucose unit**

b **Double helix**
Top: X-ray fibre diffraction pattern demonstrating a double-helix structure (courtesy of Imberty et al., 1988)
Bottom: model of the double-helix structure

c **Lamella**
Top: transmission electron microscopy image of hydrolysed starch, showing the shape of the crystalline lamellae (courtesy of Angellier-Coussy et al., 2009)
Bottom: model of a crystalline lamella made of about 100 double helices

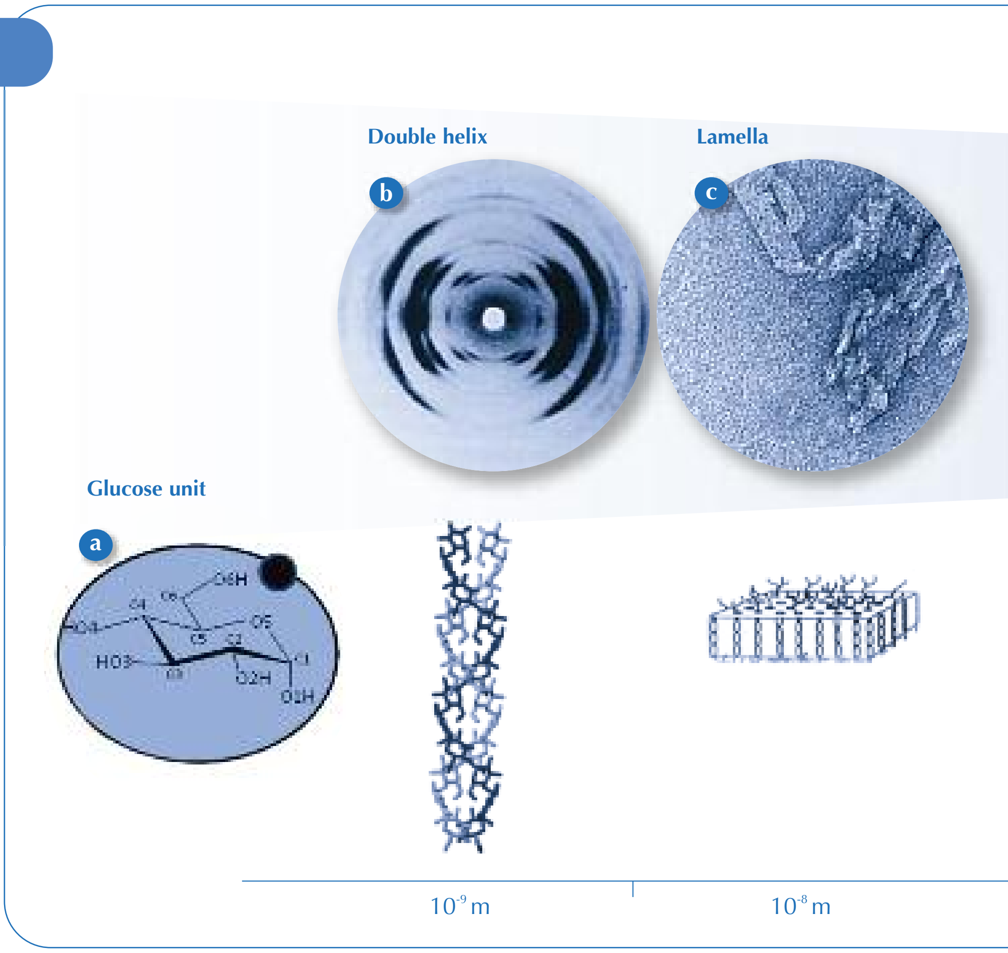
d **Superhelix**
Top: small-angle X-ray scattering (SAXS) and wide-angle X-ray scattering (WAXS) diffraction images indicating the presence of a superhelix structure (courtesy of Waigh et al., 2000)
Bottom: the superhelix model, with a pitch of 9 nm and a diameter of 18 nm

e **Blocklets**
Top: atomic force microscopy image of the typical surface of a starch granule (courtesy of Gallant et al., 1997). The bumps seen on the surface indicate the presence of blocklets
Bottom: blocklet model. The blocklets are believed to be smaller in the amorphous regions (central region) than in the semi-crystalline regions (above and below)

f **Growth rings**
Transmission electron microscopy image of an ultrathin section of hydrolysed starch granule, showing the growth rings as alternate layers of amorphous and semi-crystalline regions (courtesy of I. Paintrand, CERMAV, Grenoble, France)

g **Granule**
Top: starch granule observed by scanning electron microscopy (large image) and the corresponding granule under polarised light (inset)
Middle: set of microfocus X-ray diffraction patterns recorded on a starch granule showing the distribution and orientation of the crystalline domains in a starch granule. Each diffraction pattern corresponds to an area of about 3 μm^2 of the specimen and steps of 7 µm separate two patterns (courtesy of Buléon et al., 2009)
Bottom: starch granule section showing the radial orientation of the crystalline domains (lamellae) in a starch granule

Image courtesy of Serge Pérez, ESRF



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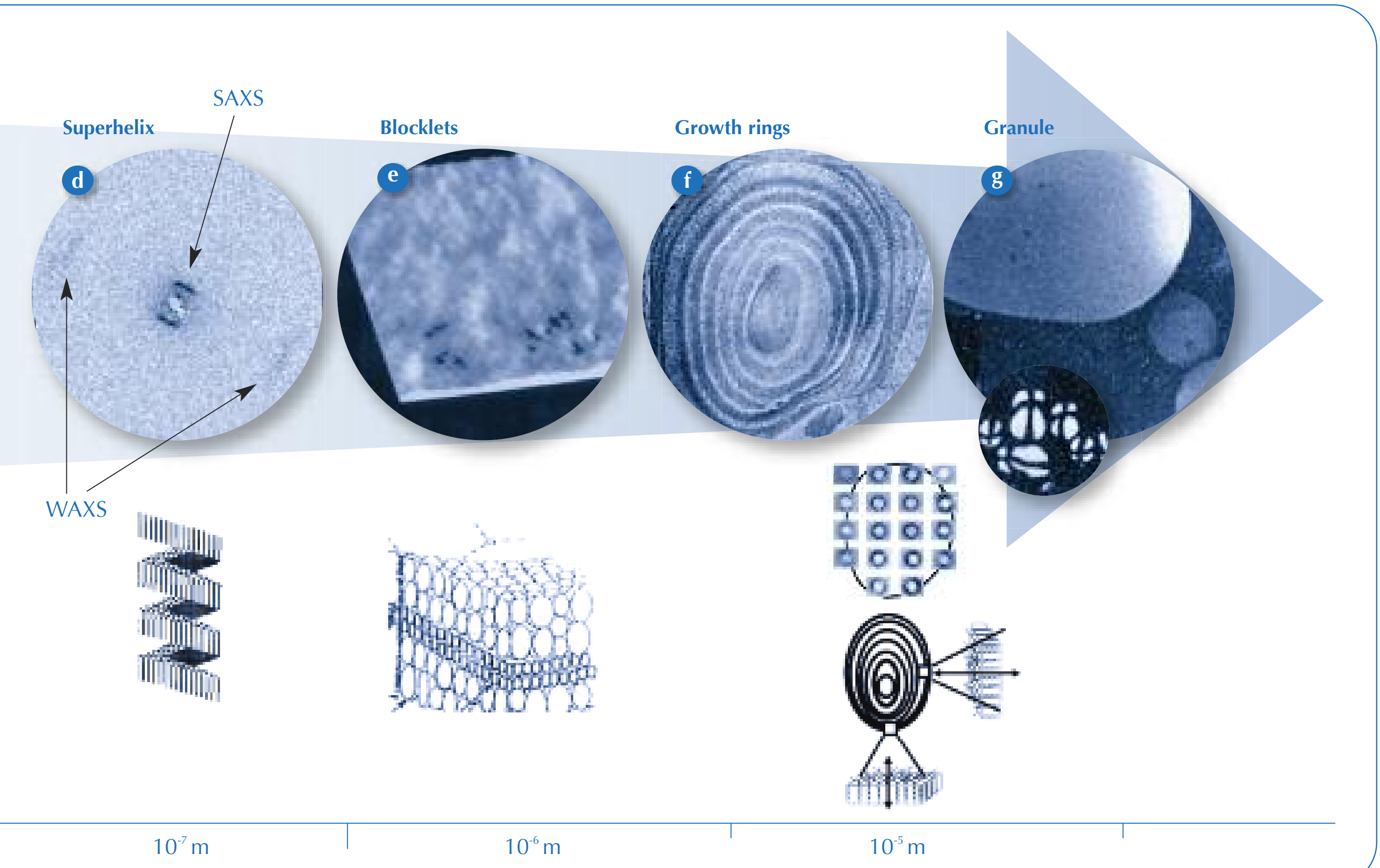

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Resources

For an extensive review of starch, see ESRF scientists' Serge Pérez and Anne Imberty's 'Starch: structure and morphology' website: www.cermav.cnrs.fr/glyco3d/lessons/starch

Imberty A, Pérez S (1988) A revisit to the three-dimensional structure of B-type starch. *Biopolymers* **27**: 1205-1221. doi: 10.1002/bip.360270803

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Dominique Cornuéjols, a physicist by training, has worked at the ESRF since 1993 as the communication manager. She is particularly involved in the ESRF's outreach and education programmes.

After receiving his doctorate in crystallography from the Université de Bordeaux, France, Serge Pérez spent years doing research in America, Canada and France. He took up his first directorate position at the Centre de Recherches AgroAlimentaires in Canada in 1987. As director of research at the French National Center for Scientific Research (*Centre National de la Recherche Scientifique*, CNRS) he moved to Grenoble in the 1990s, and 12 years later moved to ESRF as the research director. Since 2003, he has also been the co-director and then director of the Doctoral School of Chemistry and Life Sciences at the Université Joseph Fourier, in Grenoble.

Biodiversity: a look back at 2009

Image courtesy of proxyminder / iStockphoto

Image courtesy of Chad Nelson

In celebration of the International Year of Biodiversity 2010, **Matt Kaplan** takes us on a whirlwind tour through the previous year's most inspiring discoveries of biodiversity.

The boundless variety of life on Earth never ceases to amaze. In spite of the fact that the world is smothered in humans, new details continue to arise that reveal life to be ever more diverse. Sometimes these new details reveal the presence of new species; sometimes they are behaviours or chemistries that indicate existing ecological relationships are more complex than anyone realised.

With regard to species discoveries, the past year has been no different from others in recent decades, and new species have turned up as a result of intensive exploration all around the globe. Some of the work has been rather old-fashioned, with researchers literally turning over rocks in the jungle. Other projects have taken on a decidedly more modern twist, with research teams using genetics to work out that what we thought was a single species is, in fact, two species.

Perhaps the most intriguing species find reported in the past year has been a bunch of worms that a team led by Robert Vrijenhoek at the Monterey Bay Aquarium discovered off the coast of California, USA.

Five years ago, the team found worms hanging around the bones of whales and other large mammals on the ocean floor. They realised that these worms were rooting themselves in, and absorbing nutrients from, the whale bones. They were, bizarrely, animals that had become specialists at feeding on bones on the ocean floor.

Image courtesy of L. Shyamal; image source: Wikimedia Commons

Microhyla ornata frog from Savandurga, India. These frogs are also found in elephant dung

At first glance, Vrijenhoek and his team assumed that the worms on the bones were just one or two species all doing roughly the same thing, yet that number quickly expanded to five species in the years following the worm's discovery, and in 2009, the number jumped to seventeen. This led the team to theorise that there might be more than one way for a worm to feed on a bone.

None of the worms have mouths or anuses. Instead, they all have a bulbous root system that they embed in the bones, and a variety of different feathery structures that the researchers think are being used for respiration (see image on page 30).

Exactly how the worms draw out nutrients from bones is still something of a mystery, but the large number of new worms found in 2009 have so many different forms and body structures that the researchers are beginning to suggest that the ocean floor has an entire ecosystem of bone feeders of different sizes and shapes which likely have different tactics for feeding on bones.

A species that is making this point most clearly is one of the newly discovered worms which, at first glance, seems to embed itself in sediment rather than bone. Yet as the research team went to look closer, they found that these worms, although anchoring in sediment, had very long root systems that ran out to buried bone fragments. They were effectively functioning as buried bone-shard feeding specialists, making them quite different from the other bone-feeding worms which have all been found directly embedding themselves in bones. The team expects that as they further study the new worms, even more diversity will be uncovered.

Further exploration of the worms and their behaviours is definitely needed, but for the moment, it looks as if there is an entire world of bone feeders in the ocean depths.

Discovering new species is not all there is to biodiversity. Discovering new ways in which already known species interact is equally important, and from this perspective, 2009 was one of the more fascinating years, as research has revealed that the presence or absence of elephant faeces plays an important role in biodiversity.

In Sri Lanka, Asian elephants are continually being pushed out of forests and isolated from regions where they are seen as troublemakers. To be fair, there is a lot of truth to this: the elephants readily destroy trees if left in an area for long enough. However, Ahimsa Campos-Arceiz at the University of Tokyo, Japan, revealed last year that the elephants appear to be giving back to their

Image courtesy of Smithore / iStockphoto

Image courtesy of proxyminder / iStockphoto

REVIEW

- **Biology**
- **Ecology**

This article is very pleasant to read and will probably give a whole new meaning to the term 'biodiversity' to most readers. The scope is to show that biodiversity is by far richer than we can possibly imagine; to prove this, the author provides examples that will surprise and even amuse the reader.

The article could be useful in the study of ecology and specifically in the examination of the behaviour of and the relationships between different species of organisms, as it suggests 'unconventional' ways in which organisms interact with each other and with the environment.

The article could be used to discuss biodiversity and particularly the various forms it can take. Comprehension questions could include:

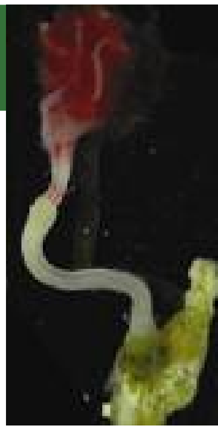
1. Biodiversity is a complex term. Explain three forms that biodiversity can take, giving one example for each.
2. In the article, there is a claim that elephant dung could become a small ecosystem. Do you agree or disagree with this claim? Explain the reasons for your decision.
3. Describe a specific behaviour adopted by certain species of seaweed that helps them defend against pathogens when they are damaged.

Michalis Hadjimarcou, Cyprus

Image courtesy of Nick; image source: Wikimedia Commons

Elephant dung with dung beetles

Image courtesy of Robert C. Vrijenhoek, Shannon B. Johnson & Greg W. Rouse; image source: Wikimedia Commons



Osedax rubiplumus from whale

Image courtesy of proxyminder / iStockphoto

environment in a small but important way: their piles of faeces provide housing to numerous species, including three species of frogs.

The dung of many large mammals has long been known to be a fertile place for plants and fungi to grow, but seeing the dung itself used as a dwelling by amphibians... well, that's rather new.

Aside from frogs, Campos-Arceiz reports in the journal *Biotropica* that he discovered beetles, termites, ants, spiders, scorpions, centipedes and crickets in many of the elephant dung piles, suggesting that an elephant dung pile can become a small ecosystem on its own. In contrast, when he examined large piles of dung from other animals, such as cows, similar levels of diversity were not found.

Campos-Arceiz proposes that the amphibians and insects might just be following the trails of dung and moving with elephant populations, suggesting that elephants literally bring their own biodiversity wherever they go.

Just as new social interactions are constantly turning up amongst well-known species such as elephants and frogs, so too are new chemical interactions. By far the most interesting interaction identified in 2009 is that of seaweeds strategically mounting antimicrobial defences on their surfaces, in locations where they need extra protection against pathogens.

In the past decade, it has come to light that seaweed species have a host of antimicrobial chemical compounds inside them. These findings have led to considerable interest in seaweeds as potential sources to be bioprospected for the development of antibiotics.

While further exploring the seaweed family and their chemical compounds, a team of researchers led by Julia Kubanek at the Georgia Institute of Technology in Atlanta, USA, discovered that the antimicrobial chemi-

Image courtesy of tswinner / iStockphoto

Image courtesy of amwu / iStockphoto

cals were not distributed throughout the seaweeds evenly. Instead, they were spread out in patches along the seaweed surface. These patches were also covered with sediment and particles that had been floating about in the water.

Kubanek and her colleagues reported in *The Proceedings of the National Academy of Sciences USA* last year that they believe the seaweed is creating its own version of a scab. As the seaweed gets cut, attacked or abraded, they believe it oozes sticky carbohydrates rich in antimicrobial chemicals from inside. These chemicals then prevent the seaweed from becoming infected and the sticky ooze collects floating particles from the water to cover up the injured area. This sort of behaviour has never been seen before in seaweed, but the authors suggests that it may be similar in function to the resin that pine trees ooze when cut.

Practically, the find is important for developing pharmaceuticals that can help wounds heal, but from a grander ecological perspective it is no more or less important than the discovery of new bone-feeding worms or of the use of elephant faeces as accommodation. Indeed, just when it seems as if the world's biodiversity could not possibly become any richer, researchers prove that it can.

Acknowledgements

The author would like to thank Drs Vrijenhoek, Campos-Arceiz and Kubanek for taking the time to proofread this work and for providing valuable feedback.

Image courtesy of bedo / iStockphoto

Image courtesy of adi7 / iStockphoto

Resources

To read more about the discoveries described in this article, read the published research:

Campos-Arceiz A (2009) Shit happens (to be useful)! Use of elephant dung as habitat by amphibians. *Biotropica* **41**: 406-407. doi: 10.1111/j.1744-7429.2009.00525.x

Lane AL et al. (2009) Desorption electrospray ionization mass spectrometry reveals surface-mediated antifungal chemical defense of a tropical seaweed. *Proceedings of the National Academy of Sciences* **106**: 7314-7319. doi: 10.1073/pnas.0812020106

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BMC Biology is an open-access journal, thus all articles are freely available online.

For more information on the International Year of Biodiversity, see: www.cbd.int

The website includes a manual for educators, *Biodiversity is Life*: www.cbd.int/iyb/doc/partners/iyb-waza-manual-en.pdf

If you enjoyed this article, you might like to browse all science topics previously published in *Science in School*. See: www.scienceinschool.org/sciencetopics

Matt Kaplan is a professional science journalist, based in both London and Los Angeles, who regularly reports on everything from palaeontology and parasites to virology and viticulture. When not stuck behind a desk, he runs wilderness expeditions in far-flung regions of the world. See: www.scholarscribe.com

For this *Science in School* article, Matt waived his usual writing fee.

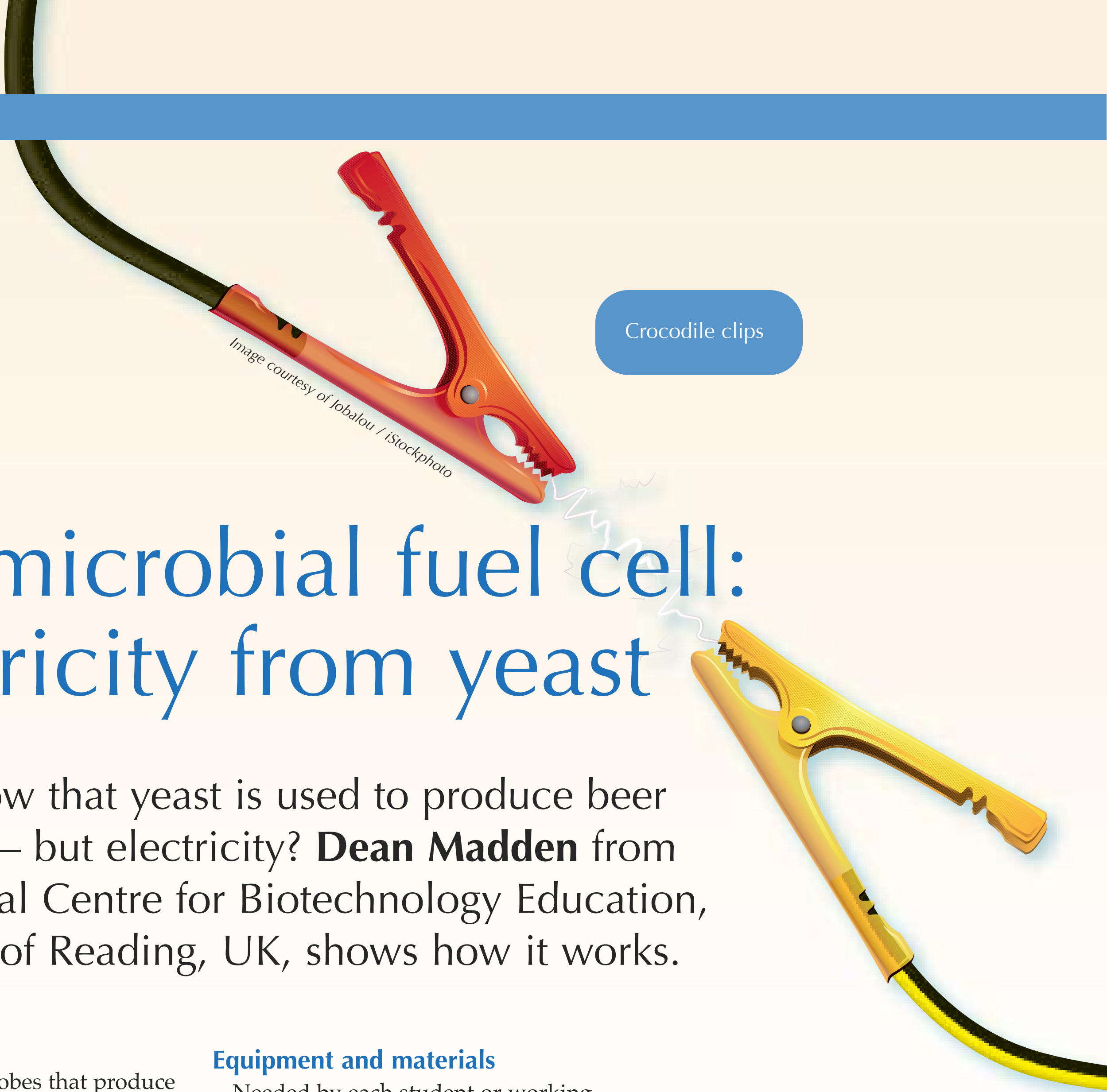


Image courtesy of Jobalou / iStockphoto

The microbial fuel cell: electricity from yeast

We all know that yeast is used to produce beer and bread – but electricity? **Dean Madden** from the National Centre for Biotechnology Education, University of Reading, UK, shows how it works.

Introduction

For decades, microbes that produce electricity were a biological curiosity. Now, however, researchers foresee a use for them in watches and cameras, as power sources and for bioreactors to generate electricity from organic waste. The microbial fuel cell described here generates an electrical current by diverting electrons from the electron transport chain of yeast. It uses a 'mediator' (in this case, methylene blue) to pick up the electrons and transfer them to an external circuit. This process is not very efficient, and this demonstration fuel cell will generate only a very small current. In the classroom, this can provide a stimulating introduction to the study of respiration and permit the study of some of the factors that influence microbial respiration. More recently, mediator-less fuel cells of greater efficiency have been developed, in which the micro-organisms donate electrons directly to the fuel-cell electrodes.

Equipment and materials

Needed by each student or working group

Equipment

- Perspex fuel cell, cut from 4 mm thick Perspex sheet
- 2 neoprene gaskets
- Cation exchange membrane, cut to fit between the chambers of the fuel cell. The membrane may be re-used indefinitely, but will melt if it is autoclaved.
- 2 x 10 ml plastic syringes, for dispensing liquids
- Petri dish base or lid, on which to stand the fuel cell
- 2 electrical leads with crocodile clips
- 0–5 V voltmeter or multimeter and / or low-current motor
- Scissors.

Materials

- 2 carbon-fibre tissue electrodes, cut to fit inside the fuel cell
- 2 pieces of J-Cloth® or similar fabric, cut to fit inside the fuel cell (the purpose of this cloth is simply to prevent the electrodes from touching the cation exchange membrane and short-circuiting the cell)

Important: All of the solutions listed below must be made up in 0.1 M phosphate buffer, pH 7.0, *not* in water.

- Dried yeast, made into a thick slurry in 0.1 M phosphate buffer (do not add glucose solution without first rehydrating the yeast in buffer)
- 5 ml methylene blue solution (10 mM)
- 5 ml glucose solution (1 M)
- 10 ml potassium hexacyanoferrate (III) solution (0.02 M) (also called potassium ferricyanide).

Procedure

1. Cut out two carbon-fibre electrodes as shown in on page 34.

Microbiology
Physics
Energy

REVIEW

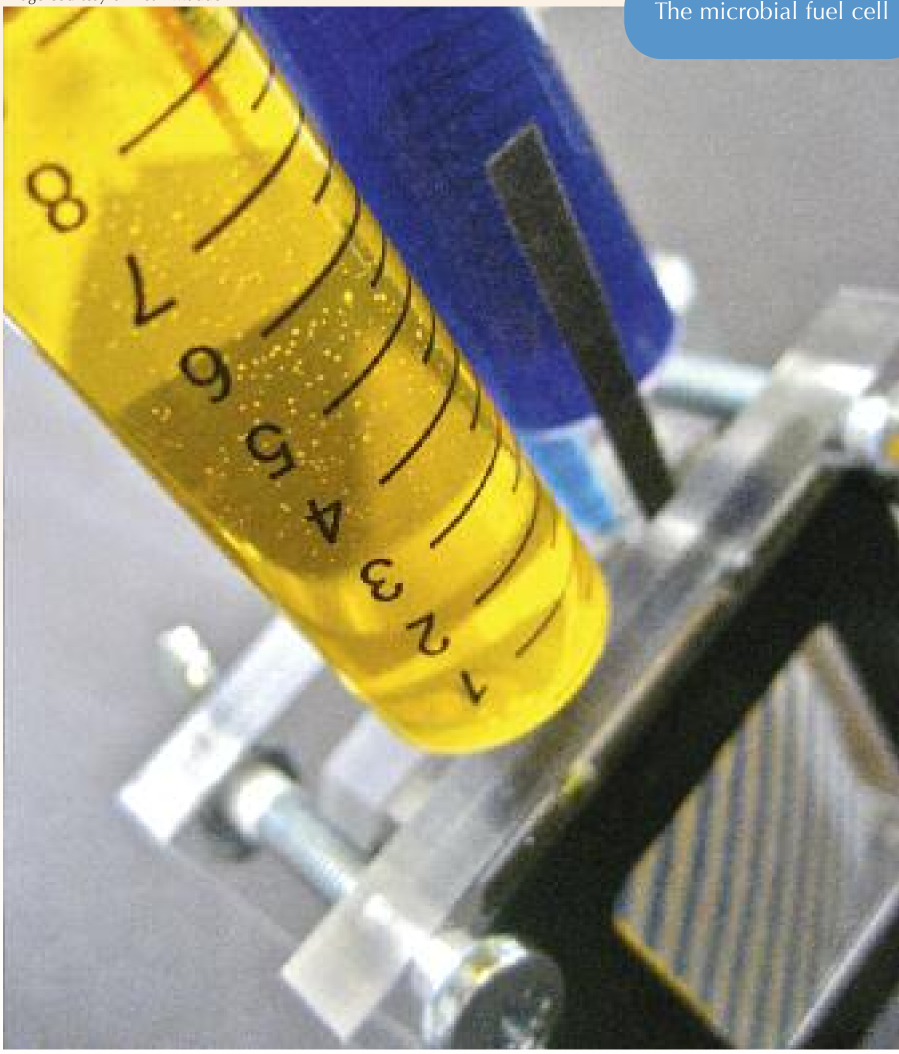
This article describes a laboratory practical for demonstrating the electron transport chain. The practical is highly relevant for biology lessons on microbial respiration. It seems obvious to use this practical as an extension of fermentation exercises.

The practical can be used interdisciplinarily at the interface of biotechnology and physics, demonstrating the use of micro-organisms for energy production. It could also be related to the production of bioethanol, as an example of an alternative biotechnological way of producing energy.

Niels Bonderup Dohn, Denmark

The microbial fuel cell

Image courtesy of Dean Madden



2. Cut out two pieces of J-Cloth to fit inside the fuel cell.
3. Assemble the fuel cell as shown on page 35.
4. Stand the assembled fuel cell on a Petri dish base or lid, to catch any liquid that may leak from the cell.
5. Combine equal (5 ml) volumes of the yeast slurry, glucose and methylene blue solutions. Syringe this mixture into one chamber of the fuel cell.
6. Syringe potassium hexacyanoferrate (III) solution into the other chamber of the cell.
7. Connect a voltmeter or multimeter (via the crocodile clips) to the electrode terminals. A current should be produced immediately – if the meter registers zero, check the connections and ensure that the carbon-fibre electrodes are not touching the cation exchange membrane.

Typical results

Microbial fuel cells of this type typically generate 0.4–0.6 V and 3–50 mA. If the cell is topped up with solutions as necessary, it will continue to generate electricity for several days.

Safety

Potassium hexacyanoferrate (III) is poisonous. Eye protection should be worn when handling this material. If the solution comes into contact with the eyes, flood them with water and seek medical attention. If swallowed, give plenty of water to drink and seek medical attention. If spilled on the skin, the solution should be washed off promptly with water. Local regulations should be observed when disposing of used solution.

Recipes

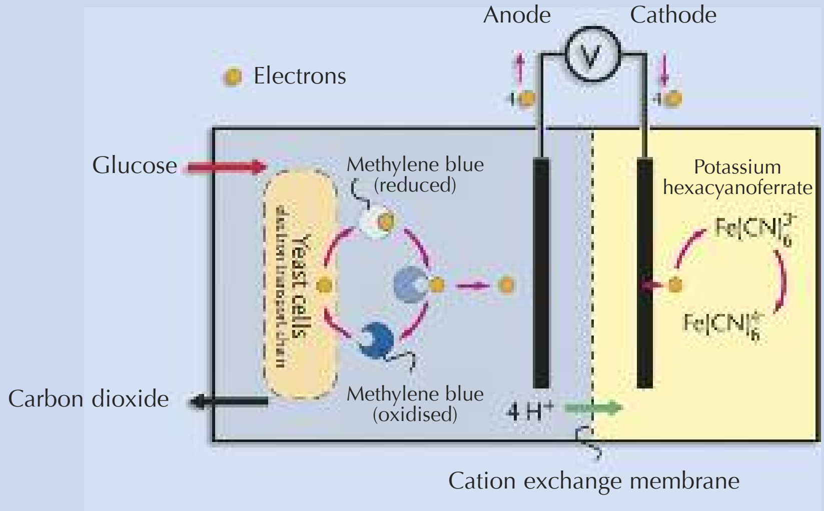
To make 0.1 M phosphate buffer, pH 7.0, dissolve 4.08 g Na_2HPO_4 and 3.29 g NaH_2PO_4 in 500 ml distilled water.

Preparation and timing

Solutions of the reagents may be prepared in advance. Note, however, that the glucose solution should be prepared no sooner than 24 hours before the work is to be carried out, as the solution is not sterile and would therefore support the growth of contaminating micro-organisms.

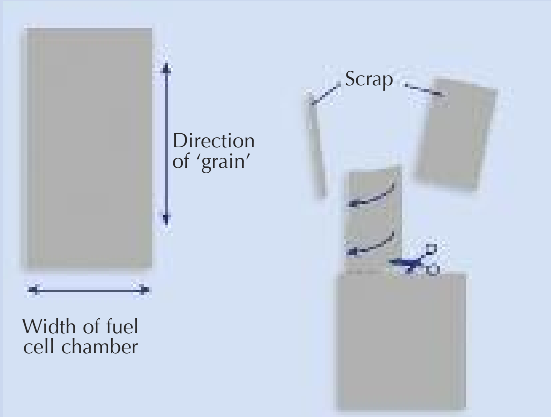
Pre-soak the cation exchange mem-

Images courtesy of Dean Madden



How the microbial fuel cell works
In one chamber of the cell, yeast cells are fed on glucose solution. A mediator, methylene blue, enters the yeast cells and takes electrons from the yeast's electron transport chain. The electrons are then passed to an electrode (anode). The electrons pass through the external circuit and are accepted by potassium hexacyanoferrate (III) in the second chamber of the cell. Hydrogen ions pass through a cation exchange membrane which separates the two chambers.
Microbial fuel cells of this type typically generate 0.4-0.6 V and 3-50 mA. This is sufficient to power a very low-current motor. If several such cells are joined in series, it is possible to light a light-emitting diode (LED)

The carbon fibre used to make the electrodes has a 'grain'. To ensure that the long 'tail' of the electrode does not tear and that it fits easily through the hole in the fuel cell, it is necessary to cut and fold the electrode as shown here



Cut about half-way through the upper piece as shown, then fold it in half, then half again to form a 'tail' on the electrode

brane in distilled water for 24 h before use.

Dried yeast can be rehydrated as the fuel cell is assembled, although it is important to add the dried yeast to buffer solution first, then to add glucose solution to the yeast slurry. If you try to rehydrate the yeast directly in glucose solution, osmotic effects will delay the process. (If using fresh yeast, simply make a thick slurry of that with the buffer solution before adding the glucose solution.)

It takes about 30 min from the assembly of the fuel cell to the generation of electricity.

Scope for open-ended investigations

Several fuel cells may be joined together in series to give a greater voltage; the current produced will remain the same, however. Conversely, increasing the size of the cell (or the electrode area) will increase the current generated, but not the voltage.

Different mediators and/or types of yeast, such as wine-makers' or bakers' yeast, may be used. Note that for safety reasons, the use of this fuel cell with other micro-organisms is not recommended.

Investigate the effect of temperature on the action of the fuel cell (remember to consider what 'controls' are necessary when making comparisons of this type).

Suppliers

Microbial fuel cells suitable for school investigations as described here are available from the National Centre for Biotechnology Education (NCBE) at the University of Reading, UK[w1].

For those who prefer to build their own fuel cells, following the instructions in this article, the cation exchange membrane and carbon-fibre tissue electrodes are also available from the NCBE. The cation exchange membrane can also be purchased from VWR[w2].

Low-current motors suitable for use with a fuel cell such as the one described here are expensive and difficult to find.

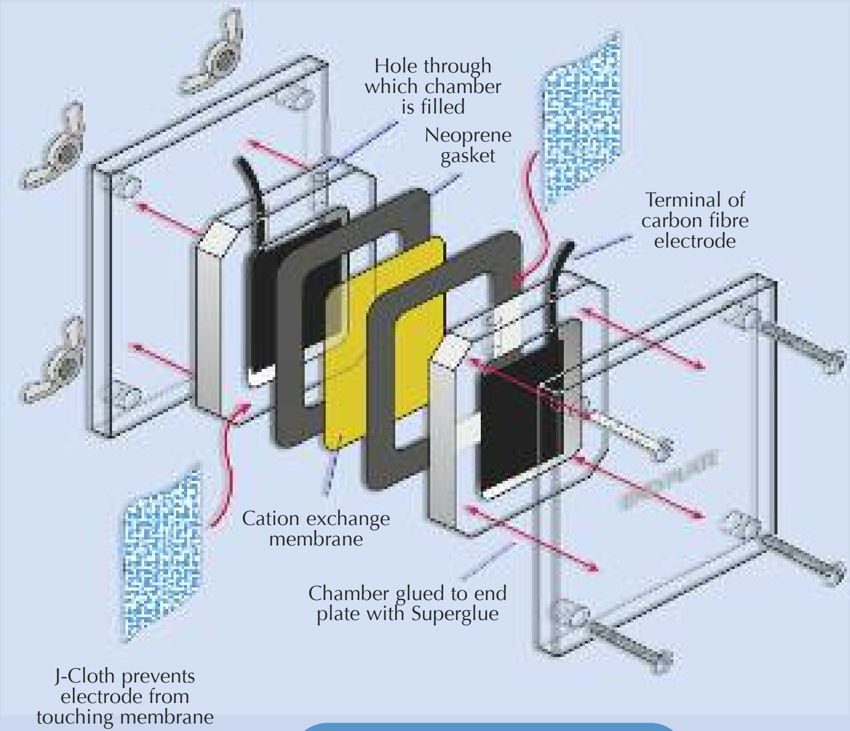
Disposal of waste and recycling of materials

Potassium hexacyanoferrate (III) solution is poisonous. Local regulations should be observed when disposing of used solution.

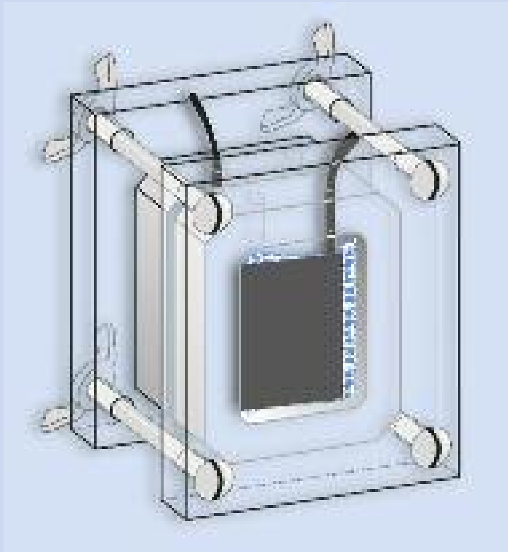
Storage of materials

The potassium hexacyanoferrate (III) solution is light-sensitive and should therefore be stored in a light-proof bottle or in a bottle wrapped in aluminium foil. It should not be kept for more than six months.

Images courtesy of Dean Madden



How to assemble a microbial fuel cell (the exact dimensions are unimportant – the one shown here is roughly 55 mm x 55 mm)



The finished microbial fuel cell

You may wish to store the cation exchange membrane in a bottle of distilled water so that it is ready to use. The water should be replaced from time to time if the membrane is stored for an extended period.

Dried yeast, even in a sealed container, has a limited shelf life. The supplier's 'best before' date should therefore be observed.

Acknowledgements

The microbial fuel cell was developed by Dr Peter Bennetto, formerly of the Department of Chemistry, King's College, London, UK. It has been adapted for school use by John Schollar and Dean Madden.

Web references

w1 – To learn more about the National Centre for Biotechnology Education (NCBE) and to order their fuel cells, see: www.ncbe.reading.ac.uk

w2 – To contact VWR, the supplier of the cation exchange membrane, see: www.vwr.com

Resources

Bennetto P (1987) Microbes come to power. *New Scientist* **114**: 36–40

Bennetto HP (1990) Electricity generation by micro-organisms. *BIO/technology Education* **1**: 163–168. This article can be downloaded from the NCBE website: www.ncbe.reading.ac.uk or here: http://tinyurl.com/ncf6ql

Lovley DR (2006) Bug juice: harvesting electricity with micro-organisms. *Nature Reviews Microbiology* **4**: 497–508. doi:10.1038/nrmicro1442

Sell D (2001) Bioelectrochemical fuel cells. In: *Biotechnology. Volume 10: Special Processes* (Second edition). Rehm H-J and Reed G (Eds). Frankfurt am Main, Germany: Wiley-VCH. ISBN: 9783527620937

For a complete list of all teaching activities published in *Science in School*, see: www.scienceinschool.org/teaching

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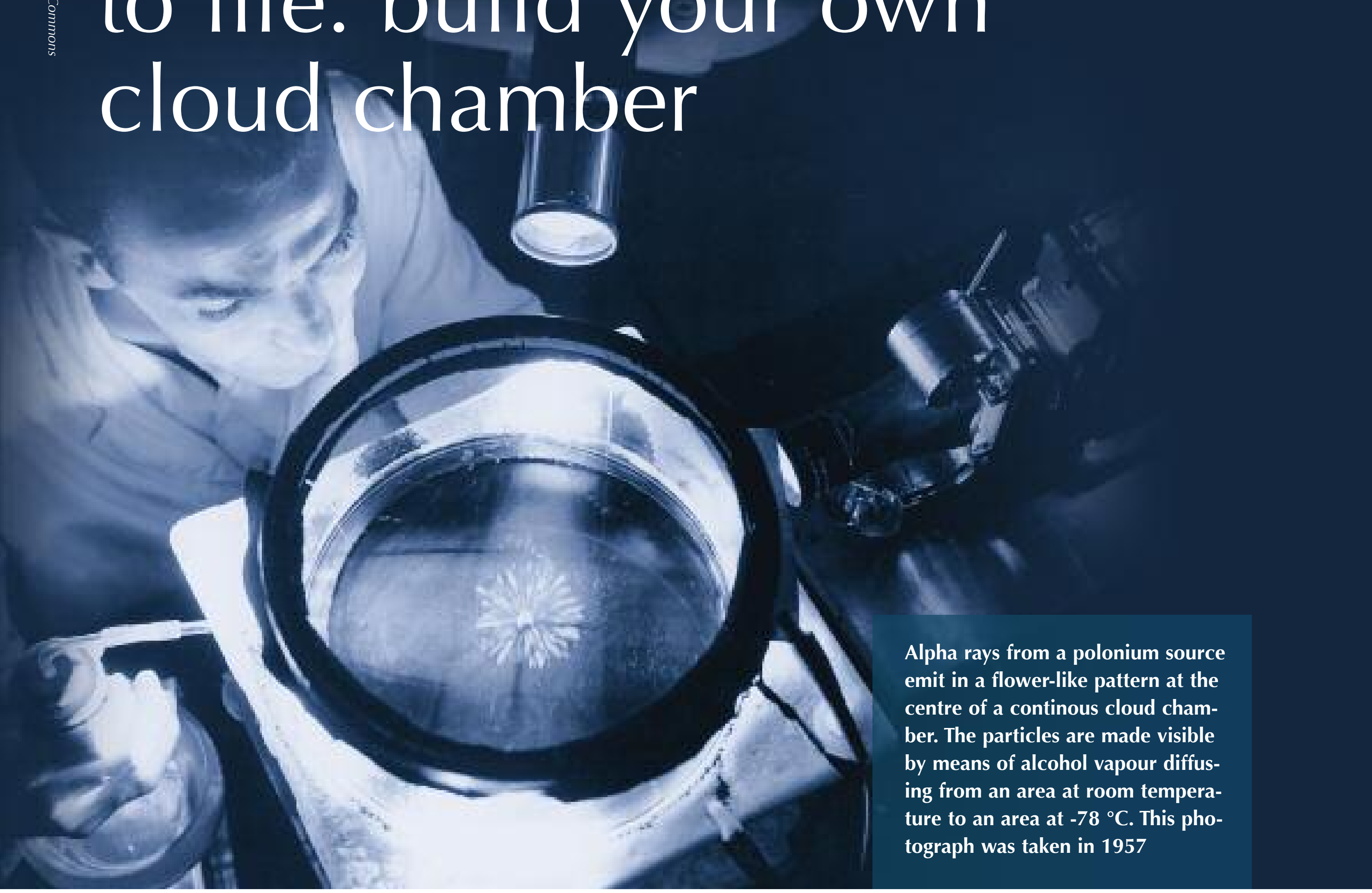
Dr Dean Madden is a biologist working for the National Centre for Biotechnology Education (NCBE)[w1] at the University of Reading, UK. The NCBE was established in 1984 and has since gained an international reputation for the development of innovative educational resources. Its materials have been translated into many languages including German, Swedish, French, Dutch and Danish.

Bringing particle physics to life: build your own cloud chamber

Public domain image; image source: Wikimedia Commons



Alpha rays from a polonium source emit in a flower-like pattern at the centre of a continous cloud chamber. The particles are made visible by means of alcohol vapour diffusing from an area at room temperature to an area at -78 °C. This photograph was taken in 1957

Particle physics is often seen as something only for huge research institutes, out of reach of the general public. **Francisco Barradas-Solas** and **Paloma Alameda-Meléndez** demonstrate how – with the aid of a homemade particle detector – you can dispel this myth by bringing particle physics to life in the classroom.

The objective of elementary particle physics is to find the basic building blocks of which everything is made and to investigate the behaviour of these building blocks. Although it can be seen as a cornerstone of science, particle physics is often neglected or poorly understood in schools, partly because it is perceived as unrelated to the things with which we interact on a daily basis. However, particle physicists detect and measure electrons, photons or muons every day with the same confidence with which all of us 'detect' cows, tables or aeroplanes. Furthermore, particle detectors (e.g. PET scanners) are routinely used, for example, by medical physicists to detect tumours and monitor the function of internal organs.

Here we demonstrate how to bring particle physics to life in the classroom, using possibly the simplest type of particle detector: a continuously sensitive diffusion cloud chamber. This homemade version consists simply of an airtight fish tank full of air and alcohol vapour, cooled to a very low temperature, which can be used to detect charged particles, particularly cosmic ray muons, if they have enough energy.

Elementary particles

Elementary particles are the simplest elements from which *everything* is made. They are not just the building blocks of matter and radiation, but also give rise to the interactions between them (for more details of elementary particles, see Landua & Rau, 2008). These particles carry energy and momentum, and can thus be seen by detectors. Strictly speaking, you cannot directly see any particles – instead, their passage through detectors is inferred from the effects they cause, such as ionisation (for charged particles). That is precisely what we do when we observe the condensation trail left in the sky by an aeroplane that we cannot see – and what we can do with our homemade cloud chamber.

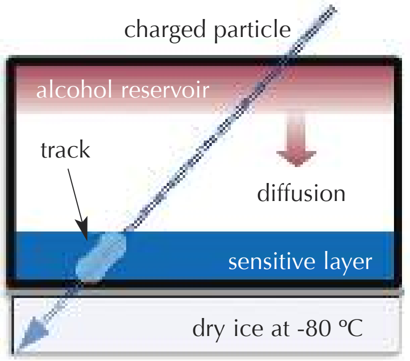
The continuously sensitive diffusion cloud chamber

This cloud chamber is basically an airtight container filled with a mixed atmosphere of air and alcohol vapour. Liquid alcohol evaporates from a reservoir and diffuses through the air from the top to the bottom of the chamber. Cooling the base with dry ice (solid carbon dioxide, which is at a constant temperature of around -79 °C while it sublimates) results in a strong vertical temperature gradient, so that a zone with supersaturated alcohol vapour forms close to the bottom. This *sensitive layer* is unstable, with more very cold alcohol vapour than it can hold. The process of condensation of vapour into liquid can be triggered by the passage of a charged particle with enough energy to ionise atoms in its path. These ions are the condensation nuclei around which liquid droplets form to make a trail.

Assembly and operation

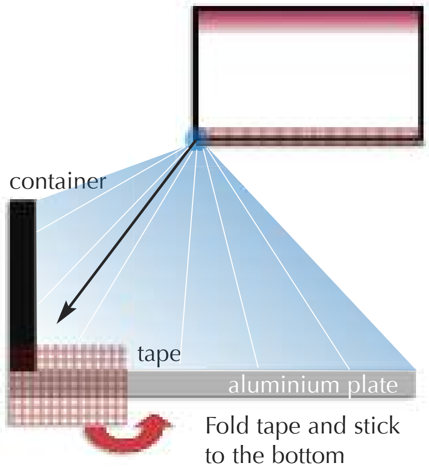
Materials

- Straight-sided, clear plastic or glass container (e.g. a fish tank) with a base about 30 cm x 20 cm, and a height around 20 cm (other sizes can be used, but the effects may vary)
- Aluminium sheet (about 1 mm thick, same thickness as the base of the fish tank)
- Shallow tray somewhat larger than the base area of the fish tank
- Two lamps, one of them strong
- Strip of felt (about 3 cm wide and long enough to wrap around the inside of the fish tank, e.g. somewhat more than 1 m long)
- Glue (not alcohol-soluble)
- Black insulating tape or duct tape
- Isopropyl alcohol (isopropanol)
- Dry ice



Outline of a continuously sensitive diffusion cloud chamber

Images courtesy of Francisco Barradas Solas



Cross-section of the cloud chamber

REVIEW

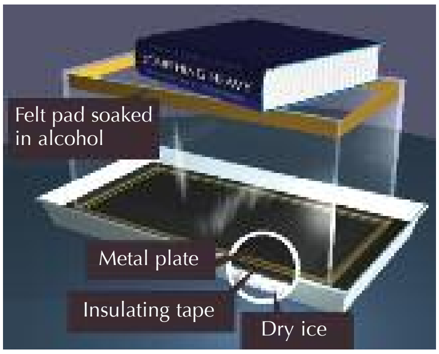
Particle Physics

Cosmic rays consist of subatomic particles that come from space and strike Earth's atmosphere, creating a shower of secondary particles that can be studied at the Earth's surface. Students in secondary education can usually only read about those particles in books or study them through simulations – although the particles constantly pass through our bodies.

Here, Francisco Barradas-Solas and Paloma Alameda-Meléndez present the idea that cloud chambers can be used by students as an experimental tool, enabling them to conduct their own investigations on radiation. They also provide details about the construction of a cloud chamber, equipment that can be built at school without too much difficulty, which enables students to observe these subatomic particles in the classroom by making their tracks visible.

Vangelis Koltsakis, Greece

Image prepared by Alberto Izquierdo; courtesy of Francisco Barradas Solas

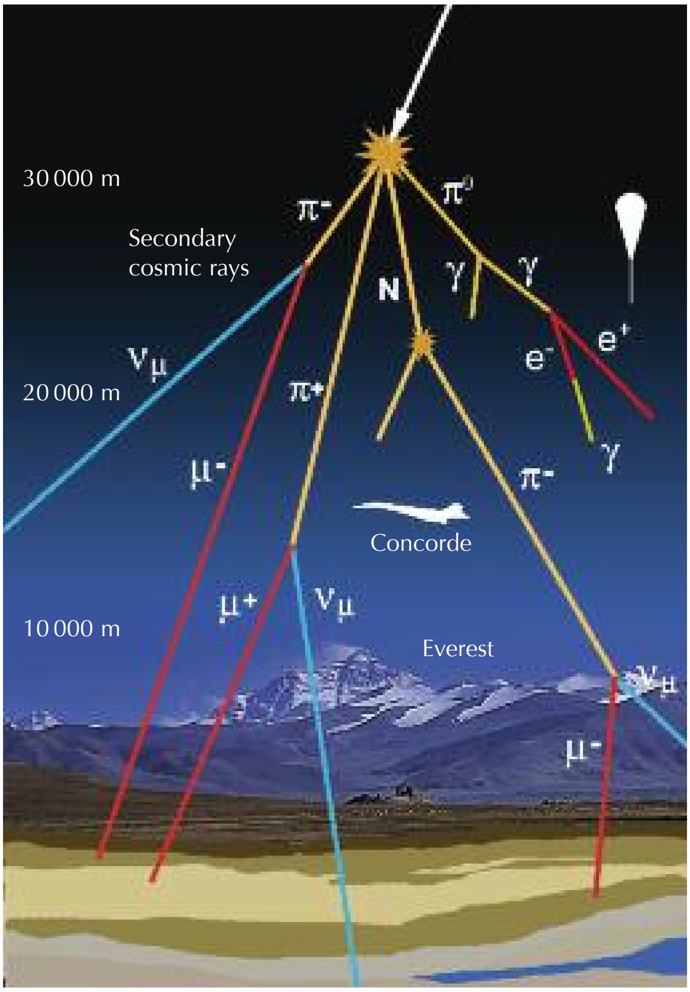


The chamber

Image courtesy of Bionerd; image source: Wikimedia Commons

Tracks of ionising radiation in a cloud chamber (thick and short: alpha particles; long and thin: beta particles)

Image prepared by Alberto Izquierdo; courtesy of Francisco Barradas Solas

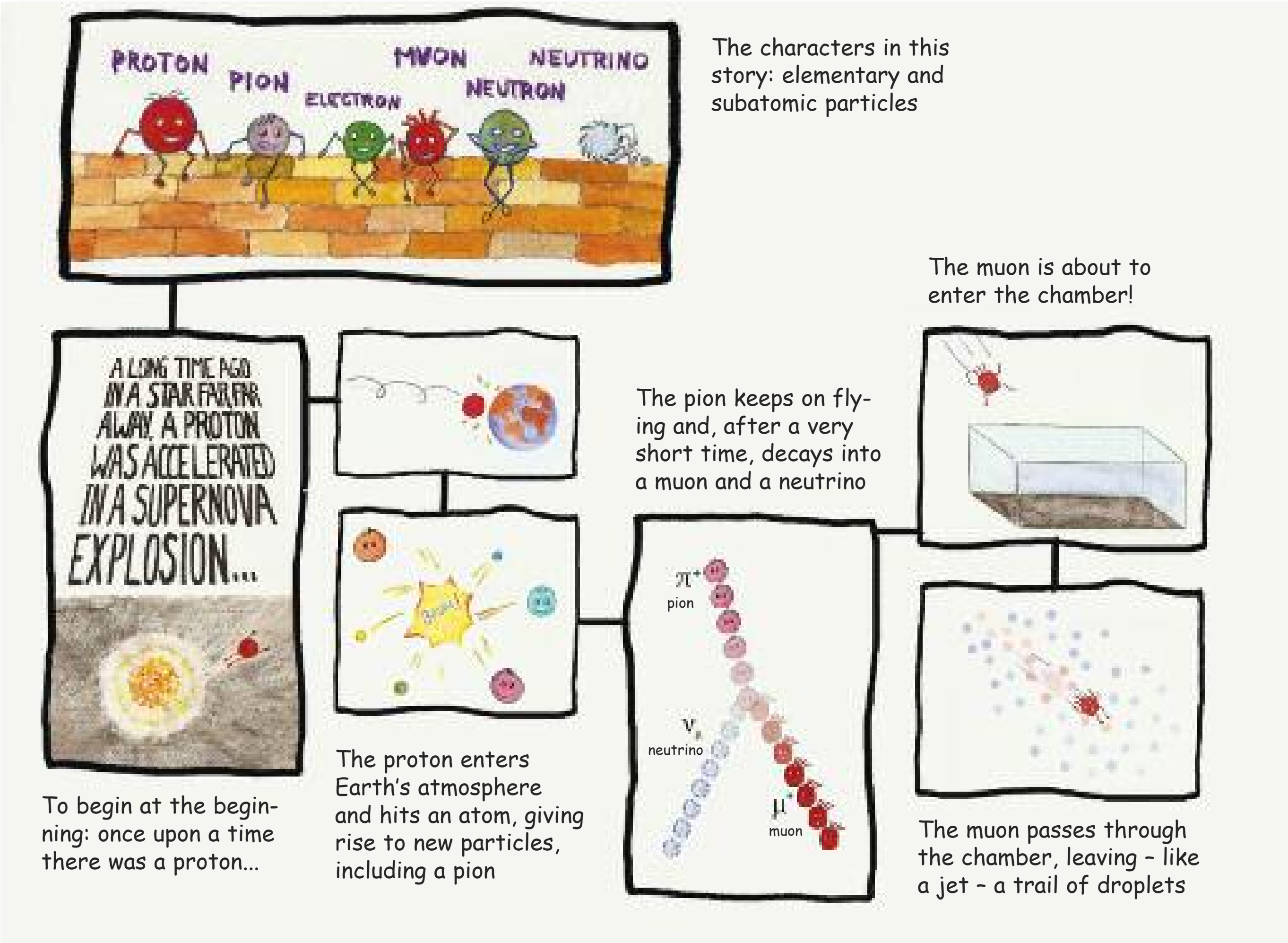


Cosmic rays

Method

1. Glue a strip of felt (the alcohol reservoir) around the insides at the bottom of the fish tank (the body of the cloud chamber). Some felt can be glued to the bottom of the tank, too.
2. Cut the aluminium sheet to fit (as closely as possible) the top the fish tank, and cover one side of the sheet with insulating tape, forming a black surface.
3. Soak the felt with isopropyl alcohol (but not so much that it drips down the sides of the chamber).
   Safety note: Do this in a well-ventilated room and remember that alcohol is flammable.
4. Turn the fish tank upside-down over the aluminium sheet. Make sure the black side of the sheet faces upwards (to make the particle tracks more visible).
5. Use insulating or duct tape to fasten the aluminium sheet to the rim of the fish tank, *sealing the chamber so that it is airtight*. This is the most *critical step* and must be carefully done, as the joint will become moist and very cold during operation.
6. Make a flat layer of dry ice in the tray and place the chamber on top of it, making sure that its base is horizontal. To *ensure good thermal contact between the metal plate and the dry ice, avoid large chunks of dry ice*: flat sheets or dust are best, but small grains will do.
   Safety note: Dry ice is around -79 ºC and should only be handled using thick gloves.
7. Keep the top of the chamber warm, for example by shining a lamp onto it. Avoid using the chamber in a cold environment, because this could prevent the correct temperature gradient from forming, meaning no tracks can be seen.
8. Leave the chamber undisturbed for about 10 min, until the temperature gradient is established. Shine a *bright light* through the chamber at a *low angle*, and look at the bottom of the chamber. At first you should see only an alcohol mist falling, but gradually, charged particle tracks should appear as thread-like condensation in the mist. Note: the tracks are more visible in a darkened room.

Taken from the cloud chamber comic strip; image courtesy of Paloma Alameda-Meléndez



Although any charged particle with enough energy, for example from ambient radioactivity, can leave its trail in the chamber, the majority of the tracks will be made by *secondary cosmic rays*: particles created when other particles (mostly protons) coming from outer space hit the upper atmosphere. Secondary cosmic rays travel at close to the speed of light and are absorbed by the atmosphere or decay in flight, giving rise to new particles including *muons*, which can reach the surface of Earth and are easily detected. Muons are charged elementary particles very similar to electrons except for their mass (which is two hundred times larger).

What you can do with the chamber?

In order to make the chamber really useful, we cannot limit ourselves to showing it and describing how it works. To support the explanation, we have prepared a short, simply written comic strip[w1] (see above), showing how the chamber works and illustrating the origin and composition of cosmic rays through the story of a cosmic proton and its descendants.

We use this chamber at school with our 12- to 16-year-old students as part of an effort to help them see particles as real physical objects. Watching the visible trails left by invisible particles and comparing them to trails left by jet engines (in which much of the same physics is involved) is the first step in a process that we continue by introducing real data and pictures from high-energy physics into otherwise standard exercises and questions[w2, w3] (Cid, 2005; Cid & Ramón, 2009) and that we conclude with another, more complicated, detector for school use: a cosmic-ray scintillation detector which allows students to record and study data by themselves (Barradas-Solas, 2007).

Why not use the *Science in School* online discussion forum to exchange ideas about how to use the cloud chamber at school? See: www.scienceinschool.org/forum/cloudchamber

Acknowledgements

The authors would like to thank Dr Eleanor Hayes, Editor-in-Chief of *Science in School*, for her assistance in giving the final form to this article.

References

Barradas-Solas F (2007) Giving new life to old equipment. *Physics Education* **42**: 9-11. doi: 10.1088/0031-9120/42/1/F03

To access this article, which is freely available online, visit the website of the Institute of Technical Education, Madrid, Spain (http://palmera.pntic.mec.es) or use the direct link http://tinyurl.com/y8ssyc5

Cid R (2005) Contextualized magnetism in secondary school: learning from the LHC (CERN). *Physics Education* **40**: 332-338. doi: 10.1088/0031-9120/40/4/002

Cid X, Ramón C (2009) Taking energy to the physics classroom from the Large Hadron Collider at CERN. *Physics Education* **44**: 78-83. doi: 10.1088/0031-9120/44/1/011

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

Web references

w1 – The comic strip (in English and Spanish) and full assembly instructions (in Spanish) are available from our website: http://palmera.pntic.mec.es/~fbarrada/cc_supp_mat.html

w2 – See, for instance, the introductory information about the LHC and simple physical calculations which take place in all particle accelerators (Physics at LHC) on the 'Taking a closer look at LHC': http://www.lhc-closer.es

w3 – The CERN website for high-school teachers (http://teachers.web.cern.ch) also includes a gallery of bubble chamber pictures which fits nicely into our project. See the direct link: http://tinyurl.com/yfbv8ls

Resources

For brief, simple overviews of particle physics aimed at the general public, see:

Close FE (2004) *Particle Physics: A Very Short Introduction*. Oxford, UK: Oxford University Press. ISBN: 9780192804341

The Lawrence Berkeley National Laboratory's online interactive tour, 'The Particle Adventure: the Fundamentals of Matter and Force': www.particleadventure.org

The virtual visitor centre of the SLAC National Accelerator Laboratory (particularly the sections on theory, detectors and cosmic rays): www2.slac.stanford.edu/vvc

The CERN website: http://public.web.cern.ch/public/en/Research/Detector-en.html

For a discussion of how some of the big questions in particle physics will be addressed by CERN's Large Hadron Collider, see:

Landua R (2008) The LHC: a look inside. *Science in School* **10**: 34-47. www.scienceinschool.org/2008/issue10/lhchow

For more detailed, yet accessible, introductions aimed at people with a scientific education and not afraid of a little mathematics, we recommend:

Barnett RM et al. (2000) *The Charm of Strange Quarks: Mysteries and Revolutions of Particle Physics*. New York, NY, USA: AIP Press. ISBN: 0387988971

Treiman SB (1999) *The Odd Quantum*. Princeton, NJ, USA: Princeton University Press. ISBN: 0691009260 Treiman's book is one of the best to begin tackling the subtleties of quantum mechanics in particle physics (which we have avoided in this article), including virtual and unstable particles, and the field/particle relationship.

To learn more about cosmic rays, see NASA's Cosmicopia: http://helios.gsfc.nasa.gov/cosmic.html

We and many others have learned about building cloud chambers from Andy Foland's cloud chamber page: www.lns.cornell.edu/~adf4/cloud.html

The American Museum of Natural History's website includes an illustrated version of the main stages of the assembly of the cloud chamber: www.amnh.org/education/resources/rfl/web/einsteinguide/activities/cloud.html

It is not easy to explain in detail the processes of supersaturation and track formation or to justify the choice of active liquid (isopropanol, in our case), as they depend in a complicated way on – for example – ionisation energies, vapour pressures, diffusion rates and various engineering aspects of the chamber. If you want to pursue this further, see the supplementary bibliography on our cloud chamber website: http://palmera.pntic.mec.es/~fbarrada/cc_supp_mat.html

For a *Science in School* article describing how to measure radioactivity from radon in the home, see:

Budinich M, Vascotto M (2010) The 'Radon school survey': measuring radioactivity at home. *Science in School* **14**: 54-57. www.scienceinschool.org/2010/issue14/radon

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Francisco Barradas-Solas has a degree in physics and teaches physics and chemistry at secondary school, although he is currently on leave, working as a scientific advisor to the regional education authority of Madrid, Spain. One of his main interests is the introduction of particle physics to schools and he has taken part in several programmes for teachers organised by CERN.

Paloma Alameda-Meléndez has a degree in chemistry and teaches physics and chemistry at El Álamo Secondary School, near Madrid.

Spectrometry at school: hands-on experiments

Nataša Gros, Tim Harrison, Irena Štrumbelj Drusany and **Alma Kapun Dolinar** introduce a selection of experiments with a simple spectrometer designed especially for schools – and give details of how to perform one of the activities.

To motivate school students through a hands-on approach to chemistry, we and our project partners developed a collection of experiments using small-scale, low-cost spectrometers. In the project, we used a simple school spectrometer developed by one of the partners (Nataša Gros). The spectrometer can be easily upgraded to form other analytical instruments, for example gas and liquid chromatographs, allowing a further range of school experiments (see the project website[w1]). Limited numbers of the instruments are available for loan to schools.

How spectrometers work

In a spectrometer, the white light from a light source (a bulb) enters a monochromator, from which only light of the chosen wavelength (colour) emerges; this then passes through a solution in the optical cell, or cuvette (see Figure 1). The solution absorbs a fraction of the light and a detector measures the resulting reduction in the light intensity (the *absorbance*). The deeper the colour of the solution, the higher the absorbance measurement.

The most widely used cuvettes have an optical path length of 1 cm and require at least 3 ml of solution for a successful measurement. The main objective of a general-purpose spectrometer is accuracy and precision of absorbance measurement: the wavelength selection should be as accurate as possible and the light highly monochromatic (i.e., with a narrow range of wavelength). As a consequence, the construction of the instrument is complicated and not very obvious to a typical user – and the instrument itself is expensive.

Instead, the main objective when developing the Spektra™ spectrometer was to produce a low-cost,

Image courtesy of Maren Beßler / Pixelio

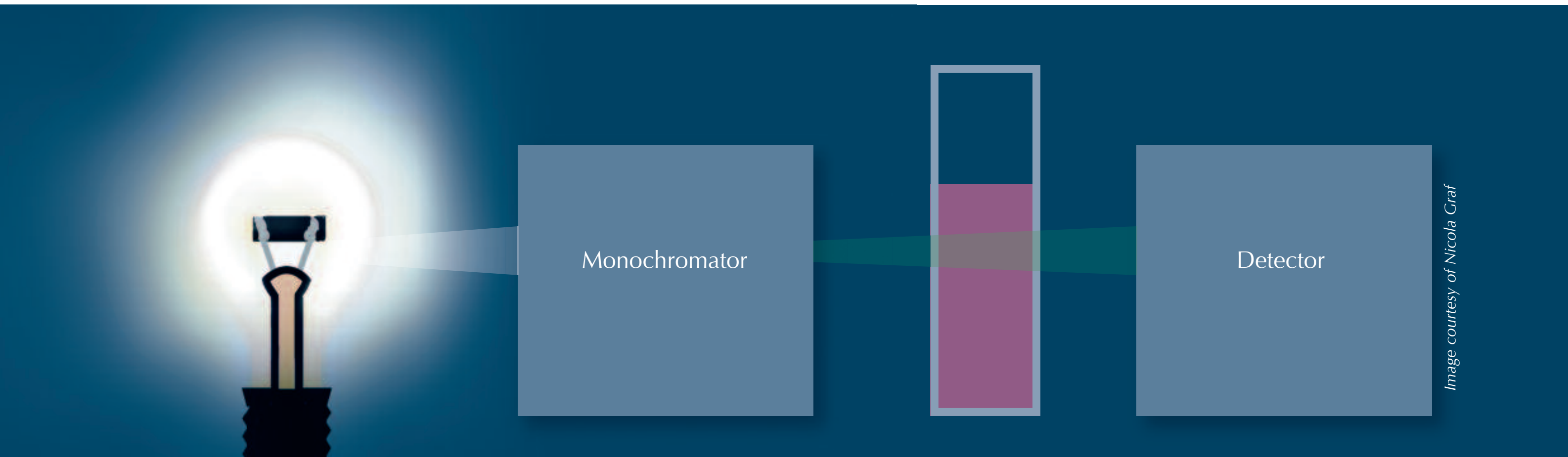

Figure 1: The main components of a conventional spectrometer

portable and robust instrument with a simple and intuitive design and operation, allowing for low reagent consumption and a simplified experimental approach (Gros, 2004). This spectrometer is primarily intended for educational purposes, especially for the introduction of concepts, but it has also proved useful for on-the-spot quantitative or semi-quantitative determinations of samples.

Spektra comprises two optical elements: a tri-colour light emitting diode (LED) and a light sensor. Blue (430 nm), green (565 nm) or red (625 nm) light can be selected; this passes directly through the liquid layer and strikes the sensor (see Figure 2). The most essential components (the light source, the measuring chamber and the sensor) are all visible: for students, the instrument is not a 'black box', but is easy to understand and operate (see Figures 3a and b).

Reactions and measurements take place in polymeric supports called blisters (similar to the plastic packaging on tablets), which allow for small volumes (0.35 ml) of tested solutions, rapid homogenisation of reagents,

REVIEW

- **Chemistry**
- **Biology**
- **Environmental science**
- **Optics**
- **Statistics**

Analytical chemistry relies extensively on spectrometric analysis, but professional instruments are expensive and thus not easily available for average schools in many countries. This article presents a spectrometer developed by one of the authors to make spectrometric analysis affordable to every secondary school. The project website details several school experiments in spectrometry, and the laboratory protocol for one experiment is included in the article.

I would recommend this article for introducing analytical chemistry in science lessons (not only chemistry, but also biology and environmental science), particularly for secondary schools that do not have a well-equipped laboratory. The proposed approach is simple and friendly enough to encourage teachers and students to try the suggested experiments and to explore new ones.

Teachers could use the article for a discussion of the methodology of spectrometry and the theory of spectrometric measurements. The experimental analysis provides the opportunity to analyse the obtained data mathematically, thus linking chemistry and statistics.

The article could also be used for a comprehension exercise. For example:

Given the procedure for making the calibration curve from the stock standard solution, complete the following table:

Flask	A	B	C	D	E
Volume of standard glucose solution (ml)	2	3	6	8	10
Volume of distilled water (ml)	98	97	94		
Glucose concentration (mg/ml)	0.3			1.2	1.5

Giulia Realdon, Italy

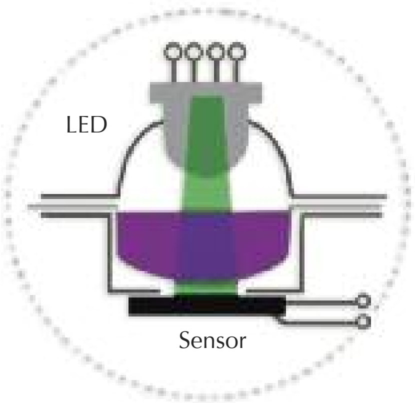

Image courtesy of Nataša Gros

Figure 2: Measuring chamber of the Spektra spectrometer

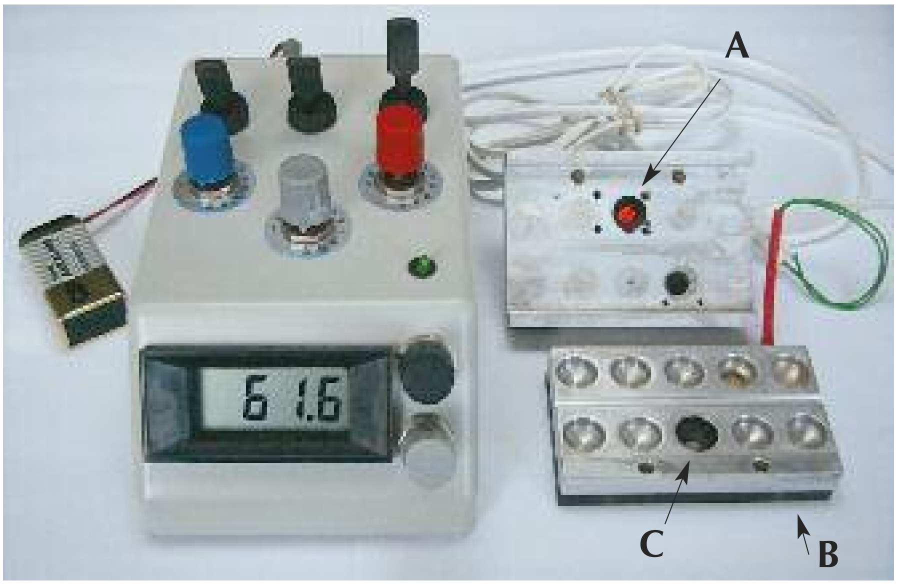

Image courtesy of Nataša Gros

Figure 3a: A prototype of the Spektra spectrometer. A: the LED light source; B: the measuring chamber; C: the measuring site with the sensor at the bottom

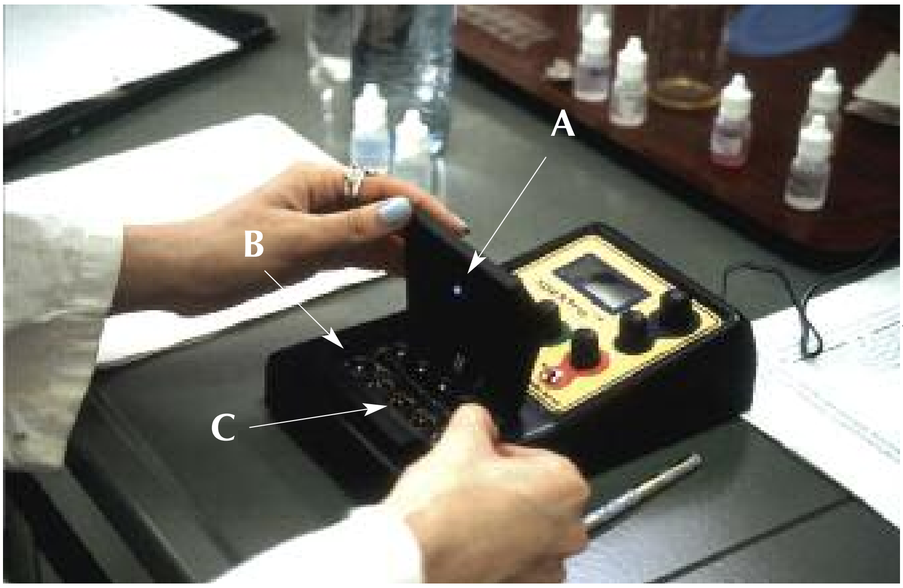

Image courtesy of Nataša Gros

Figure 3b: The final Spektra design. The instrument is more compact, but the three essential components (A: light source; B: measuring chamber; C: sensor) are still visible

and small volumes of chemical waste. Experimental work with Spektra is simple and safe, requiring no special laboratory training or laboratory glassware. The volumes of solutions needed are very small: even a drop-based experimental approach can be used where appropriate.

The spectrometer can be purchased online[w2]. Alternatively, the University of Bristol[w3], UK, offers a limited number of Spektra spectrometers for loan by teachers who wish to either try the experiments with their students or develop other practical investigations. For teachers who prefer a conventional instrument, Mystrica colorimeters (using normal, full-scale cuvettes) are also affordable and good quality[w4].

Hands-on experiments in spectrometry

As part of the project, a range of practical spectrometry activities was developed to raise interest in science, and to inspire potential future scientists amongst school students. These activities covered topics as varied as water analysis, the physics of light and colour, investigations into Lambert-Beer's law, chemical equilibrium, environmental analysis, kinetics of chemical reactions and the analysis of food.

The food analysis experiments cover the spectrometric determination of iron levels in samples of dried herbs or flour; alcohol content of spirits; glucose levels in jam; colour of beer; colour (quality) of paprika; phosphate levels in apple juice; phosphates and nitrites in meat products; and casein concentration in cheese. Another protocol allows the process of alcohol fermentation to be monitored.

The step-by-step instructions for determining the glucose level in jam are presented here; full details of all other experiments – including some suitable for outreach events in primary schools – are available on the project website[w1]. The website also has instructions for upgrading the Spektra instrument to a gas or liquid chromatograph, together with details of experiments that can be carried out with the upgraded equipment (see also Gros & Vrtačnik, 2005).

CLASSROOM ACTIVITY

Spectrometric determination of the glucose level in jam

A number of reactions between sugars and other chemical reagents produce coloured products; the intensity of colour is related to the initial concentration of sugar. The absorbance of sample solutions can be measured and compared to the absorbance of standard solutions of known sugar concentrations. Only a limited number of colour-change reactions are known for polysaccharides, and most involve simple sugars, usually reducing sugars.

Glucose determination was chosen primarily because students know what sugars are – the activity has widespread appeal. Furthermore, determining the sugar content of jams may have industrial applications in aspects such as quality control.

One method to determine the sugar concentration of jam involves hydrolysing many of the non-reducing sugars (in jam, principally sucrose) to glucose, using sulphuric acid (H_2SO_4), after which the sample is neutralised with sodium hydroxide (NaOH). When heated with 3,5-dinitrosalicylic acid (DNSA; also known as 2-hydroxy-3,5-dinitrobenzoic acid), reducing sugars (e.g. glucose and fructose) produce a red-brown product. For more details of this reaction, see Miller (1959).

The concentration of the coloured complex can be determined with the spectrometer using the blue LED (430 nm): the initial sugar concentration of the jam samples can then be read off a calibration curve created using known glucose concentrations.

BACKGROUND

Reducing and non-reducing sugars

In chemical terms, a reducing sugar is an aldose such as glucose, which has an aldehyde group that can be oxidised to a carboxylic acid. The more common chemical test to detect reducing sugars is to warm them with either Benedict's or Fehling's solutions, which contain copper(II) ions that are reduced to copper(I) oxide and can be observed as a brown-orange precipitate.

Non-reducing sugars, such as sucrose, may have a ketone rather than an aldehyde functional group, which cannot reduce copper(II) ions. When treated with Benedict's or Fehling's solutions, non-reducing sugars produce no coloured precipitate.

Equipment and reagents

- Spektra spectrometer (or other spectrometer)
- Cuvettes or blisters
- Pipettes
- 100 ml volumetric flasks
- Conical flasks
- Test tubes
- Balance
- Water bath
- Funnel
- Filter paper
- Jam samples
- DNSA reagent (3,5-dinitrosalicil acid)
- Sulphuric acid (H_2SO_4) solution (approximately 2 mol/l)
- Sodium hydroxide (NaOH) solution (w=10%)
- Sodium potassium tartrate ($NaK(CH_2OH)_2(COO)_2.4H_2O$)
- Glucose powder ($C_6H_{12}O_6$)

Preparation of solutions

DNSA reagent: To prepare the DNSA reagent, dissolve 10 g DNSA in 200 ml NaOH solution (about 2 mol/l). Heat the solution and stir thoroughly. Dissolve 300 g sodium potassium tartrate in 500 ml distilled water to form a colour stabiliser. Combine the two solutions, stir well and top up to 1 l with distilled water.

Jam (sugars): Weigh 1-2 g jam into a conical flask and add 10 ml sulphuric acid. Heat in a boiling water bath for 20 min, stirring periodically until hydrolysis is complete. Leave the sample to cool and carefully add 12 ml sodium hydroxide. Stir and filter into a 100 ml volumetric flask, and top up to 100 ml with distilled water. Using a pipette, transfer 10 ml solution into another 100 ml volumetric flask and top up to 100 ml with distilled water to produce the test solution. Stir well.

Jam (reducing sugars): Weigh 3.0 g jam into a conical flask, add 50 ml distilled water, heat and stir for 10 min. Filter into a 100 ml volumetric flask, and top up to 100 ml with distilled water. Using a pipette, transfer 10 ml solution into another 100 ml volumetric flask and top up to 100 ml with distilled water to produce the test solution. Stir well.

Stock glucose solution (15 mg/ml): Place 1.5 g glucose in a 100 ml volumetric flask and top up to 100 ml with distilled water. Stir.

Creating the calibration curve

1. Mark five volumetric flasks (100 ml) with the letters A–E. Into each labelled flask, pipette the volumes of standard glucose solution and distilled water specified in Table 1.

Flask	A	B	C	D	E
Volume of stock glucose solution (ml)	2	3	6	8	10
Volume of distilled water (ml)	98	97	94	92	90
Glucose concentration (mg/ml)	0.3	0.45	0.9	1.2	1.5

Table 1: Preparing the standard glucose solutions

2. Label and fill six test tubes as specified in Table 2.

Sample number	Blank	1	2	3	4	5
Standard glucose solution (flask)	N/A	A	B	C	D	E
Volume of standard glucose solution (ml)	0	1	1	1	1	1
Volume of DNSA reagent (ml)	1	1	1	1	1	1
Volume of distilled water (ml)	3	2	2	2	2	2

Table 2: Preparing the solutions for the calibration curve

3. Heat the test tubes and their contents in boiling water for 5 min; the DNSA reagent will react with any sugar present, producing a red-brown product.
4. Cool the test tubes, add 6 ml distilled water to each and shake well.
5. Using the blue LED (430 mm) of the spectrometer, measure the transmittance of each solution.

The readings from the Spektra instrument are transmittances expressed in percentages and should be divided by 100 to obtain the transmittance values used in the subsequent calculations. Transmittance is related to absorbance as described by the equation: $A = -\log T$. See the second and third columns in Table 3. The image below shows the calibration solutions; even the blank (water and DNSA with no glucose) is an intense colour. It is therefore necessary to measure all the samples, including the blank, against distilled water. The glucose-specific absorbance of the samples is then calculated by subtracting the absorbance measurement of the blank from the absorbance measurement of the sample (see the fourth column of Table 3).

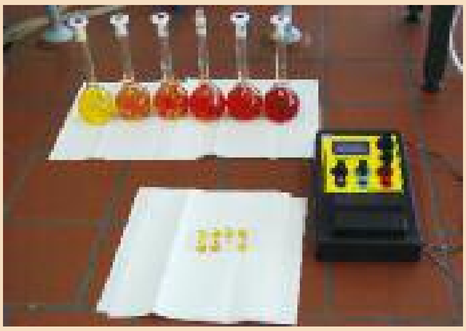

Figure 4: The calibration solutions

Image courtesy of Irena Šrumbelj Drusany

6. Plot glucose concentration against glucose-specific absorbance, as shown in Figure 5.

Glucose concentration (mg/ml)	Transmittance (Spektra reading, T%)	Absorbance (A)	Glucose-specific absorbance ($A - A_{blank}$)
0 (Blank)	27.54	0.56	0
0.3	23.44	0.63	0.07
0.45	20.04	0.69	0.13
0.9	18.21	0.74	0.18
1.2	15.13	0.82	0.26
1.5	14.45	0.84	0.28

Table 3: Calibration curve – sample absorbance measurements of different concentrations of glucose solution

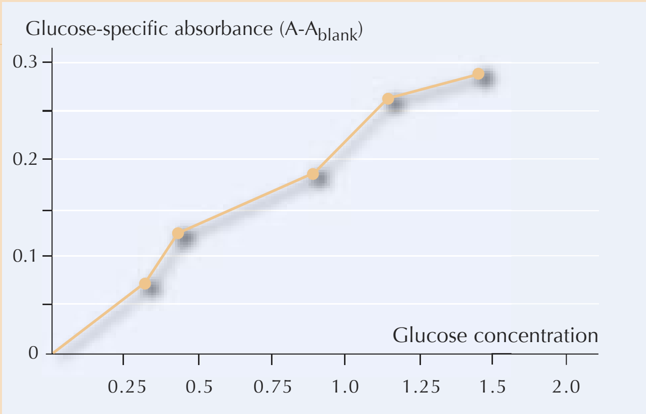

Figure 5: Sample calibration curve – glucose-specific absorbance against concentration of glucose

Measuring the jam samples

The jam samples should be treated similarly to the glucose solutions used for the calibration curve.

1. For each jam to be tested, put 1 ml prepared jam sample (see 'Preparation of solutions') in a test tube and add 1 ml DNSA reagent and 2 ml distilled water.
2. Heat the test tubes and their contents in boiling water for 5 min; the DNSA reagent will react with any sugar present, producing a red-brown product.
3. Cool the test tubes, add 6 ml distilled water to each and shake well.
4. Using the blue LED (430 nm) of the spectrometer, measure the transmittance value (T%) of each jam sample. Divide by 100 to obtain T, convert T to A using the equation $A = -\log T$, and use that to calculate the glucose-specific absorbance ($A - A_{blank}$).

Table 4 shows an example of the transmittance values obtained and the calculated glucose-specific absorbance of each sample.

Sample	Transmittance (Spektra reading, T%)	Absorbance (A)	Glucose specific absorbance ($A - A_{blank}$)
1	18.6	0.73	0.17
2	21.3	0.67	0.11

Table 4: Sample results for jam samples

5. Using your calibration curve, convert the absorbance measurements (A) into the concentrations of glucose (mg/ml) in your samples.
   Using the examples from Table 4, the glucose concentrations read off the calibration curve give:
   Sample 1: 0.8 mg/ml
   Sample 2: 0.5 mg/ml

6. From the glucose concentrations, calculate the mass of glucose in a 1 g jam sample using the following equation:
   Mass glucose (g per 1g sample) = mass concentration (mg/ml) x 10 x 100 ml

   where
   mass concentration is the value read off the calibration curve
   10 is the dilution (see 'Preparation of solutions')
   100 ml is the volume of 1g of jam sample.

   In our example,
   Sample 1: mass glucose (g per 1g sample) = 0.8 mg/ml x 10 x 100 ml = 0.8 g
   Sample 2: mass glucose (g per 1g sample) = 0.5 mg/ml x 10 x 100 ml = 0.5 g.

   The calculations above assume that the initial jam sample was 1 g. If, for example, the sample had weighed 2 g, the figures above would need to be divided by 2 to get the mass of glucose in g per 1 g sample.

Acknowledgements
The authors wish to thank the European Commission Directorate General for Education and Culture for the financial support of the Hands-on Approach to Analytical Chemistry for Vocational Schools II (AnalChemVoc II, LLP-LDV-TOI-2008-SI-15) project via the Leonardo da Vinci programme.

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Gros N, Vrtačnik M (2005) A small-scale low-cost gas chromatograph. *Journal of Chemical Education* **82**: 291-293. doi: 10.1021/ed082p291

Miller GL (1959) Use of dinitrosalicylic acid reagent for determination of reducing sugar. *Analytical Chemistry* **31**: 426-428.

This article is freely available from the website of the American Chemical Society. See: http://pubs.acs.org/doi/pdf/10.1021/ac60147a030

Web references
w1 – For more information about the project, see: www.kii2.ntf.uni-lj.si/analchemvoc2/file.php/1/HTML/experiments.htm

w2 – The Spektra instrument can be purchased from Laboratorijska tehnika Burnik: www.lt-burnik.si/index.php?newlang=english

w3 – The University of Bristol's ChemLabS (www.chemlabs.bris.ac.uk) offers a limited number of Spektra spectrometers for loan by teachers who wish either to try out the experiments with their students or to develop other practical investigations. Interested teachers should contact Tim Harrison (t.g.harrison@bristol.ac.uk).

w4 – For more details about Mystrica colorimeters, see: http://mystrica.com/Colorimeter.aspx. The website also describes a number of possible experiments; particularly good are those involving enzymes reactions.

Resources
If you enjoyed this and other teaching activities in this issue of *Science in School*, you might like to browse our collection of previously published teaching activities. See: www.scienceinschool.org/teaching

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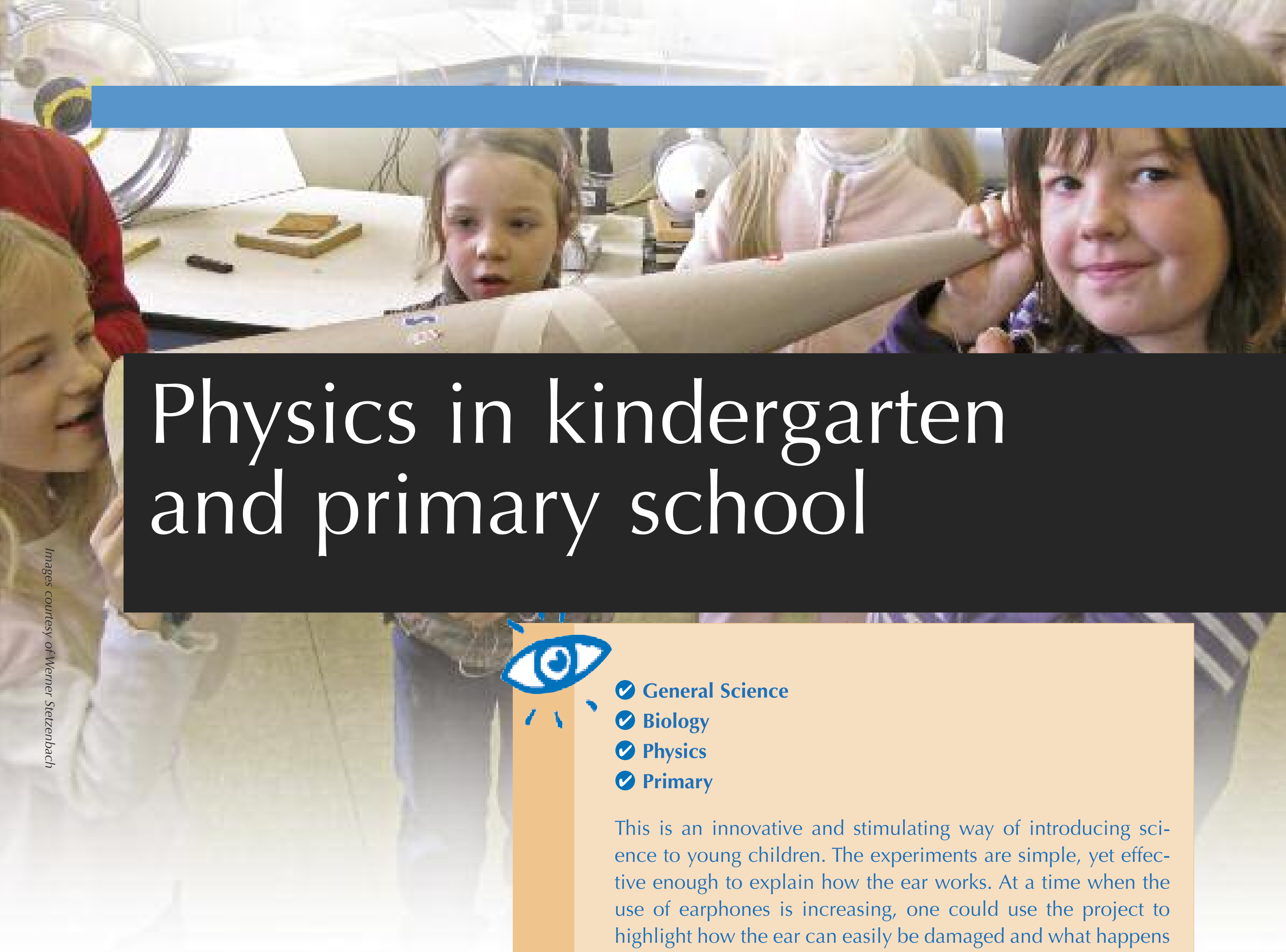
Image courtesy of Cornerstone / Pixelio



Images courtesy of Werner Stetzenbach

Physics in kindergarten and primary school

Werner and **Gabriele Stetzenbach** tell us how kindergarten and primary-school children discover the world of physics together with secondary-school students as their mentors. Why not try it in your school?

REVIEW

- General Science
- Biology
- Physics
- Primary

This is an innovative and stimulating way of introducing science to young children. The experiments are simple, yet effective enough to explain how the ear works. At a time when the use of earphones is increasing, one could use the project to highlight how the ear can easily be damaged and what happens in such cases.

The article can be used by two separate audiences: the first are kindergarten and primary-school teachers. They can use the experiments detailed in this article and the additional activities developed by the project (available online) in their classroom. Some kindergarten and primary-school teachers may find it difficult because they do not have the necessary science background; this problem may be overcome through prior preparation, the help of a science specialist or the assistance of prepared secondary-school students, as in the presented project. Suggested background reading material can also be found in the 'Resources' section.

For secondary-school science teachers, the article provides details of how to set up a similar project with their students. If secondary-school students are involved, then such a project can be very motivating for them and should also help them to grow into more responsible adults.

The experiments are ideal to use for primary/kindergarten science, but may also be used in integrated/coordinated science. They are helpful for biology lessons to teach about the ear and hearing, and for physics lessons, to teach about the transmission of sound, the ear as a real-life application for the transmission of sound, or cleaning using ultrasound (jostling of dirt particles instead of the jelly babies).

Paul Xuereb, Malta

BACKGROUND

Setting up a similar project with your students

Secondary-school students have a different perspective from teachers and educators, which can be very helpful when dealing with small children, as they can be easily accepted as 'big brothers or sisters'. The secondary-school students involved in our project benefited a great deal from the experience: they learned to give presentations, became more self-confident and improved their organisational skills – all without the pressure of a standard classroom situation. Additionally, they got a first-hand insight into the work of teachers, educators, scientists and engineers.

A team should consist of 4-5 secondary-school students and a supervising teacher. In an initial brainstorming session, let the students come up with their own ideas; this will motivate them to be very creative. They may find it helpful to consult books and websites of teaching activities. By letting each student work on a separate topic, students of different abilities can be involved. The teacher should moderate the meetings, provide the experimental materials and help to set up the experiments.

To inspire fun and curiosity, experiments should be easy to set up and, ideally, should involve several senses at once. When the younger children are able to experiment by themselves, they often express and test their own ideas.

It is important to contact potential project partners (kindergartens or primary schools) early on in the project. Whereas kindergartens tend to be open to many scientific subjects, the experiments for primary schools may need to fit the curriculum topics taught in science or nature lessons, if the subject exists.

Ask the secondary-school students to present their projects to each other, to get suggestions for improvements from the whole team. Remember to test the experiments with children of the target age beforehand, to estimate the required time. Up to seven younger children is a good group size. In our experience, each activity takes about 25-60 minutes, although we did not set a time limit.

The activities might take more time than expected, since children sometimes ask to repeat a section they particularly enjoyed. Keep in mind that young children enjoy being able to take small experiments home, or taking part in a small competition in which they can win prizes such as a jelly baby in an inflated balloon.

Especially when experimenting themselves, primary-school children had no trouble concentrating for up to two hours without a break. Before reorganising groups or starting a new experiment, hand out treats or drinks to mark the break.

And don't forget, if this is a new experience for everyone involved, there may be reservations on both sides (the kindergarten or primary school, and the secondary-school team). However, if you discuss potential issues during the preparatory phase, this should be easily overcome.

A number of projects have emerged in recent years to foster the curiosity of children in kindergarten and primary school. In 2001, we started one such initiative[w1] in Winnweiler, which has since been extended throughout Germany with the help of several sponsors. Together with Werner's secondary-school students from the Wilhelm Erb Gymnasium[w2] in Winnweiler, we developed physics teaching activities for children aged 4-10. With the secondary-school students as mentors, we went into kindergartens and primary schools and successfully ran experiments with the children on topics such as air, electricity, magnets, light, shadows, hearing, flotation and lightning.

A collection of teaching activities, experiences and background information has been published in a German-language brochure (THINK ING, 2007). Most of the experiments, as well as a general introduction to the project, are also available to be downloaded as English-language PDFs from the website of Science on Stage Germany[w3]. Below are step-by-step instructions for a set of experiments on hearing, suitable for both kindergarten and primary-school children. The online PDFs also contain further experiments from this section.

Attack on the eardrums

The aim is for the pupils to understand the function and importance of the ear, so that they will turn their MP3 players down to prevent damage to their auditory systems. On a journey from a sound source to the inner ear, sound production and the anatomy of the ear are explained.

Auditory walking tour

Get the pupils to take a walk through the grounds of the school or kindergarten, once with and once without earplugs, to experience the loss of environmental impressions when they partially 'switch off' their hearing. They will also learn about the dangers that (partially) deaf people are exposed to.

Do we really hear everything?

The human ear can perceive sounds with 20 to 20 000 oscillations per second. The number of oscillations per second is called the frequency. As we get older, we lose the ability to hear very high frequencies. Dogs can hear sounds with up to 35 000 oscillations per second (35 kHz), bats even higher-frequency sounds. Use a normal whistle and a dog whistle for the children to compare. Typically, a dog whistle is within the range of 16-22 kHz, with only the frequencies below 20 kHz audible to the human ear (and depending on the individual state of your hearing, you may not even hear these).

Adjust the volume of a signal generator with amplifier and loudspeaker to a medium level at an audible frequency. Then turn up the frequency to 50 kHz, and slowly tune it down from there. Ask the first child who can hear something to describe the sound (a high-pitched whistle).

Do our ears have favourite sounds? An individual auditory diagram

By testing our own hearing range, we can estimate the state of our hearing. Connect a signal generator with an oscilloscope and loudspeaker as indicated (see image below).

Using the signal generator, generate sounds between 250 and 16 000 Hz according to Table 1. To make the sounds comparable, make sure that they all generate a 'wave line' of equal 'height' on the oscilloscope.

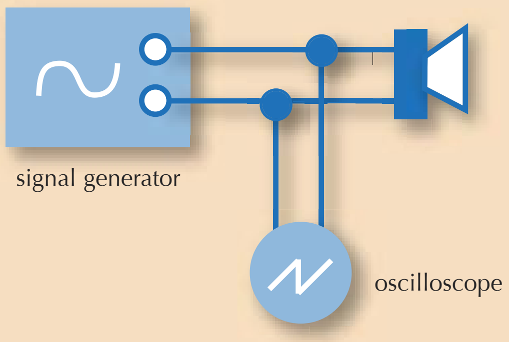
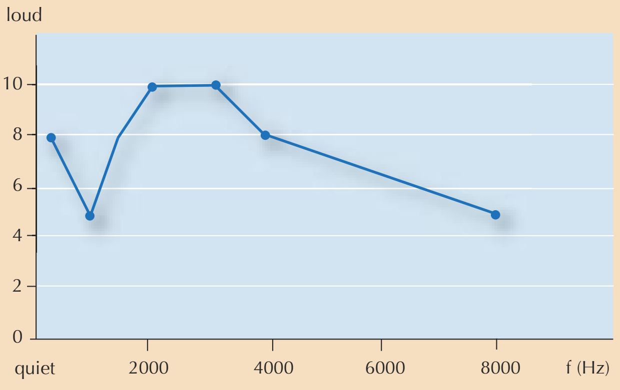


Image courtesy of Nicola Graf

How do you perceive the sound?	Sound 1	Sound 2	Sound 3	Sound 4	Sound 5	Sound 6	Sound 7
	16 000 Hz	8000 Hz	4000 Hz	2000 Hz	1000 Hz	500 Hz	250 Hz
very loud (10)							
loud (8)							
medium loud (5)							
quiet (3)							
very quiet (1)							

Table 1: individual auditory diagram



auditory diagram girl 8 years

Ask each child to complete the table (which can also be downloaded as a worksheet from the *Science in School* website[w4]), recording whether they experience each sound as being very loud, loud, medium loud, quiet or very quiet. This can be a little tricky. To make it easier, start with 16 000 Hz and do pairwise comparisons between neighbouring frequencies to be measured, i.e. 'How do you perceive the sound at 16 000 Hz? Now listen to the sound at 8000 Hz – how do you perceive it in comparison?' And so on. Typically, the human ear is most sensitive to the frequencies at which we usually speak (about 200–3500 Hz).

With the help of a secondary-school mentor (or teacher), each child should plot the perceived volume (e.g. loud = 8) against the frequency of the sound.

It is useful to make the same measurements with adults (e.g. teachers or parents) as well, because as we age, we hear high-pitched sounds less well. You may notice this when the TV is on – young children may hear a high-pitched whistling noise whereas adults do not.

How does sound reach the ear? The swinging candle

Because sounds are transported by variations in air pressure, sound moves air particles. The movement of a candle flame is used to illustrate this. Sound with a low frequency can even blow out a candle flame.

Materials

- A CD player with a bass loudspeaker playing techno music
- A candle and matches
- A paper funnel
- A (bass) drum with a hole in the back
- A signal generator with amplifier
- A loudspeaker suitable for low frequencies (at least as low as 100 Hz)
- Cables

Procedure

1. Place a burning candle in front of a CD player with a bass loudspeaker playing techno music. The flame will flicker in time with the music. If the effect is not very visible, use a paper funnel between the loudspeaker and the candle to enhance it.
2. Place the burning candle in front of the hole at the back of a drum. Beat the drum on the other side and watch the flame move or be blown out.
3. Using the cables, connect the loudspeaker to the signal generator and turn it to a low frequency (100 Hz). The candle will be blown out. To enhance the effect, you can use a paper funnel between the loudspeaker and the candle.

What happens in the ear?

Use a plastic or paper model (which may be homemade) of the ear to illustrate the different parts of the ear, which will be explained in the following experiments.

Images courtesy of Werner Stetzenbach

The outer ear: the auricle and eardrum

The auricle collects sound like a funnel. Use a paper funnel as an ear trumpet to improve hearing: whisper into it and see how it magnifies the sound.

The outer ear acts like an organ pipe that is closed at one end, so that the air in it can vibrate. This vibration is passed on to the eardrum, a membrane that behaves like a drum, and then through mechanical linkage to the three ossicles (small bones).

Materials

- A bass loudspeaker
- A signal generator with amplifier or a CD player with amplifier
- Cables
- Jelly babies

Image courtesy of Werner Stetzenbach

Procedure

Using the cables, connect the bass loudspeaker to the signal generator or CD player. Place some jelly babies on the speaker. Watch them 'dancing' with the vibrations of the loudspeaker membrane, which represents the eardrum.

The middle ear: the ossicles

Materials

- Two tambourines
- A drumstick
- A table tennis or styrofoam ball tied to a string
- A baking tray
- A wooden mallet or similar wooden instrument
- A bowl
- Aluminium foil or cling film
- Rice grains or sugar

Procedure

1. Hang the table tennis or styrofoam ball (representing the ossicles) in front of one of the tambourines, touching its surface (T2 in the image below). Beat the other tambourine (T1, the sound source) with the drumstick and watch the ball move, as the sound waves reach T2.

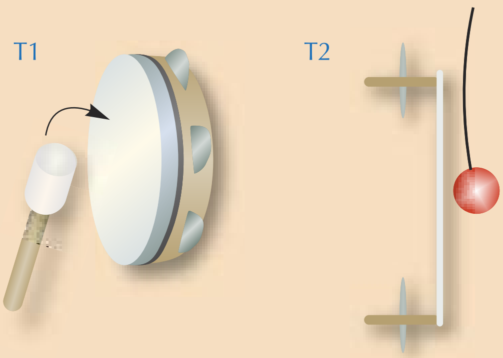


Image courtesy of Nicola Graf

2. Cover the bowl with foil or film pulled taut, and place rice grains or sugar on top. Hold the baking tray close, bang it with a mallet and watch the rice or sugar (representing the ossicles) jump.

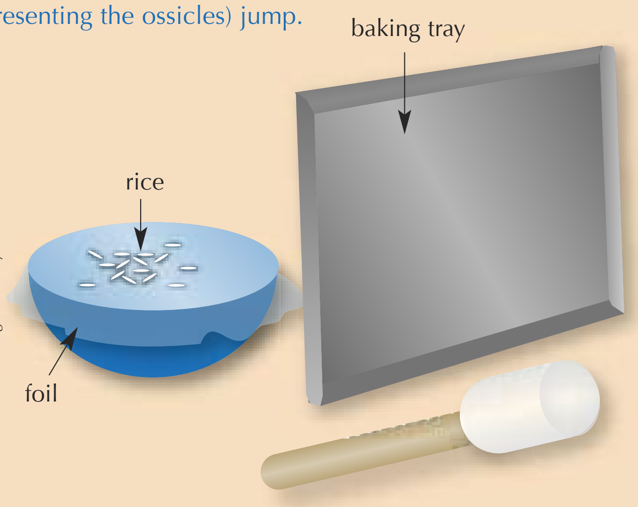


Image courtesy of Nicola Graf

The inner ear: the cochlea

There are auditory nerves in the hair cells of the cochlea. Sound (changes in air pressure) makes them move, which triggers information to be transmitted to the brain. The louder the sound, the more the hairs move. Very loud noises can even damage the hair cells.

A glass tube is used as a model for an uncoiled cochlea. Cork dust or talcum powder inside the tube represents the hair cells.

Materials

- A glass tube
- Cork dust or talcum powder
- Two stands (see image)
- A signal generator
- A loudspeaker
- Cables

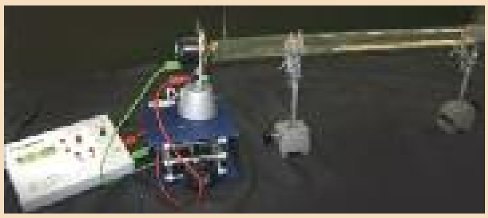


Image courtesy of Werner Stetzenbach

Procedure

Fill the bottom of the glass tube with cork dust or talcum powder and mount it horizontally on the stands.

Using the cables, connect the loudspeaker to the signal generator and place it in front of one opening of the glass tube.

Adjust the frequency of the sound (depending on the tube's length) until the tube resonates (for any given length, there are multiple frequencies at which it will resonate), making the dust vibrate visibly. This represents the movement of the hair cells.

Reference

THINK ING (2007) *Physik in Kindergarten und Grundschule II.* Köln, Germany: Deutscher Institutsverlag. ISBN: 9783602147816

Web references

w1 – To learn more about the Germany-wide *Physik in Kindergarten und Grundschule* project, see: www.think-ing.de/index.php?node=1218

w2 – For more information about the Wilhelm-Erb-Gymnasium Winnweiler, see: www.weg-winnweiler.de

w3 – To download the materials in English, see: www.science-on-stage.de/index.php?p=3_15&l=en

w4 –Table 1 can be downloaded as a Word document from the *Science in School* website: www.scienceinschool.org/repository/docs/issue14_kindergarten_worksheet.pdf

w5 – Science on Stage brings together science teachers from across Europe to share best practice in science teaching. Originating in 2000 as Physics on Stage, it was broadened in 2003 to cover all sciences. Science on Stage Germany organises many activities for teachers both in and outside Germany, and currently hosts the Science on Stage Europe office. For more information, see: www.science-on-stage.de

Resources

'Promenade 'round the Cochlea' is a regularly updated website providing background information and teaching suggestions on the auditory system. See: www.cochlea.org

Skidmore University, NY, USA, provides a useful collection of links for teaching the ear and the auditory system: www.skidmore.edu/~hfoley/Perc9.htm#teach

You can find a nice animation of the flow of sound waves through the ear here: www.sensory-systems.ethz.ch/Lectures/Auditory/Auditory_Animations_1.htm

The Howard Hughes Medical Institute website offers a report on recent research into our senses, including the quivering bundles that let us hear and how to locate a mouse by its sound. See: www.hhmi.org/senses

The Neuroscience for Kids website explains how our sense of hearing works, and includes some experiments and teaching materials: http://faculty.washington.edu/chudler/bigear.html

The 'How the Body Works' section of the About Kids Health (Trusted Answers from the Hospital for Sick Children) website has an explanation of the ear, including an interactive diagram of the auditory system. See: www.aboutkidshealth.ca or use the direct link http://tinyurl.com/yzzt5bv

The website of the US education research organisation SEDL offers online lesson plans for teaching the five senses. See: www.sedl.org/scimath/pasopartners

If you enjoyed this article, you might like to look at other teaching activities and articles suitable for primary school on the *Science in School* website. See: www.scienceinschool.org/primary

Werner Stetzenbach has a physics degree and for the last 33 years has taught physics at secondary school. At the Wilhelm Erb Gymnasium, he is the head of sixth form (*Studiendirektor*) and the school specialist on didactic questions. He is part of the 'Physics in kindergarten and primary school' working group of Science on Stage Germany[w5] and has organised more than 25 training courses for educators and grammar-school teachers. He has also organised more than 50 workshops and training courses for physics teachers at secondary schools on the topic 'Physics in daily life: low-cost, high-tech hands-on experiments'.

Gabriele Stetzenbach is a medical assistant (*Arzthelferin*). Her role in the project was to make sure the experiments were appropriate for the target age and to help the secondary-school students with the practical setup. She also coordinated the collection of feedback on the project and played a major role in making sure the project would be expanded nationwide.

Image courtesy of Werner Stetzenbach

The ‘Radon school survey’: measuring radioactivity at home

Marco Budinich and **Massimo Vascotto** introduce a school project to measure radon levels in your own home.

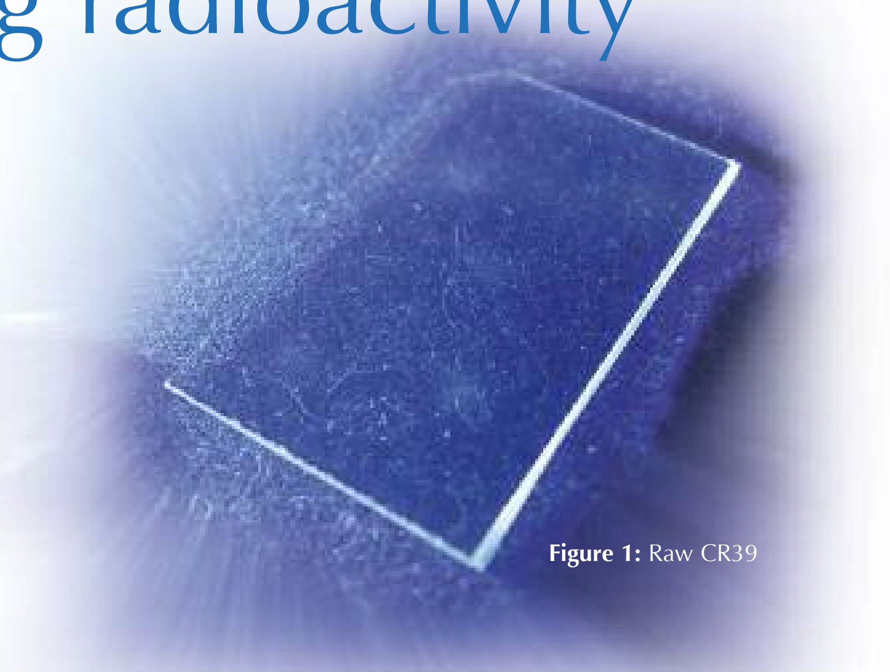


Figure 1: Raw CR39

Image courtesy of the University of Trieste

The simple word ‘radioactive’ evokes something both mysterious and scary, and few realize that, most of the time, radioactivity is a natural phenomenon we have to live with. Radon is a naturally occurring radioactive gas and is the most frequent cause of lung cancer after smoking, representing the form of radioactivity with highest social impact.

Radon leaks out of rocks and, because it is a gas, mixes with the air we breathe. The higher its concentration, the more radioactivity we are exposed to. Radon concentration is quite erratic: one house may be filled with radon while the neighbouring houses have no detectable radon levels. Since radon comes mainly from rocks, its concentration is correlated with soil composition, water occurrence and, more generally, geology. Knowing how much radon we breathe at home is thus important for our health[w1]. The ‘Radon school survey’ (RSS) project[w2, w3] involves high-school students measuring radon concentration in their own homes.

Normally, measuring radon requires equipment well beyond the budget of a school; instead, we used a simple, safe and robust method to produce meaningful results by detecting α-radioactivity from radon. The nucleus of a radon-222 atom decays into polonium-218, emitting a ‘heavy’ α-particle (a helium-4 nucleus). When the α-particle strikes a solid object, it causes local damage, as a bullet would to a wall: it leaves a little hole or *nuclear track*. Our ‘wall’ was a tiny plastic target; after exposing it to radiation, we could simply count the number of holes left by the α-particles, and from that information, calculate the average radon concentration during the exposure time.

The plastic we used, CR39, (also known as PADC – poly allyl diglycol carbonate), was developed for the construction of aeroplane cockpits in World War II and is now used in unbreakable optical lenses, and also in nuclear physics to detect α-particles and neutrons.

Materials

- For each student, a CR39 radon dosimeter in a plastic screw-top box (see Figure 3). (See the list of suppliers for more information)
- Sodium hydroxide (NaOH)
- Distilled water
- A water bath (or cheap thermostatic fryer)
- A microscope with micro camera (see ‘Suppliers’)

Method

1. To quantitatively measure the level of radon, leave the dosimeter for one to six months in the same place. The bedroom is a good choice to reflect our exposure to radon, as it is a place where we spend a lot of time. After that, the detector is ready to be analysed.

To make the nuclear tracks left by the α-particles visible with a simple microscope, they must first be widened by chemical etching.

2. Place the dosimeter in a beaker and cover it with a solution of 240 g sodium hydroxide per litre of dis-

REVIEW

This project shows how the teaching of radioactivity, which is usually a classroom-based topic, can be extended outside the school. Students test for the presence of radon in their own homes and then perform more thorough analyses in the school laboratory; the fact that they can in effect 'see' the radiation makes it less abstract. This will motivate the students to research the effects of radon and other sources of radiation, and to conduct careful analyses and detailed interpretation of the results.

Most of the apparatus and materials indicated by the authors are commonly found in a science laboratory. This encourages teachers to try this project with their own students so that they can actually see the effects of radiation in their own homes. Such a project instils in students an investigative approach towards science.

The article can be used in physics lessons to introduce the topic of radioactivity (types of radiation, background radiation, effects of radiation). It could also be used in chemistry (radioactive elements), geology (soil and rock properties) or advanced mathematics (exponential decay and the Poisson distribution) lessons. Moreover, being a rather sensitive topic, it can be extended to class discussions on how radioactivity can be used to serve humanity, and what can happen when radioactivity reaches alarming levels.

Catherine Cutajar, Malta

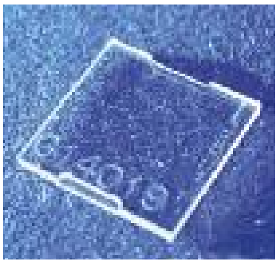


Figure 2: CR39 dositometer

Figure 3: CR39 inside the 'exposure camera'

Figure 4: Microscope with micro camera

Images courtesy of the University of Trieste

tilled water. Heat at 80°C for at least 4 h. (If you are using a thermostatic fryer, test the water temperature first.) If you are preparing several dosimeters, use fresh sodium hydroxide solution for each one.

Safety note: sodium hydroxide is corrosive, and must be handled with care.

3. Leave the dosimeter to etch for 4 h, then rinse it well. The tracks are now about 10 μm in diameter and can be viewed with a microscope.
4. Place the dosimeter under the microscope, take some pictures, and use them to count the nuclear tracks and to determine their average density (Figure 5).

Radon concentration is calculated using the formula:

$$Rn = D\ fc\ /\ \Delta t$$

where

Rn is the radon concentration (Bq/m^3)

D is the track density (number of tracks/m^2)

fc is the calibration factor (the density of tracks corresponding to 1 Bq/m^3 per exposure day; this information is provided by the manufacturer)

Δt is the exposure time.

Sample results

The radon concentration found in our houses can vary by four orders of magnitude over the course of one day, and depends on many factors including weather, air circulation and pressure, and other seasonal changes. What is important for health purposes, however, is the *average* radon concentration. For that reason, radon measurements are typically taken over long periods.

Since the project began in 2003, some 2000 high-school students in Friuli Venezia-Giulia (north-east Italy) have taken part. Using calibrated CR39 dosimeters, we have performed four long-term surveys, some short-term measurements and a few verifications of sites with high radon levels.

Table 1: Sample results from the RSS project

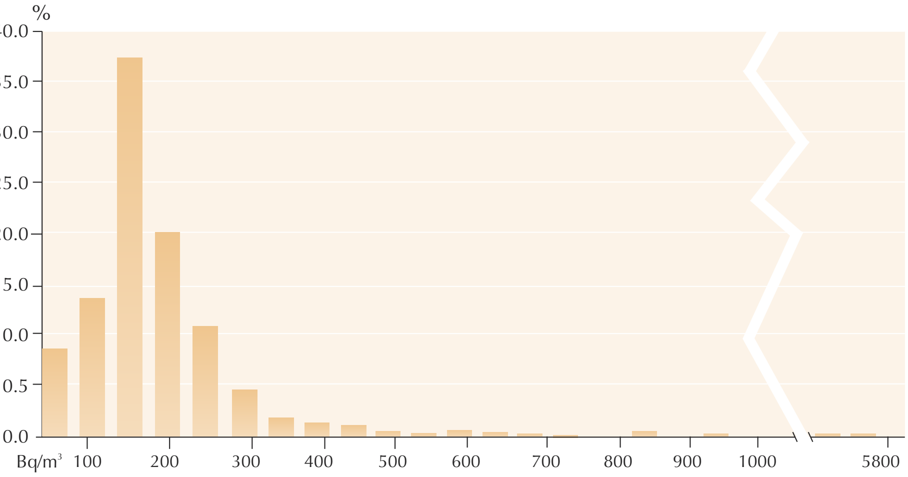
Radon measurement (Bq/m^3)(n=897)	Summer 2005 survey (n=860)	Winter 2007 survey
Rn≤200 (limit for post-1990 buildings)	89% (795)	70% (604)
200<Rn≤400 (limit for pre-1990 buildings)	9% (80)	20% (168)
Rn>400	2% (22)	10% (88)

The project is still continuing, and schools that carry out measurements are welcome to submit their data to our project.

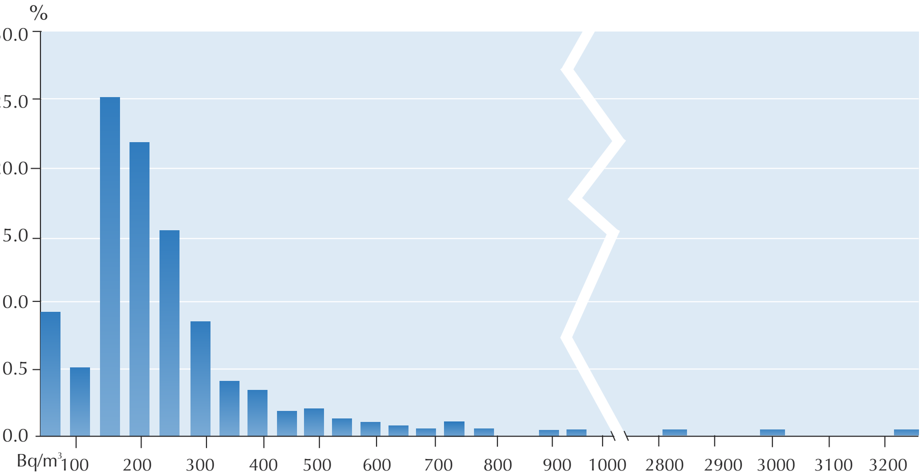
In the summer of 2005, 89% of the 897 radon measurements made by the students were under 200 Bq/m³, i.e. below the limit that the European Commission recommends for new buildings (The Commission of the European Community, 1990). Only 2% (22 measurements) exceeded the limit of 400 Bq/m³ recommended for pre-1990 buildings. Of those, 0.4% (4 measurements) exceeded 1000 Bq/m³, with the highest measurement being 5699 Bq/m³ (see graph).

In the winter of 2007, the 860 measurements were generally somewhat higher: 70% below 200 Bq/m³ and a further 20% between 200 and 400 Bq/m³. In this survey, 10% (88 measurements) exceeded the limit of 400 Bq/m³. However, the highest measurement made was lower than that of summer 2005: only 3227 Bq/m³ (see graph).

In those cases where levels of radon above the limit were detected, the measurement was repeated, and if the levels were still too high, we recommended that the students contact the regional environmental protection agency, which could advise on how to keep radon out of the house. An example of a simple radon reduction method is to ventilate rooms. More labour-intensive methods include insulating the house from the ground.



Measurements taken in the summer of 2005. n=897, 7 schools. Mean average 130, standard deviation 292, maximum 5699, minimum 0, median 87



Measurements taken in the winter of 2007. n=860, 10 schools. Mean average 208, standard deviation 275, maximum 3227, minimum 0, median 140

Suppliers

CR39 can be bought from optical lens manufacturers or from suppliers of radon detectors[w4] (see Figures 1 and 2). Optical lens manufacturers sell the plastic material (CR39) cut into any shape (about €1), while the detector suppliers sell a calibrated, ready to use, CR39 radon dosimeter (about €7). One suggestion is to use the cheaper option for a yes/no measurement, reserving the more expensive detectors for places where radon has already been detected.

We use a cheap Konus Academy microscope[w5] (models 5304 & 5829) with a micro camera and the associated imaging software (see Figure 4).

Acknowledgements

We would like to thank all students, teachers, school personnel and families involved in the project and our collaboration partners, the local environment protection agency, ARPAF-VG[w6].

We gratefully acknowledge the support of our sponsors[w3], Progetto Lauree Scientifiche, INFN and the Physics Department of the University of Trieste.

Image courtesy of the University of Trieste

Figure 5: Nuclear tracks 10x (holes marked with arrows)

BACKGROUND

The RSS project

The RSS project is very multidisciplinary, involving not only physics but also chemistry, geology (for soil properties), mathematics (involving, for example, the exponential decay law and Poisson distribution of tracks), and social considerations (incidence of radon risks).

The topic sheds some light on the 'dark mysteries' of radioactivity and is socially relevant, especially in a radon-prone area like our region; students and their parents are usually curious to know the radon level in their houses. So far, the project has involved almost 5000 people in our region – students, families, teachers and school personnel – making them aware of a health risk.

Besides measuring radon, the other major goal of this project is to interest high-school students in science and scientific careers, by getting them to take part in a real scientific study, carrying out the measurements themselves. Students are made aware that we are surrounded by science and that it is possible to do serious science in everyday life, with simple equipment.

The organisers of the project and many of the participants are now involved in a further project[w7] – to investigate the levels of ^{137}caesium left in their region as a result of the Chernobyl accident in 1986.

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The Commission of the European Community (1990) *Commission Recommendation on the Protection of the Public against Indoor Exposure to Radon* (90/143/Euratom). http://ec.europa.eu/energy/nuclear/radioprotection/doc/legislation/90143_en.pdf

Web references

w1 – For more information about radon, see the websites of the UK Health Protection Agency (www.hpa.org.uk), the US Environmental Protection Agency (www.epa.gov) and the Swiss Federal Office of Public Health (www.bag.admin.ch, in English, Italian, French and German).

w2 – Further information about the RSS project and detailed protocols for both the measurements and data collection are available on the following websites.

For a presentation about the project (in Italian), see: www.ts.infn.it/eventi/ComunicareFisica/presentazioni/vascotto.pdf

For presentations about the project (in both English and Italian), see also the Fisica a Trieste website: http://physics.units.it/didattica03/orientamento/laboratori.php

w3 – The RSS project was funded by:

Progetto Lauree Scientifiche, an Italian national project to disseminate scientific culture and raise interest in scientific disciplines and careers; see: www.progettolaureescientifiche.it

INFN, the Italian National Institute for Nuclear Physics. See: www.infn.it

The Physics Department of the University of Trieste; see: http://physics.units.it

w4 – Suppliers of CR39 include:

Intercast Europe (cheap CR39 without calibration): www.intercast.it

FGM Ambiente (CR39 calibrated dosimeters): www.fgmambiente.it

Radosys (CR39 calibrated dosimeters): www.radosys.com

TASL (CR39 manufacturer): www.tasl.co.uk

w5 – For more information about Konus (including their microscopes and micro cameras), see: www.konus.com

w6 – ARPA-FVG is the regional environmental protection agency of Friuli Venezia Giulia. For more information, see: www.arpa.fvg.it

w7 – For more information about the caesium project, see the (Italian) project web page (http://physics.units.it/didattica03/orientamento/laboratori.php#cesio) or contact Marco Budinich directly (marco.budinich@ts.infn.it)

w8 – See Marco Budinich's web page: wwwusers.ts.infn.it/~mbh/MBHgeneral.html

Resources

If you enjoyed this article, you might also like to read other articles on science education projects in *Science in School*. See: www.scienceinschool.org/projects

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Marco Budinich[w8] is a physicist at the University of Trieste, Italy, where he is responsible for the outreach activities of the physics department.

Massimo Vascotto, the project coordinator, has a degree in physics and teaches maritime disciplines (e.g. navigation, meteorology and oceanography) at a nautical high school (for trainee marines) in Trieste. He has collaborated for many years with the physics department at the University of Trieste and with INFN, the Italian National Institute for Nuclear Physics, where he is an associate physicist in science communication projects.

Image courtesy of oversnap / iStockphoto

Natural selection at the molecular level

We know that particular genetic sequences can help us to survive in our environment – this is the basis of evolution. But demonstrating which genetic sequences are beneficial and how they help us to survive is not easy – especially in wild populations. **Jarek Bryk** describes some relevant recent research.

When humans first left Africa some 150 000 years ago, settling in the valleys of the Tigris and Euphrates, sailing between the islands of Indonesia and trekking over the Bering Strait to America, they encountered many challenges. Coming from hot, dry African savannahs, the populations had to adapt to the local conditions, and over generations their physiology and appearance changed accordingly (Harris & Meyer, 2008). People's skin became paler after they had lived in less sunny regions (Lamason et al., 2005). Populations whose members drank milk from domesticated animals retained the ability to digest lactose into adulthood, a feature lost soon after infancy among non-milk-drinking groups (Tishkoff et al., 2007). Populations that ate starch-rich food produced more salivary amylase, the enzyme that helps to break down starch (Perry et al., 2007).

At least some of these changes are thought to have been a consequence of *positive selection* (see glossary for all italicised terms). This implies that in a particular environment (the *selection pressure*) in the past, individuals that happened to have an advantageous DNA sequence survived and left more offspring than individuals with a different, less beneficial, sequence. Today, using the genomic sequences of many species, including humans and their closest evolutionary relatives, scientists can compare *traits* and DNA sequences from populations or species with different lifestyles and from different environments to identify which sequences may have played a role in the adaptations. This, in turn, allows researchers to investigate the function of a DNA sequence and its potential *adaptive value* for an organism.

Some of the genes known to affect skin colour in humans show a specific geographic pattern of sequence variation; in particular, sequence comparisons between European and African populations suggest that variation in skin colour is due to positive selection. Lightness of skin positively correlates with increasing latitude, and several hypotheses have been proposed to explain its potentially advantageous effects. One hypothesis, which states that light skin favours the production of vitamin D, is supported by observations that dark-skinned people living at high latitudes suffer from vitamin D deficiency. Furthermore, light skin is more sensitive to the harmful effects of sunlight: greater exposure to sunlight correlates with increased incidence of skin cancer in pale-skinned people. Therefore, pale skin in human populations living at higher latitudes may be an evolutionary compromise between protection from the carcinogenic effects of sunlight and allowing

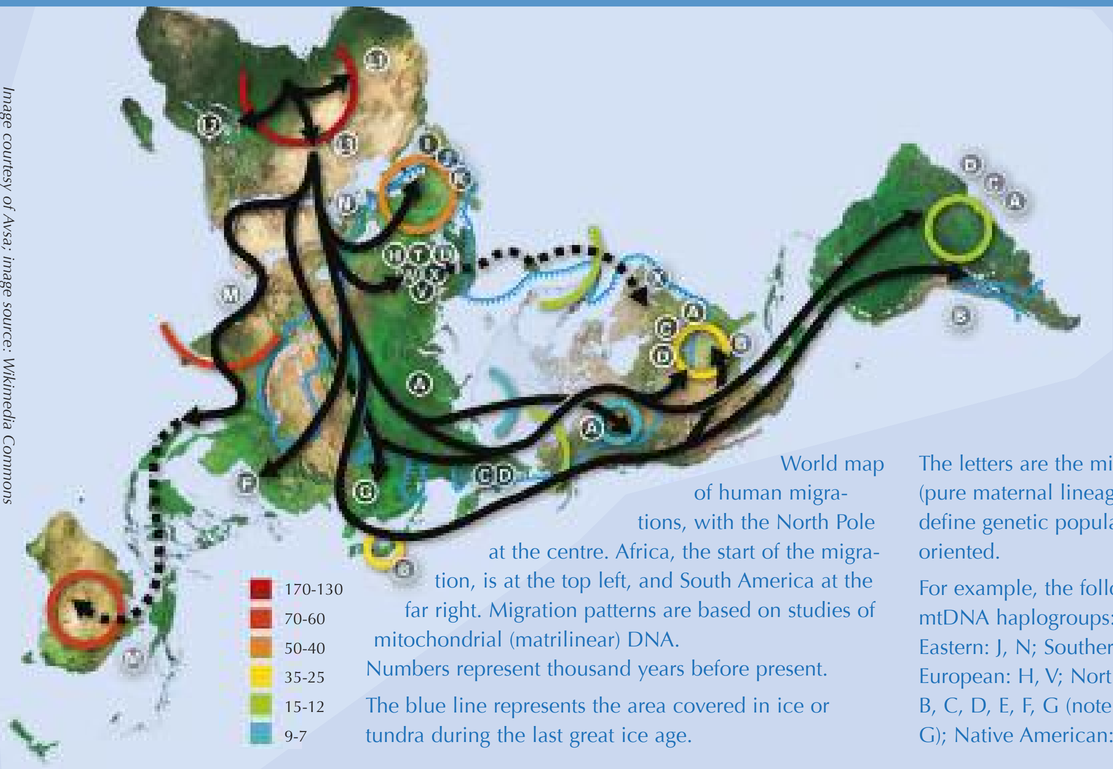


Image courtesy of Avsa; image source: Wikimedia Commons

World map of human migrations, with the North Pole at the centre. Africa, the start of the migration, is at the top left, and South America at the far right. Migration patterns are based on studies of mitochondrial (matrilinear) DNA.

Numbers represent thousand years before present.

The blue line represents the area covered in ice or tundra during the last great ice age.

The letters are the mitochondrial DNA haplogroups (pure maternal lineages); Haplogroups can be used to define genetic populations and are often geographically oriented.

For example, the following are common divisions for mtDNA haplogroups: African: L, L1, L2, L3, L3; Near Eastern: J, N; Southern European: J, K; General European: H, V; Northern European: T, U, X; Asian: A, B, C, D, E, F, G (note: M is composed of C, D, E, and G); Native American: A, B, C, D, and sometimes X

sufficient production of an essential vitamin.

Although this is a solid hypothesis, the evidence behind it is indirect. A direct demonstration of the adaptive value of this trait would require measuring whether, at higher latitudes, individuals with paler skin show improved survival and reproduction. Such demonstrations in our species, however, are difficult: survival experiments (in which individuals with different traits are exposed to an environment to see which survive) cannot

Image courtesy of JBryson / iStockphoto

REVIEW

The article describes a range of interesting examples of evolutionary adaptations at the molecular level in humans. The difficulty in elucidating causal relationships between adaptive DNA sequences and individual fitness in humans and the need to use other experimental organisms are highlighted.

The article provides excellent material for comprehension questions focusing on the understanding of natural selection and fitness in humans and experimental organisms. For example:

1. Explain the processes involved in natural selection.
2. What do you understand by the term ‘fitness’?
3. Explain how the sickle-cell allele confers a selective advantage in some human populations.
4. What are the problems associated with establishing causal relationships between adaptive DNA sequences and fitness in humans?
5. Construct a flow chart to explain the adaptive value of coat colour in Oldfield mice.
6. How were the scientists able to correlate genetic changes in *Staphylococcus aureus* with bacterial growth and antibiotic responsiveness?

This article also enables students to research the link between DNA, amino acid sequence, protein structure and function in sickle-cell anaemia. The text is suitable for directing discussion in the classroom on the methods and problems associated with investigating the molecular basis of evolutionary relationships and the ethics of genetic testing in human populations. Interdisciplinary studies could be organised around the history of science and evolutionary population genetics.

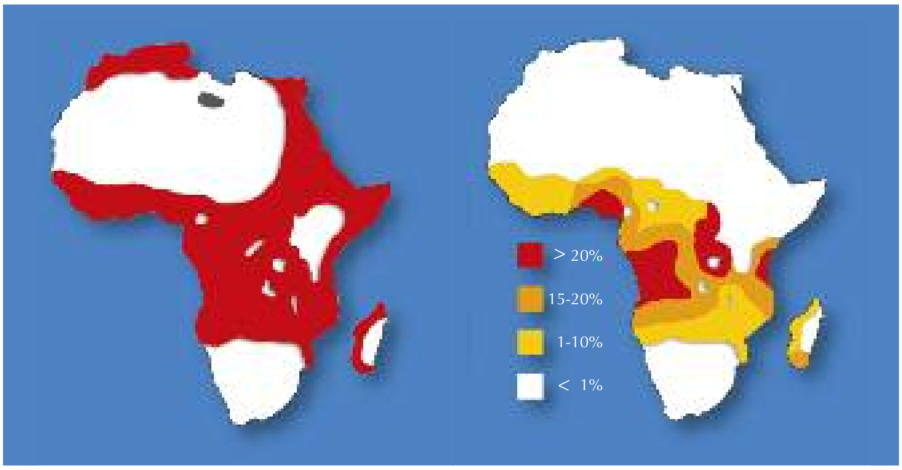
Mary Brenan, UK

be performed on humans, and our long generation time makes it difficult to investigate differences in reproductive rates. The circumstances in which it is possible to observe the adaptive value of any trait in humans are therefore very limited — but they do exist.

One example involves two diseases: sickle-cell anaemia and malaria. The gene involved in sickle-cell anaemia has two variants, or *alleles*: a 'normal' allele and a sickle-cell allele. Individuals with two sickle-cell alleles suffer from serious sickle-cell anaemia, whereas those with one sickle-cell and one normal allele do not exhibit such severe symptoms. Mortality data suggest that the sickle-cell allele can, however, be advantageous: in populations exposed to the malaria parasite, individuals carrying one sickle-cell allele and one normal allele are more likely to survive than people carrying two normal alleles, because the parasite (*Plasmodium falciparum*) requires healthy blood cells to invade and multiply. Therefore, the frequency of the allele that causes sickle-cell anaemia increases in malaria-exposed groups – the allele is adaptive in this environment.

Another example demonstrating the adaptive value of a human trait concerns a fragment of chromosome 17, known to have been inverted in our ancestors more than three million years ago (Stefansson et al., 2005). The fact that this variant spread across European populations suggests that it has been positively selected for – it has conferred an advantage on individuals that carry it. By genotyping almost 30 000 Icelanders, scientists investigating the hypothesis were able to determine that over the last 80 years, individuals who carried the sequence variant had on average 3.2% more offspring per generation than individuals with the normal sequence, a plausible explanation of how the variant came to spread so rapidly.

Image courtesy of Anthony Allison; image source: Wikimedia Commons



Comparison of the distribution of malaria (left) and sickle-cell anaemia (right) in Africa

BACKGROUND

Glossary

Adaptive value: a *trait* has an adaptive value if it enables an individual to survive and reproduce better in a given environment than individuals that do not possess this trait. More formally, a trait is regarded as adaptive if it increases *fitness*.

Allele: a variant of a gene.

Fitness: a hard-to-define formal term from evolutionary biology and population genetics; it describes the average number of offspring over one generation that are associated with one genotype compared to another genotype in a population. Thus genotypes that produce more offspring have greater fitness. For a good overview of fitness and genotype, see Wikipedia[w1].

Genome: the total DNA of an organism. This is usually understood to be the nuclear DNA, as opposed to mitochondrial or plastid DNA. For further information, see 'What is a genome' on the US National Library of Medicine website[w2].

Positive selection: natural selection is one of the mechanisms of evolution; it describes the different survival and reproduction of individuals in a given environment. Natural selection is called 'positive' when it promotes certain *traits* that help individuals who have them, to survive and reproduce better than others.

Selection pressure: a feature of the environment (e.g. temperature; presence of parasites; predation or aggression from members of the same species) that imposes differential survival and reproduction of individuals.

Trait: one or a set of features of an organism's characteristics (e.g. height; resistance to antibiotics; ability to see colours or to roll one's tongue).

Although the two examples clearly demonstrate the recent action of positive selection in humans, the molecular mechanisms of how the sequence variations confer their advantages are not well understood and must be investigated on a case-by-case basis. To elucidate the causal relationships between putatively adaptive DNA sequences and an individual's *fitness*, scientists turn to organisms that are easier to experiment on than humans.

For instance, coat colour in the Oldfield mouse, *Peromyscus polionotus*, matches the soil of the habitat, providing camouflage. Mice living on the pale sands of Florida beaches are much lighter than inland-living mice of the same species. The adaptive value of this trait was demonstrated experimentally more than 30 years ago: mice with a coat that matched the soil colour were eaten less frequently by owls than the other, less camouflaged mice. However, scientists have only recently identified the genetic loci behind this adaptive trait (Hoekstra et al., 2006): variation in coat colour largely depends on different alleles of the *McR1* gene. The protein encoded by this gene acts as a biochemical switch driving the production of either eumelanin, a dark pigment in the skin, or pheomelanin, a light pigment. The different alleles of the *McR1* gene activate the pigment-producing pathway to a different extent, favouring the production of one pigment or the other.

Another example of a demonstrated causal relationship involves *Staphylococcus aureus*, a bacterium that can cause various diseases including pneumonia or heart valve inflammation. In a rare natural experiment, a patient with recurrent *S. aureus* infections was treated for three months with vancomycin, one of the few antibiotics that are still effective against *S. aureus*. Before and at intervals throughout the treatment, scientists collected samples (isolates) of the pathogen and sequenced the entire *genome* of the first and last isolates. When they compared the three million base pairs (the 'letters' of the genetic code) that constitute this bacterium's DNA, they found only 35 differences between the first and last isolates. By partially sequencing the intermediate isolates, the scientists then worked out the order in which these changes must have occurred. By testing the bacterial resistance to vancomycin in vitro in the different isolates, they were able to correlate particular genetic changes with effects on the bacteria's growth and response to the drug. For instance, the first and second isolates of bacteria differed by six nucleotide substitutions (changes to the 'letters') in two genes. These six mutations alone were clearly advantageous: they increased the bacterium's tolerance to vancomycin fourfold, allowing bacteria carrying these mutations to survive and reproduce better, becoming more common in the patient's body. Twenty-six subsequent mutations over the following weeks of treatment doubled the tolerance, effectively producing a vancomycin-tolerant strain of *S. aureus* (Mwangi et al., 2007).

In short, investigating the molecular basis of adaptive evolution in wild populations is not easy. The challenges include defining the selective pressures, identifying the DNA sequences behind the associated traits, measuring individuals' fitness, and finding mechanistic explanations for how the sequence changes influence the adaptive traits. However, with the use of model organisms and recent technological developments, these investigations are now becoming feasible, increasing our understanding of how specific changes at the genetic level allow organisms to adapt to their environment.

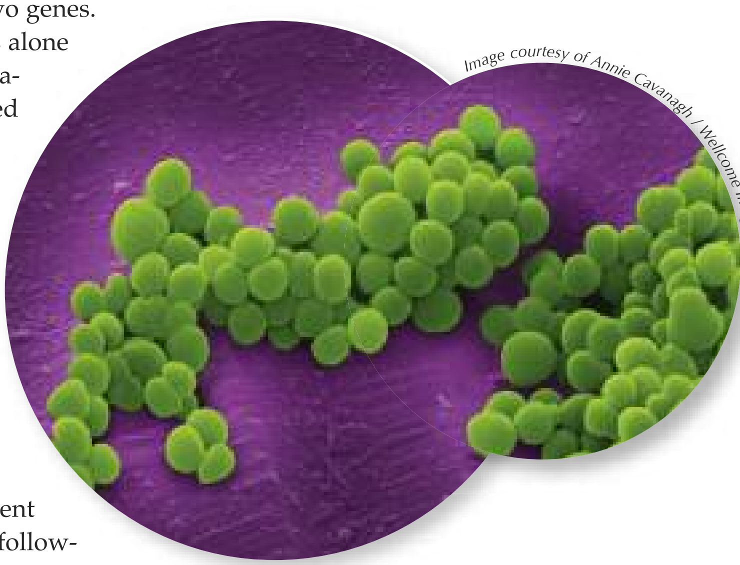
Image courtesy of EM Unit, UCL Medical School, Royal Free Campus / Wellcome Images

Scanning electron microscope image of sickle-cell and other red blood cells

Image courtesy of Hugh Sturrock / Wellcome Images

A mosquito with its abdomen full of blood. This species, *Anopheles stephensi*, is the insect vector that transmits malaria in India and Pakistan

Image courtesy of Annie Cavanagh / Wellcome Images



Scanning electron micrograph of clusters of methicillin-resistant *Staphylococcus aureus* bacteria

Acknowledgements

The author is grateful to David Hughes, Mehmet Somel and Ania Lorenc for helpful comments on the article.

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Hoekstra H et al. (2006) A single amino acid mutation contributes to adaptive beach mouse color pattern. *Science* **313**: 101-104. doi: 10.1126/science.1126121

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See also the follow-up paper in which the discovery of Agouti, a negative regulator of *McR1* contributing to adaptive coat colour in *Peromyscus*, is described:

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This article is freely available to download from the *Heredity* journal website: www.nature.com/hdy

An overview of Hopi Hoekstra's latest research is available on John Hawks' blog: http://johnhawks.net/weblog/topics/evolution/selection/hoekstra-2009-adaptive-pigmentation.html

Lamason RL et al. (2005) SLC24A5, a putative cation exchanger, affects pigmentation in zebrafish and humans. *Science* **310**: 1782-1786. doi: 10.1126/science.1116238

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Tishkoff SA et al. (2006) Convergent adaptation of human lactase persistence in Africa and Europe. *Nature Genetics* **39**: 31-40. doi: 10.1038/ng1946
See also an overview of this research in *The New York Times*: www.nytimes.com/2006/12/10/science/10cnd-evolve.html?_r=1

Web references

w1 – For a good overview of the terms 'fitness' and 'genotype', see Wikipedia: http://en.wikipedia.org/wiki/Fitness_(biology) and http://en.wikipedia.org/wiki/Genotype

w2 – For more information about genomes and the Human Genome Project, see 'What is a genome' on the US National Library of Medicine website: http://ghr.nlm.nih.gov/handbook/hgp/genome

Resources

If you found this article interesting, you may like to read some other *Science in School* articles about evolution:

Haubold B (2010) Review of *Why Evolution is True. Science in School* **14**. www.scienceinschool.org/2010/issue14/evotrue

Leigh V (2008). Interview with Steve Jones: the threat of creationism. *Science in School* **9**: 9-17. www.scienceinschool.org/2008/issue9/stevejones

Patterson L (2010) Getting ahead in evolution. *Science in School* **14**: 16-20. www.scienceinschool.org/2010/issue14/amphioxus

Pongsophon P, Roadrangka V and Campbell A (2007) Counting Buttons: demonstrating the Hardy-Weinberg principle. *Science in School* **6**: 30-35. www.scienceinschool.org/2007/issue6/hardyweinberg

For more information about malaria, see:

Hodge R (2006) Fighting malaria on a new front. *Science in School* **1**: 72-75. www.scienceinschool.org/2006/issue1/malaria

To learn more about the structure of starch, which salivary amylase helps to break down, see:

Cornuéjols D (2010) Starch: a structural mystery. *Science in School* **14**: 22-27. www.scienceinschool.org/2010/issue14/starch

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Jarek Bryk is a post-doctoral researcher at the Max Planck Institute for Evolutionary Biology in Plön, Germany, where he tries to find and analyse adaptive genes in mice.

Chemistry and light

Peter Douglas and **Mike Garley** investigate how chemistry and light interact in many aspects of our everyday life.

Image courtesy of BlackJack3D / iStockphoto

Since time immemorial we have used the Sun's rays to warm ourselves during the day and the glow of a flame to light up our world at night. Today, we control the inter-conversion of energy to make light from electricity, heat and chemical reactions; in our daily lives, we use chemistry and light in communication, electronics, medicine and entertainment; and photochemists are working for a cleaner, brighter future by devising new methods to convert sunlight into useful energy and to remove pollutants photochemically.

Making light: lamps, lasers, LEDs and liquid light

The essential component in the process of making light is the interconversion of energy. Different types of lamps and lighting devices convert energy in different ways and with differing efficiencies.

In the tungsten lamp, electrical energy heats a filament to a white-hot glow; thus, thermal energy is converted into light energy. Light emission from the solid filament is a continuum and gives a visible spectrum, much like a rainbow. Unfortunately the efficiency with which electrical energy is converted to visible light energy is only about 5-10%.

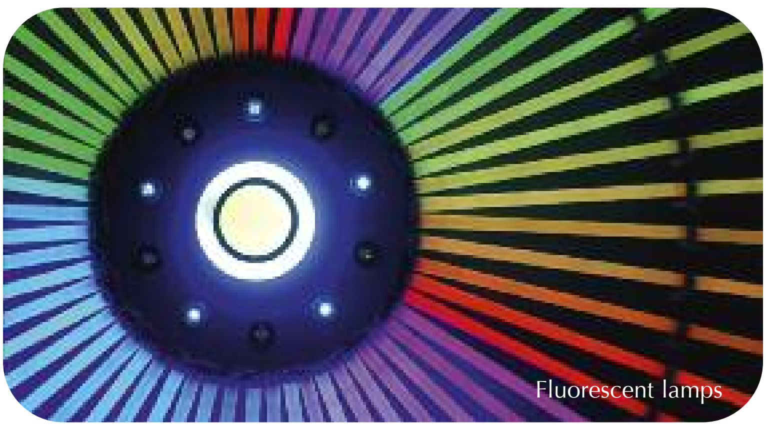
In the fluorescent lamp, electrical energy is converted into atomic excitation energy in the vapour of mercury atoms inside a tube. In this case, the energy conversion efficiency is about twice that of a tungsten bulb at

REVIEW

- Physics
- Chemistry

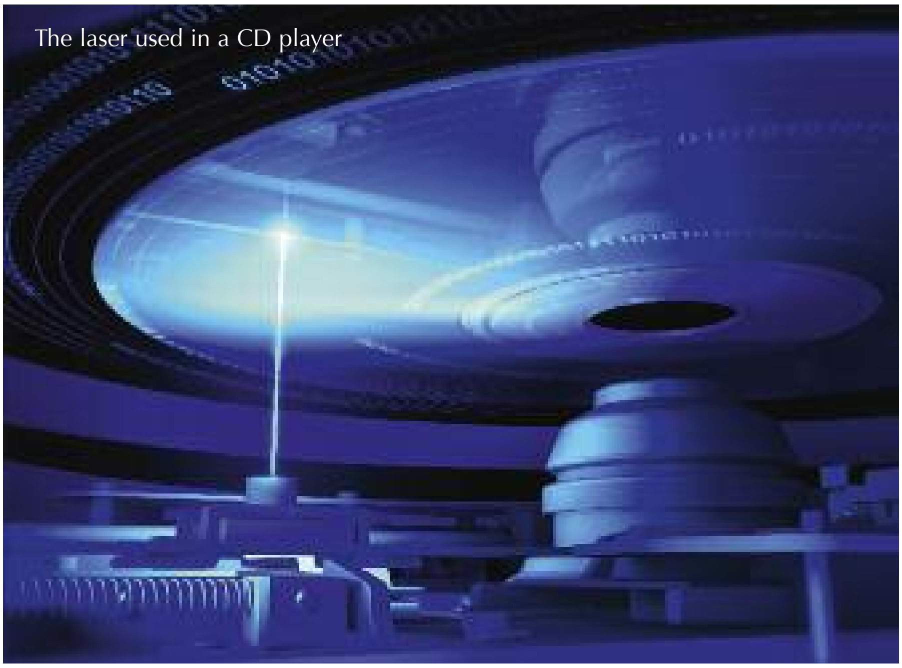
There is more to light than what we can see. The use of light is found in every aspect of science, from the brightening of the dark to the breakdown of plastic. This article gives an overview of the practical uses of light and makes interesting background reading for students researching light as a form of energy.

Andrew Galea, Malta



Fluorescent lamps

Image courtesy of mipokcik / iStockphoto



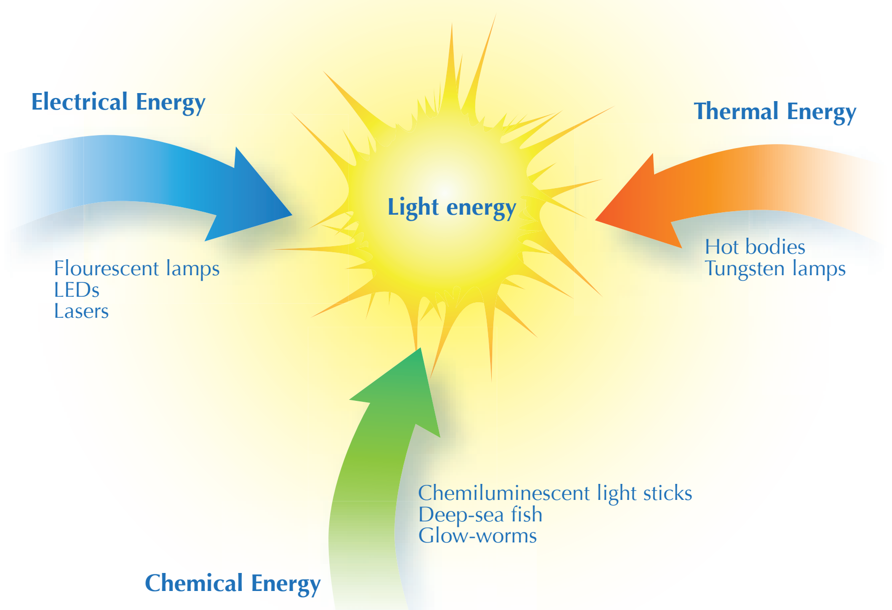
The laser used in a CD player

Image courtesy of Petrovich9 / iStockphoto

around 20%. However, the spectrum of light emitted by these lamps (when the electrons return to their non-excited state) is not continuous; instead, light is emitted at specific wavelengths and colours corresponding to the electrical energy levels of the mercury atoms. Household fluorescent tubes, therefore, have a coating of white phosphor inside to convert this light emission into a more continuous spectrum. Replacing the mercury vapour with other gases, such as neon (which gives an orange light) or other inert gases, allows the production of many different coloured fluorescent lamps, used for luminous displays and signs (see image on page 63). Different phosphor coatings also change the colour of the light from the lamp.

Electrical energy can be converted still more efficiently into light by light-emitting diodes (LEDs); electricity excites electrons in specially designed *semiconductor* (see glossary for all italicised terms) layered structures to produce visible light, with a conversion efficiency of up to 35%. *Electroluminescent* paper uses the same principle. Many lasers also use electrical energy to generate high-intensity laser light, which can be collected into a very narrow, intense beam. High-power lasers can cut metal or can even be used as light scalpels in surgery. Lasers are also used in communications and digital technology in barcode readers and optical disc readers.

'Liquid light' relies on a different kind of energy conversion – *chemiluminescence* – to produce a cold light through chemical reactions rather than thermal energy. This is how chemiluminescent light sticks work. In nature, glow worms and creatures that live in the darkness of caves or the deep sea use chemiluminescence for inter- and intra-species signalling.



Energy conversion: sources of light

Image courtesy of Nicola Graf

Image courtesy of NEUROtiker; image source: Wikimedia Commons

Glow-worm

Photochemistry: fluorescence, plastics, photography and medicine

One type of light emission – *fluorescence* – is used in optical brighteners in washing powders. They absorb the small amount of invisible UV light in the Sun's spectrum, and re-emit it as blue light, making clothes look 'whiter than white'. Fluorescence is also used in the security markings on banknotes, while *phosphorescence* (similar to fluorescence but with a longer life) is used in safety signs. Fluorescence, phosphorescence and chemiluminescence are also used in novelty items such as luminous body paint, hair gel, lipstick and jewellery.

Light can be used to make plastics. Plastics are made by polymerisation – the joining together of lots of small molecules (monomers) to give one long molecule (a polymer). This process often needs something with enough energy to start the process going, although once started, the energy released in the joining-up step is usually enough to keep the process going. When light is absorbed by a molecule, that molecule becomes more energetic because of the energy of the photon it has absorbed; we say the molecule has been excited. These excited-state molecules are excellent polymerisation initiators because of this extra energy – thus light can be used to convert liquid monomers into a solid plastic. This process called *photopolymerisation* gives us dental glues that harden under UV light (see image on page 66), as well as photo-curing paints which are used to print images onto a wide variety of substrates – soft-drink cans for example.

The saprobe *Panellus stipticus* displaying chemiluminescence

BACKGROUND

Glossary

Chemiluminescence: The generation of light directly from a chemical reaction, e.g. the light from glow-worms and chemiluminescent light sticks.

Electroluminescence: The direct generation of light from electricity, e.g. in the display screens of mobile phones.

Fluorescence: The emission of light associated with the transition of an electron from an excited state to a lower-energy state during which an electron does not have to change its spin. Because of this, the light emission happens very quickly after excitation, usually within a few nanoseconds. Thus if the excitation source is removed, fluorescence stops within a few nanoseconds.

Luminescence: A general term for the emission of light.

Phosphorescence: The emission of light associated with the transition from an excited state to a state of lower energy where an electron does have to change its spin. This allows the light emission to occur more slowly, sometimes over a timescale of seconds in molecules and often longer in solid-state phosphors. Thus if the excitation source is removed, phosphorescence can sometimes still be seen, e.g. 'glow in the dark' stickers or the afterglow from the phosphor on a fluorescent tube which can be seen immediately after the light has been switched off (i.e. once the fluorescence has stopped).

Photodynamic therapy: A medical procedure in which light is used to destroy tumours in cancer treatment.

Photopolymerisation: The process by which light is used to create a polymer from monomeric molecules. Photopolymerisation is used to set photo-curing paints, inks and glues. Photo-curing glues are commonly used in dentistry.

Semiconductor: For the purposes of this article, the important feature of a semiconductor is the arrangement of electronic energy levels into two 'bands': a full low-energy 'valence band' and an empty high-energy 'conduction band'. Excitation promotes an electron from the valence band into the conduction band, leaving behind a 'hole'. Both the hole and the electron are mobile and can migrate to the semiconductor surface where they can act as oxidant and reductant, respectively, in the destruction of pollutants.

Image courtesy of dem10 / iStockphoto

Photopolymerisation is used in dentistry

Image courtesy of Peter Douglas

Dr Douglas and his glass baby 'Bili Rubin', show how light is used in the cure for jaundice

Unlike conventional paints, a photocuring paint is set by light rather than by heat and/or air oxidation.

Photographic film relies on the photochemical properties of silver halides. When a grain of silver halide on a film absorbs a photon of light, an atom of silver is made. The film is then chemically processed, and the metallic silver grains comprise the black part of a black and white negative.

The best known use of photochemistry in medicine is the treatment of jaundice, a build-up in the body of a yellow, fat-soluble, neurotoxic substance called bilirubin. Bilirubin is generated constantly as a by-product of haemolysis (the breakdown of red blood cells), but it is normally metabolised in the liver into a water-soluble form that is subsequently excreted. If, however, the liver is damaged or not fully formed, the uncontrolled build-up of bilirubin can be fatal. Exposure to blue light cures jaundice through a photochemical transformation that converts bilirubin into a water-soluble form, allowing its excretion. Hospital wards for prema-

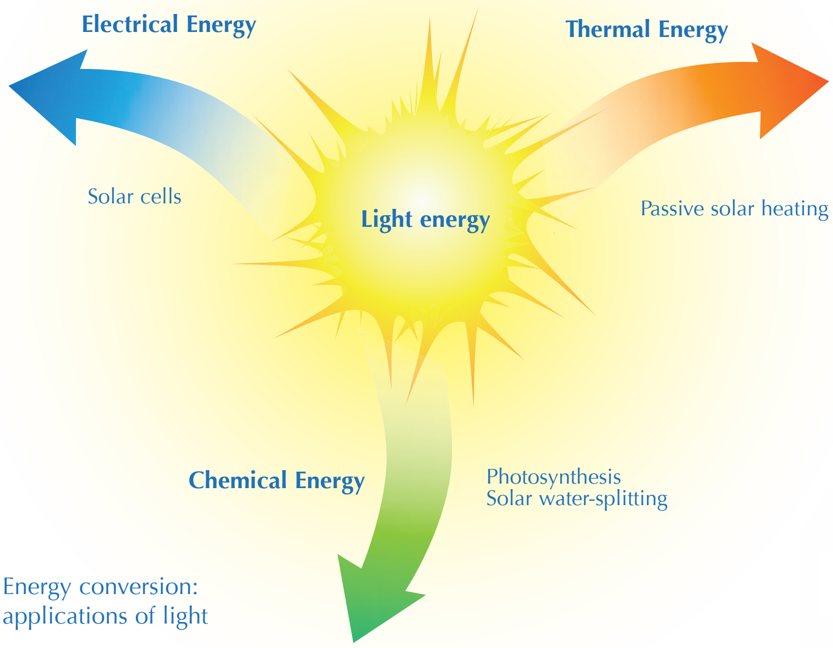
BACKGROUND

The London International Youth Science Forum

The basis of this article was a demonstration lecture by Dr Peter Douglas and Dr Mike Garley on the use of chemistry and light in our everyday lives. The lecture was part of the London International Youth Science Forum 2009 and was attended by 250 students from 40 countries.

At the London International Youth Science Forum 2010, Dr Douglas will explore future developments in science with leading scientists, dignitaries and industry pioneers. A key element of the programme is the opportunity to visit industrial sites, research centres, scientific institutions and organisations, including world-class research institutions and laboratories. For further details on how school students can participate, see: www.liysf.org.uk

Image courtesy of Nicola Graf



Energy conversion: applications of light

Image courtesy of Geckly / iStockphoto

ture babies – who are particularly prone to jaundice – have cots with special lights for the treatment of jaundice.

Another medical application for photochemistry is the use of *photodynamic therapy* to fight cancer. A highly coloured compound with a particular photochemistry is injected directly into a tumour. This compound preferentially adsorbs to cancer cells rather than to normal cells and, when irradiated with light from a laser or other source, forms excited-state molecules that react with oxygen to generate chemicals that are lethal to cancer cells.

Image courtesy of the London International Youth Science Forum


The participants of the London International Youth Science Forum

Clean energy, clean planet

The world's energy demands are increasing whereas its non-renewable supplies are limited. One way to address this problem is by using less energy (e.g. with energy-saving light bulbs). Another way is to exploit renewable sources of energy such as the silicon solar cell, which converts light energy into electricity. The original single-crystal cells, developed in the 1950s to power satellites, were very expensive. Now, much cheaper polycrystalline and amorphous silicon cells are commonly used in powering items such as calculators and battery chargers, as well as in larger-scale domestic, industrial and even national energy installations. In the classroom, the conversion of sunlight into electricity can be observed in a Grätzel cell, which employs artificial photosynthesis using natural dyes found, for example, in cherries (see Shallcross et al., 2009).

Another real problem for the future is the need for a clean transportable fuel. Hydrogen can be generated indirectly from solar energy through the electrolysis of water, but this reaction is wasteful in energy terms. Thus, a great deal of research currently focuses on splitting water into hydrogen and oxygen directly using sunlight.

How else can chemistry and light contribute to a clean planet? Titanium dioxide (TiO_2) is a semiconductor with some interesting photochemical properties. It is used as a white pigment because it scatters visible light effectively. It also absorbs UV light. When used as pigment or as a UV absorber in sunscreens, each particle is coated with silica to prevent the bare TiO_2 surface from coming into contact with its environment. This is necessary because when irradiated with UV light, TiO_2 particles generate very reactive chemical species which will destroy any complex molecules next to them. This apparent disadvantage of bare TiO_2 is now put to great use in the destruction of pollutants because when bare titanium dioxide is irradiated with UV light in solution, it completely destroys any organic compounds close to its surface. As a result, any organic pollutants present are completely mineralised to carbon dioxide, water, and ammonium and chloride ions.

These examples illustrate that chemistry and light are all around us – they are an important part of our technological world, and have an important role in our cleaner, brighter future!

Titanium dioxide sample

Public domain image; image source: Wikimedia Commons

Reference

Shallcross D et al. (2009) Looking to the heavens: climate change experiments. *Science in School* **12**: 34-39. www.scienceinschool.org/2009/issue12/climate

Resources

For a comparison of the spectra of different light sources – and instructions for building your own spectrometer, see:

Westra MT (2007) A fresh look at light: build your own spectrometer. *Science in School* **4**: 30-34. www.scienceinschool.org/2007/issue4/spectrometer

For a full list of *Science in School* articles about energy, see: www.scienceinschool.org/energy

Dr Peter Douglas is a senior lecturer in chemistry in the School of Engineering at Swansea University, UK. After postgraduate studies with Nobel Prizewinner George Porter at the Royal Institution of Great Britain, Peter worked for Kodak Ltd, then joined Swansea University. His research interests lie in applied physical chemistry and photochemistry.

Dr Mike Garley recently retired from his position as senior experimental officer in the chemistry department at Swansea University. A physical scientist by training, he was a research assistant with British Steel, then a part-time lecturer in physics at Swansea Institute before joining Swansea University.

Committed to sharing their enthusiasm for the wonder of science with young people and the general public, Peter Douglas and Mike Garley regularly give their demonstration lecture "Chemistry and Light" at venues across the UK and Europe.

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Hypselodoris bullocki, a large nudibranch Image courtesy of Jeffrey Jeffords (www.divegallery.com)

Model of a linear accelerator at CERN Image courtesy of Paulo José Carapito

Safety note

For all of the activities published in *Science in School*, we have tried to check that all recognised hazards have been identified and that suitable precautions are suggested. Users should be aware however, that errors and omissions can be made, and safety standards vary across Europe and even within individual countries.

Therefore, before undertaking any activity, users 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.

Unless the context dictates otherwise, it is assumed that:

- Practical work is carried out in a properly equipped and maintained science laboratory
- Any electrical equipment is properly maintained
- Care is taken with normal laboratory operations such as heating substances
- 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 / or students are taught safe techniques for activities such as handling living organisms, hazardous materials and equipment.

Credits

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Juggling careers: science and teaching in Germany

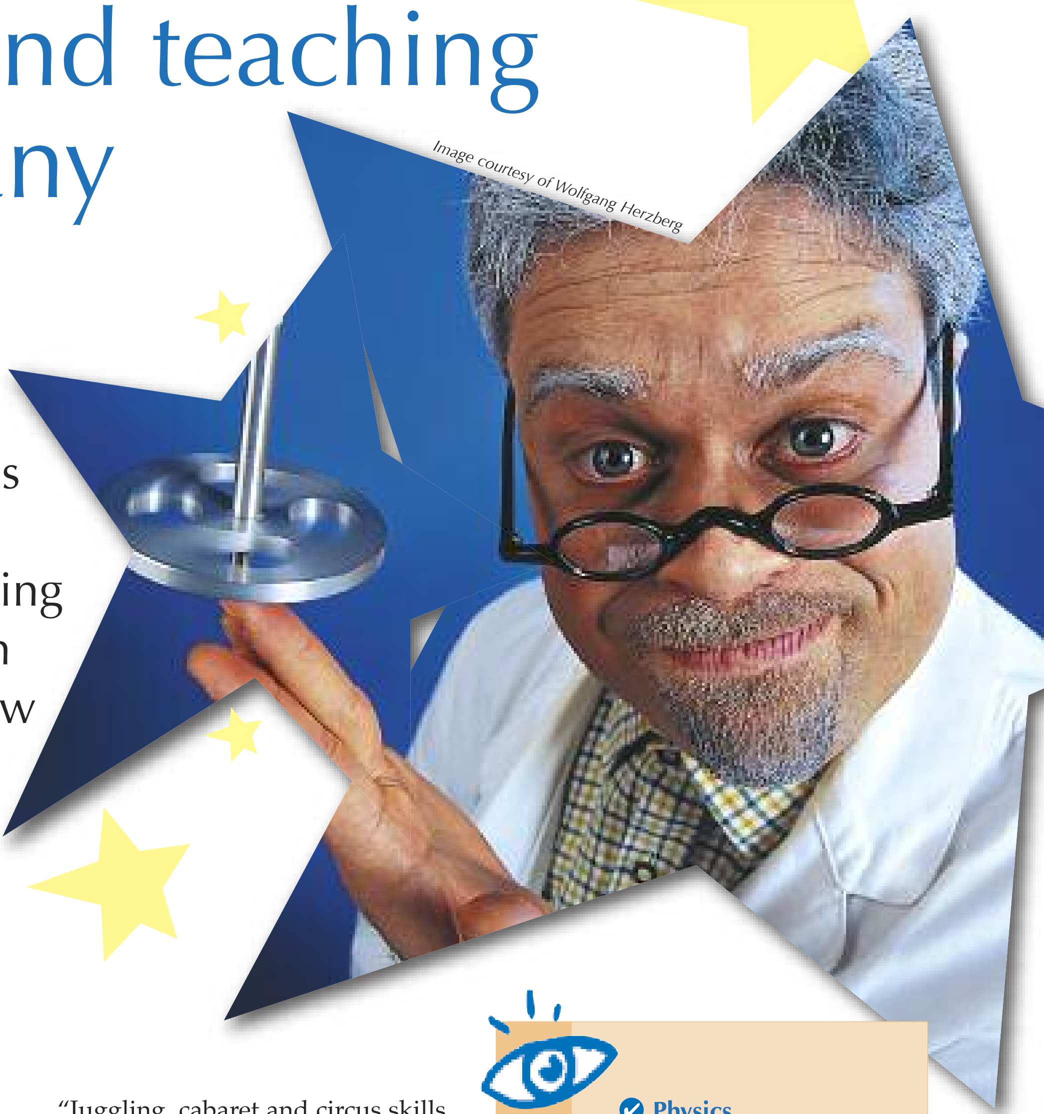


Image courtesy of Wolfgang Herzberg

Jörg Gutschank tells **Vienna Leigh** how his circus skills inspired him to take up teaching and saw him through his training – and how they help in the classroom.

When you're a teacher, it helps to have a cool hobby. One friend of mine, a geography teacher, spends her weekends as a resident DJ in a nightclub – and needless to say, she never gets accused of being over the hill. Nothing demands instant awe and respect like the discovery that a teacher has a secret exciting life going on after hours.

That's something that Jörg Gutschank knows all about, too. When he's not teaching physics, mathematics and computer science at a German secondary school, the Leibniz-Gymnasium[w1], you'll find him juggling, riding a unicycle or even performing daredevil stunts on a flying trapeze!

"Juggling, cabaret and circus skills have always been a hobby of mine, even when I was studying physics – or maybe because of that," says Jörg, who started teaching in secondary school in 2004. "During my PhD a friend and I had the idea to combine our hobbies with our profession – we were both physicists – and in 1999 we were inspired when we saw an advertisement for a festival called 'Physics on Stage'[w2] being held at the European Organization for Nuclear Research [CERN] in Geneva."

Jörg and his friend, Marcus Weber (né Hienz), decided to develop a physics show to contribute to the

REVIEW

Physics

This article offers an interesting view of the odd routes people may take into teaching. It has given me ideas for working with our dance and sports departments to illustrate some applications of physics. I particularly like Jörg's emphasis of the importance of the question, not the answer.

Devon Masarati, UK

Jörg Gutschank with his magic boxes, as a 'professor' in the Physikanten physics shows

Image courtesy of Wolfgang Herzberg

four-day festival, which was being held for the first time in November 2000 and comprised presentations, performances and workshops from physics educators and scientists from 22 countries. "We were thrilled that our show, 'A top, a buoy and a ping-pong ball', was selected for an on-stage performance at the festival," says Jörg. "It was an interactive show involving experiments on angular momentum, aerodynamics and buoyant forces."

From that moment, the pair spent days and nights preparing the show. "We wrote a script and hired a professional director for our rehearsals," remembers Jörg. "We bought equipment, planned and built experiments, and our preparations were even recorded by journalists for a television broadcast!"

The final test was the dress rehearsal at the University of Dortmund, after which they had to pack all the equipment and send it to CERN for the big event. "This first Physics on Stage festival was a great and inspiring experience," says Jörg. "I met many teachers who were eager to exchange their wonderful ideas about teaching and about physics."

The show was so successful that Jörg and Marcus went on to found Physikanten & Co[w3], a company which produces and performs physics shows at science festivals, museums and schools and for companies all over Europe. Themes such as the greenhouse effect, acoustics, electricity and fire are brought to life with props, costumes and special effects. The performances are a mix of comedy, spectacular experiments and audience participation. Physikanten have appeared several times on German TV and in 2008 performed their biggest show ever, an open-air event at the Paul Scherrer Institut near Zürich.

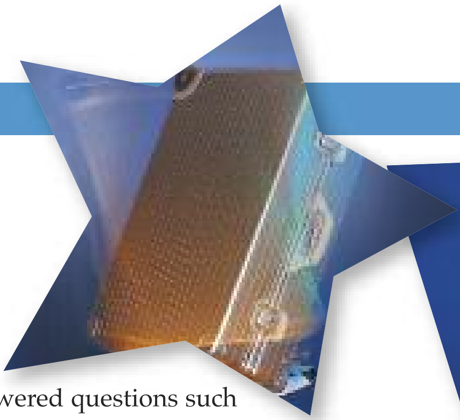
While Marcus stayed to run the company, Jörg was inspired to follow a different path. "After three brilliant years I decided that I really wanted to be a teacher, because I wanted to carry on working with people and do something useful for society, and so I applied for a scheme 'Seiteneinstieg', which allows scientists to move into teacher training," he says.

Images courtesy of Jörg Gutschank

As well as his core subjects, Jörg now teaches science and robotics at his school, a German upper secondary school or *Gymnasium*. "Personally, I prefer to decide what I teach. For this reason I prefer my new subjects to the traditional subjects, physics and mathematics, since there are no official curricula for science and robotics," he says. "It's great to have this freedom of choice and I tend to pass it on to my students by having them choose the details of what they want to do. That's only possible in subjects without an official curriculum."

This means that Jörg and his colleagues have the chance to set up and plan special projects, which is where his creative edge comes in useful again. "My first project was about toys, and it was great fun to combine my ideas with those of my 5th and 6th year pupils [aged 10-12]," he says. "We built little rockets, a boat with a steam engine, and a geyser. Some pupils wanted their hamster to produce electricity with a generator from a bicycle – but for the sake of the hamster, we had only one short session of five minutes doing that!

"In another project, the children had to find out things about their



Images courtesy of Wolfgang Herzberg

body. They answered questions such as why we need two eyes, by playing with a ball and closing one eye. This way the pupils could see the difference between trying to catch with one eye or with two."

Teaching these subjects is made possible due to the special profile of the school, which offers additional bilingual and scientific tuition and which, from this term onwards, is an IB world school. "This means we'll also be teaching the International Baccalaureate diploma programme in addition to the German leaving certificate [*Abitur*]," says Jörg. "Since we're only just starting, we'll be able to teach very small groups, which I prefer. I'll be giving a physics course to only five students – four of whom are female, incidentally – and I'm looking forward to teaching such a small group."

Although such working conditions are to be envied, Jörg agrees that there are some very particular challenges still to be overcome in teaching science. "I think it's most important that we don't give the impression that science is something finished which has to be learnt by heart, but that it's something which is evolving and which needs constant questioning," he says. "This can only work when the teacher admits to the students that he doesn't know everything and that the point is not to know but to question, and to look for ways to solve problems. Involving everyday things and demonstrating the science behind students' day-to-day lives is a great way of inspiring minds that ask questions about everything.

"A positive feeling towards science comes, I think, from this impulse to ask questions – an impulse which is inspired by the teacher. Career decisions are influenced by the attitude towards the subject and the teacher, so a positive feeling and a good relationship makes it more likely that a student will decide to pursue a scientific career."

Web references

w1 – The website of the Leibnitz Gymnasium is: www.leibniz-gym.de

w2 – In 2005, the Physics on Stage science teaching festival was extended to Science on Stage. The sister project of *Science in School*, Science on Stage, was organised by the seven research organisations of EIROforum (www.eiroforum.org) and supported by the European Commission. The project has now developed further into Science on Stage Europe. For more information, see: www.scienceonstage.net and www.scienceonstage.eu

w3 – To learn more about the Physikanten & Co, see: www.physikanten.de

Resources

For more information about Jörg, see his website: www.school.gutschank.eu

If you enjoyed this article, you might also like to read other teacher profiles in *Science in School*. See: www.scienceinschool.org/teachers

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Vienna Leigh studied linguistics at the University of York, UK, and has a master's degree in contemporary literature. As well as spending several years as a journalist in London, she has worked in travel and reference publishing as a writer, editor and designer. She's been widening her scientific horizons in recent years as the information and publications officer at the European Molecular Biology Laboratory and as editor of its newsletter, *EMBL&cetera*.

A scientific mind

Lucy Patterson talks to Yasemin Koc from the British Council about scientific thinking as a versatile tool for life.

"The beauty of science is that it can be applied to any field," explains Yasemin Koc, a young scientist with a wealth of varied career experience behind her. "It teaches a certain analytical way of thinking. A problem is broken down into pieces and examined from a number of different angles. It helps you to understand certain things better. It can be a tool, like another language." It's a tool that Yasemin has put to very good use, through her undergraduate and PhD studies, as a business analyst for the international bank JP Morgan, and now as the advisor for science communication and innovation to the British Council, based in London, UK.

The foundation for Yasemin's interest in science was laid in school. "I became interested in chemistry at grammar school when our teacher told us that he would be collecting our notebooks to rate them. I panicked and ended up rewriting the whole thing. By the end I understood so much that I got full marks in all my chemistry exams.

"In addition to chemistry, volleyball was my big passion (I had played for several different teams in Schwaig near Nürnberg, Germany), and it definitely helped that the coach was my chemistry teacher!"

Yasemin feels like a European: she was born in Nuremberg, has a German passport, and went to school in the area. When she was 18, however, her family, of Turkish roots, moved to Istanbul where she graduated from a German school two years later.

The first of her passions then took

Image courtesy of Joss / iStockphoto and enot-poloskun / iStockphoto

REVIEW

Why should young people pursue a career in science? Is a scientific mind useful in management? How can a scientific career help a career in business?

Too few school students consider studying science – most think that science studies are difficult and that, at the end, there would be few career opportunities. However, "The beauty of science is that it can be applied to any field" are Yasemin Koc's magic words – words that might motivate students to enter science.

Alessandro Iscra, Italy

Images courtesy of Yasemin Koc

Yasemin (second from the right) as a panel speaker on the Arab science and technology strategy at a conference in Cairo, Egypt

Yasemin fencing

her to the Vienna University of Technology [w1], Austria, to study physical and analytical chemistry, and across the Atlantic for a master's degree at MIT[w2] in Boston, USA, analysing synthetic spider silk in a materials lab. Her next stop was London, UK, where she did a five-year PhD in nanotechnology at Imperial College[w3] (to take nanotechnology to the classroom, see Harrison, 2006, and Mallmann, 2008). "At the time, in 2003, nanotechnology was the hottest science field to enter. I contacted professor Andreas Manz, a pioneer in the field, and started my project in his lab soon after."

Yasemin developed a diagnostic tool, the top-secret details of which are now patented by the American company that funded her research (Benninger et al., 2006). The handheld device (similar to an airport metal detector) uses microfluidics nanotechnology to detect a disease in the saliva of an infected person: the person being tested spits on the device, which returns a result in less than one minute.

After completing her PhD, Yasemin decided to change tack a little, becoming a business analyst for JP Morgan[w4]. There, she used her problem-solving skills as a scientist to analyse businesses – how they are organised, how they communicate and how they handle data – and tried to find ways to make them more efficient. "Banks love taking on scientists since they have the ability to think analytically. You present them with a problem, they divide it into its individual components, investigate where the problem might lie, and find an efficient solution."

One year later, Yasemin was again ready for a new challenge. Her current job is the advisor for science communication and innovation to the British Council[w5], an international cultural relations organisation promoting British culture and education opportunities globally. As part of the science team, Yasemin works on several programmes designed to build collaborations with and between scientists, and to encourage discussion and exchange between science and society.

"I find my job immensely inspiring, as its main purpose is to connect: we connect the scientists with each other, scientists with policymakers, scientists with society. We want to enable scientists to make a real change."

How does Yasemin spend a typical day? This turned out to be a question that she happily found somewhat difficult to answer: "A day-to-day description of my job would be difficult because it varies so much – which is basically what makes my job so amazing! One day I might attend a meeting with the Royal Society[w6] to discuss a series of science policy seminars we are planning to run. For example, at the moment I am working with our South African offices on a science policy seminar discussing food, bringing together scientists, policy makers, students and people from the street to discuss the issues of food in modern times.

"Last week I had a meeting with the Norwegian Academy of Sciences and Letters[w7] about our round of debates on the relationship between science and society, bringing together politicians from Norway and the UK, scientists and other critical minds. A few weeks ago, I attended a breakfast meeting at the House of Lords [the upper house of the British parliament] on nanotechnology.

"The situations I experience in this job can be just mind-blowing. I meet science ministers, members of Parliament, famous researchers, famous thinkers, journalists…but the most exciting part of my work is creating the connection between scientists and non-scientists by understanding the scientific world."

Could this be something for you, too? Here's Yasemin's recommendation if you're interested in a job like hers: "Anyone who has done a scientific degree and believes in the connection of science and other disciplines should apply for a job like this!"

Church of Our Lady clock in Nuremberg, Germany

Image courtesy of bcphotobiz / iStockphoto

The Blue Mosque in Istanbul, Turkey

Image courtesy of damircudic / iStockphoto

The Houses of Parliament and Big Ben at night, London, UK

Image courtesy of compassandcamera / iStockphoto

Web references

w1 – To learn more about the Vienna University of Technology (*Technische Universität Wien*), see: www.tuwien.ac.at

w2 – For more information on the Massachussetts Institute of Technology (MIT), see: http://web.mit.edu

w3 – You can find out more about Imperial College London on their website: www3.imperial.ac.uk

w4 – To find out more about JP Morgan, see: www.jpmorgan.com

w5 – Learn more about the British Council, including information and help for teachers interested in including an international perspective in their class or school: www.britishcouncil.org

w6 – The Royal Society is the UK's national academy of science. See: www.royalsoc.ac.uk

w7 – To learn more about the Norwegian Academy of Sciences and Letters (*Norske Videnskaps-Akademi*), see: www.dnva.no

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Mallmann M (2008) Nanotechnology in school. *Science in School* **10**: 70-75. www.scienceinschool.org/2008/issue10/nanotechnology

Resources

To learn about the careers of other young scientists, see the scientist profiles previously published in *Science in School*: www.scienceinschool.org/scientists

Lucy Patterson finished her PhD at the University of Nottingham, UK, in 2005, and has since been working as a postdoctoral researcher, first in Oxford, UK, then in Freiburg and Cologne, Germany. During this time she has worked on answering several different questions in developmental biology, the study of how organisms grow and develop from a fertilised egg into a mature adult, using zebrafish embryos. She has a broad interest and enthusiasm for science, and is currently developing her own embryonic career as a science communicator.

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The *Practical Chemistry* website

Reviewed by Tim Harrison, University of Bristol, UK

Chemistry

The *Practical Chemistry* website is a must for any science teacher or technician who wishes to engage and enthuse students in the excitement of experimental work or who wishes to demonstrate chemistry safely.

This resource, begun in 2006, is continually developing, and at the time of writing contains 213 hands-on and demonstration chemistry practicals. The practicals are grouped into four sections. The *Introductory* section contains some of the simpler experiments for those students just beginning their studies of chemistry. In the *Intermediate* section, the experiments depend on students having been taught some basic chemistry; in the UK, these experiments would target students aged 14-16. The *Advanced* section is aimed at pre-university students. The final section, *Enhancement*, targets chemistry teachers who want experiments that are instructive and fun for students who are perhaps in chemistry clubs, and those who wish to perform the more spectacular chemistry demonstrations suitable for events such as science festivals and open days.

Each experiment includes a brief introduction, notes on lesson organisation and timing, apparatus and chemical requirements, technical notes, procedure, teaching notes and, where appropriate, web links.

Before each experiment is published online, the organisers of the website test them so that they "will work in any school laboratory". In particular, the team has attempted to make sure that all hazards are identified and suitable precautions noted.

A number of instructions on how to safely carry out standard chemistry laboratory techniques are also available. It should be noted that health and safety requirements may well differ from country to country, so this needs to be taken into account before use. Guidelines on health and safety are given at: www.practicalchemistry.org/health-and-safety.

Teachers who have exciting practical experiments may contribute to this body of work by submitting them through the website. Once they have been thoroughly assessed, the experiments may then become published online.

The *Practical Chemistry* website is the result of a joint project of the Nuffield Curriculum Centre[w1] and the Royal Society of Chemistry[w2] in association with CLEAPSS[w3].

Details

URL: www.practicalchemistry.org

Maintained by a team led by Emma Woodley of the UK Royal Society of Chemistry.

Web references

w1 – Nuffield Curriculum Centre explores new approaches to teaching and learning. See: www.nuffieldcurriculumcentre.org

w2 – The Royal Society of Chemistry is the professional body for chemists in the UK. See: www.rsc.org

w3 – CLEAPPS is an advisory service for practical science and technology in UK schools. See: www.cleapss.org.uk

Resources

For a list of all chemistry-related articles published in *Science in School*, see: www.scienceinschool.org/chemistry

Why Evolution is True

By Jerry A. Coyne

Reviewed by Bernhard Haubold, Max Planck Institute for Evolutionary Biology, Plön, Germany

Biology
Evolution

When I recently told a taxi driver that I was on my way to give a lecture on evolution in northern Germany, the young man asked me, looking straight ahead, "So, do you think Darwin got it right?" A bit taken aback, I answered that yes, by and large, Darwin had got it just right – only to be told that there was strong evidence that evolution was false. I was being chauffeured by a friendly creationist.

Against this background of rising creationism, American biologist Jerry Coyne has given us a wonderful exposition as to *Why Evolution is True*. This is one of the rare books that is aimed at the beginner, but can also be enjoyed by the expert. It is based almost entirely on a naturalist's perspective on evolution, leaving out the genetics and the mathematics. This is a good thing, as it makes evolution accessible and emulates Darwin, who, after all, knew little mathematics and got the genetics wrong.

Coyne lays out his case in nine chapters. After an introduction that explains the elements of evolution, we hit rock bottom: the fossils that have been collected for the past one and a half centuries. One of the most spectacular recent finds, the fossil species *Tiktaalik roseae*[w1], links terrestrial tetrapods with fish. It had been predicted to exist, and a likely place to find it was a particular site in the Canadian Artic, where after five years of excavation it was finally unearthed in 2004.

This predictive power of evolution is a recurrent theme of Coyne's book. The chapter 'Remnants' deals with vestiges and atavistic features. Given the fact of common descent, these should not surprise us, but I was still intrigued to read that human babies are occasionally born with fully formed tails, and that dolphins have inactivated 80% of their olfactory receptors, as most of them are useless under water.

The mechanism underlying dolphins' adaptation to aquatic life is natural selection, the topic of the central chapter of the book. Natural selection is not popular among doubters of evolution, but in fact it can easily be observed around us in the increase of antibiotic resistance, recurrent influenza epidemics, and plant and animal breeding. In addition, natural selection can be measured in the laboratory and Coyne explains some of the most exciting work in experimental evolution of the past two decades.

A special kind of natural selection is exerted though female mate choice and male competition for females. This 'sexual selection' is an old idea, but it has been difficult to pin down. Coyne cites elegant experiments that explain why male peacocks have such splendid tails.

If natural selection is, as Coyne entitles the corresponding chapter, the 'Engine of Evolution', species are its product. But to explain speciation is to explain reproductive isolation, and in many cases this has little to do with adaptation. Speciation is Coyne's own research speciality, and he argues that in the vast majority of cases, it is an accidental by-product of geographic separation.

Although to doubters, the evolution of dinosaurs and dolphins might be harmless, they draw the line at human evolution. The chapter 'What about us?' carefully lays out how we know that modern humans originated in Africa only 150 millennia ago. Coyne's presentation of the fossil evidence for this, complemented by a comprehensive time line and fine drawings of anatomical details, is particularly compelling. One consequence of the recent origin of modern humans is that we are genetically more similar to each other than one might expect given our diverse shapes and colours.

The topic of human genetic similarity brings us close to what Coyne calls the "unpleasant emotional consequences" that some people – including perhaps my taxi driver – feel when contemplating human evolution. Emotional reactions to evolution are also bound to come up in class, where Coyne's book will be particularly helpful. Teachers of secondary-level biology will find it full of vivid examples ready for transfer to the classroom. The lucid text is augmented by a glossary summarising the vocabulary of evolution, annotated suggestions for further reading, and a succinct guide to relevant web pages that cover topics ranging from Darwin's collected works to resources for students and teachers. Perhaps best of all, Coyne's measured tone may well entice students and readers to experience the liberating emotional consequences of contemplating the truth of evolution.

Details

Publisher: Oxford University Press
Publication year: 2009
ISBN: 9780199230846

Web reference

w1 – To learn more about *Tiktaalik roseae*, visit this dedicated website: http://tiktaalik.uchicago.edu

Resources

Read more about natural selection and molecular evolution in:

Bryk J (2010) Natural selection at the molecular level. *Science in School* **14**: 58-62. www.scienceinschool.org/2010/issue14/evolution

Learn more about common descent and gills in human embryonic development in:

Patterson L (2010) Getting ahead in evolution. *Science in School* **14**: 16-20. www.scienceinschool.org/2010/issue14/amphioxus

For a list of all resource reviews published in *Science in School*, see: www.scienceinschool.org/reviews

Science comics and cartoons

Comics have generally been considered as nothing more than a cheap pastime. However, **Mico Tatalovic** suggests some useful comics to help promote and explain science to students.

Image courtesy of Jaleel Shujath, Edward Dunphy and Max Velati

Image courtesy of Graham Manley (grahamman@hotmail.co.uk). Planet Super Powers resources can be found on the Planet Science website at www.planet-science.com/psp

Image courtesy of *The Young Scientists*, Singapore – a science comic magazine series for children (www.theyoungscientists.in)

There is an increasing amount of evidence that comics and still cartoons can be useful when teaching science. Children enjoy reading comics, and both the visual appeal of the artwork and the intriguing narrative (which can be humorous and educational) make comics an excellent medium for conveying scientific concepts in an interesting way.

As scientists have become aware of this novel and appealing form of engaging with young people, a variety of educational science comics and cartoons has been produced and is now available for teachers to 'spice up' their science lessons. Some examples of these comics and their associated websites are given here.

They can be used by teachers as a lesson starter, to determine students' prior knowledge (such as existing scientific vocabulary, preconceptions and misconceptions), to motivate students to ask questions, and to help gauge students' understanding of science topics by allowing them to produce their own comics and punchlines. With older groups, the comics could be set as preparatory homework for subsequent classroom discussion of the story's scientific merit and credibility.

Unless indicated otherwise, all of the following resources are free.

General science

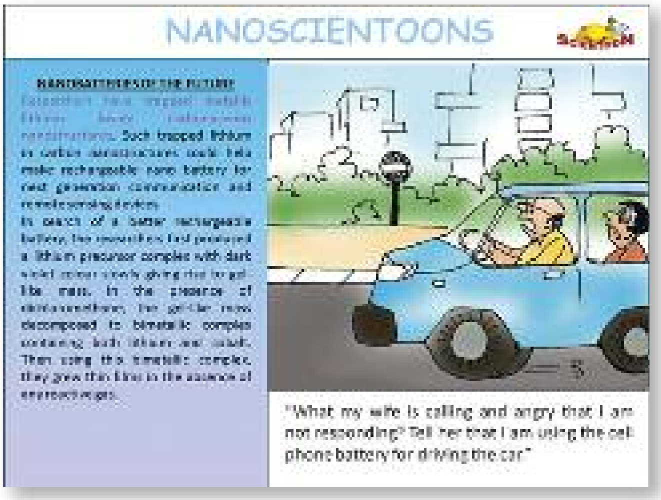
Newton and Copernicus

These are short comic strips about two lab rats whose conversations can motivate students to think about science and research: www.newtonandcopernicus.com
A description of how to use these cartoons in the classroom can be found at: www.csun.edu/~jco69120

Scientoons

Indian scientist and science communicator Pradeep Srivastava has created cartoons embedding new research, ideas, data or scientific facts within the caricatures, satirical comments or dialogue: www.scientoon.com

Image courtesy of Pradeep Srivastava



Planet Super Powers

Created by Planet Science, *The Battle for the Planet Science* comic includes a competition to 'engineer' your own superhero. A teacher's pack and activities are also available: www.planet-science.com/randomise/index.html?page=/psp/home.html&page=/psp/index.html

The Adventures of Archibald Higgins

This adventure series is the brainchild of French astrophysicist Jean-Pierre Petit, and the comics cover many advanced science topics in many languages: www.savoir-sans-frontieres.com

Concept Cartoons

These are single-frame cartoons that depict a single problem, such as 'Would a snowman melt faster, slower or at the same rate if we put a coat around it?'. Offering no immediate solution, these cartoons make students think about the problem and discuss it. There are a few free examples online and the complete collection can be ordered in English and Welsh, as books, posters, photocopiable cartoons or a CD-ROM, from: www.conceptcartoons.com/index_flash.html

The Young Scientists

This comic book magazine, aimed at 5-13-year-olds, communicates science and the life stories of great scientists and promotes creative thinking and practical experimental skills. You can order the books and download sample issues from: www.theyoungscientists.in/products.html

Max Axiom

These comics cover a variety of topics from electromagnetism to natural selection and are aimed at students aged 8-14. They feature the superhero Max Axiom who 'will do whatever it takes to make science super cool and accessible'. Copies can be ordered from: www.capstonepress.com/aspx/pDetail.aspx?EntityGUID=8bd6f56b-a478-44aa-ba47-93b69dce0b27

Jim Ottaviani's comics and graphic novels

Nuclear engineer Jim Ottaviani's comics include *Dignifying Science* (why women are underrepresented in science), *Suspended in Language* (Niels Bohr's life and scientific discoveries), *Fallout* (science and politics of the first atomic bombs), *Two-fisted Science* (the history of science),

Image courtesy of Jean-Pierre Petit (www.savoir-sans-frontieres.com)

Levitation (psychics and psychology of magic), *Wire Mothers: Harry Harlow and the Science of Love* (the science of love) and *Charles R. Knight: Autobiography of an Artist* (the story of an artist whose paintings influenced 20th century scientific fact and fiction). The books can be ordered from: www.gt-labs.com

Big Time Attic comics and graphic novels

Zander and Kevin Cannon have illustrated non-fiction graphic novels such as *Bone Sharps, Cowboys and Thunder Lizards* (scientists who discovered dinosaur fossils), *The Stuff of Life* (all about DNA) and *T-Minus: The Race to the Moon* (astronomy). Their books can be ordered from: www.bigtimeattic.com

Biology, health and medicine

Interferon Force

An exciting story about the battle between the immune system's interferon molecules and flu viruses. Free hard copies are also available from: www.interferonforce.com

Adventures in Synthetic Biology

A good introduction to genetic modification and similar topics, available in English and Spanish: http://openwetware.org/wiki/Adventures

The Conundrum of the Killer Coronavirus

A two-page comic all about severe acute respiratory syndrome (SARS): www.biotechinstitute.org/resources/YWarticles/14.1/14.1.3.pdf

World of Viruses

Graphic novels developed by the University of Nebraska in Lincoln, Nebraska, USA, which each present advanced scientific material about various viruses. You can download a sample and order the books here: www.worldofviruses.unl.edu/materials/stories.html

Friends Forever – A Triumph Over TB

A story illustrated in comic form for patients with tuberculosis, which aim to raise awareness of the disease: www.nyc.gov/html/doh/downloads/pdf/tb/tb-patient-comicbook.pdf

Luís Figo and The World Tuberculosis Cup

An educational comic book featuring a celebrity footballer and his support of the Stop TB Partnership to raise awareness of tuberculosis: www.stoptb.org/figo/assets/documents/bookdownload/FigoComicBook_ENG_low_res.pdf

X-Men Life Lessons

This comic book can be used to help young people who have survived serious burn injuries, and comes with a discussion booklet: www.starlight.org/xmen

Medikidz

A group of five superheroes are followed on a journey around Mediland (the human body) so that young people can learn about medical issues. The books can be ordered via the website, which also provides additional resources for children on medicine: www.medikidz.com

Jay Hossler's comics and graphic novels

Jay Hossler, Assistant Professor of Biology at Juniata College, Huntington, Pennsylvania, USA, has written and illustrated graphic novels such as *Clan Apis* (bee behaviour), *Sandwalk Adventures* (how natural selection works and how it differs from creation stories) and *Optical Allusions* (eye biology and evolution). You can read some of the shorter comics online and order the graphic novels from his website: www.jayhosler.com

Image courtesy of Jaleel Shujath, Edward Dunphy and Max Velati

Cardiocomic

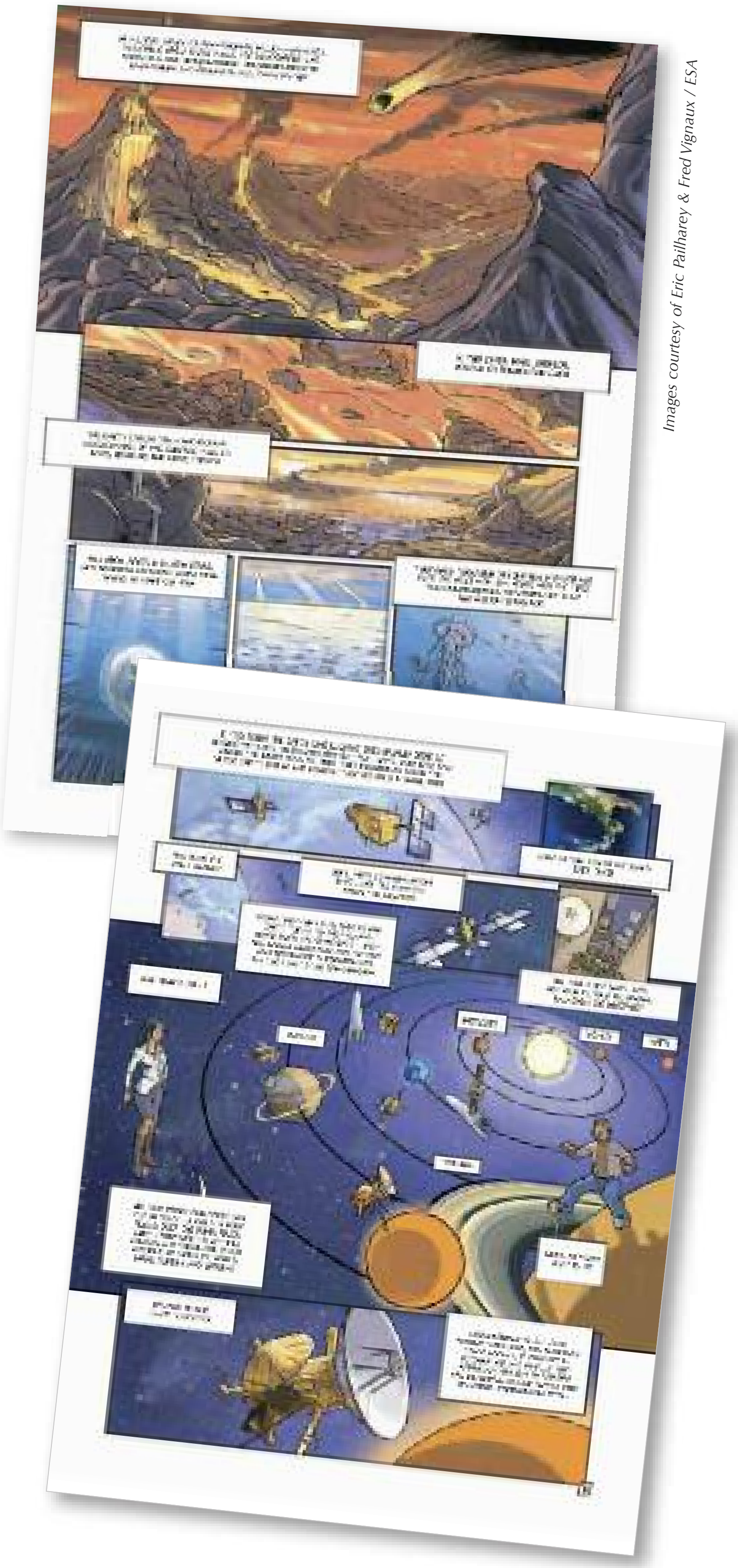
In 2009, the Centre d'Investigació Cardiovascular (Cardiovascular Research Centre, CSIC-ICCC) in Barcelona, Spain, ran its first competition for school students to draw cartoons about cardiovascular disease. You can find the cartoons in Spanish and Catalan, as well as details on the 2010 competition, here: http://cardiocomic.blogspot.com

Menudos corazones
The Spanish 'Menudos corazones' foundation for children and young people with cardiopathies has edited three comics on the topic to help these youngsters cope better with their situation: www.menudoscorazones.org/index.php?option=com_content&task=view&id=295&Itemid=122&lang=es

Chemistry

Selenia
This chemistry comic series is designed to teach chemistry to pupils aged 7-10. Each issue covers a single subject, has an engaging narrative that explains the science involved, and features a glossary explaining the scientific terms: www.sciencecomics.uwe.ac.uk

Vladimir Prelog
A Croatian chemistry comic: http://prelog.fkit.hr/program/popularizacija/Prelog_strip.pdf



Images courtesy of Eric Pailharey & Fred Vignaux / ESA

Physics, astronomy and space science

Cassini-Huygens: a probe to Titan
On 14 January 2005, the European probe Huygens entered the atmosphere of Titan – one of Saturn's moons. Based on this major event in space exploration, the European Space Agency (ESA) has developed a comic book with supporting fact sheets for teachers to use in the classroom. They are available in Dutch, English, Finnish, French, German, Spanish and Swedish. See: www.esa.int/SPECIALS/Education/SEM6ZC9FTLF_0.html

Cindi in Space
A superhero style comic about the ionosphere and satellites, available in English and Spanish: http://cindispace.utdallas.edu/education/cindi_comic.html

The STEL Mangas
The Solar-Terrestrial Environment Laboratory (STEL) of Nagaya University in Japan has produced a series of eight Manga comics on topics such as global warming, solar radiation, geomagnetism and cosmic rays. The comics are freely available in English and Japanese and for translation into other languages: www.stelab.nagoya-u.ac.jp/ste-www1/doce/outreach.html#anc_booklets

Environmental issues and agriculture

Ozzy Ozone

Produced by the United Nations Environment Programme, this interactive comic provides information and activities about the ozone layer, environment, climate change and the atmosphere: www.ozzyozone.org

Eco Agents

An interactive online comic created by the European Environmental Agency to engage students with topics such as ecology and sustainable energy: http://ecoagents.eea.europa.eu

Science Stories

Comic stories from the Rothamsted Research Institute, an agricultural research centre in Harpenden, UK, depicting researchers from the institute, in cartoon form, describing their areas of research: www.rothamsted.ac.uk/schools/ScienceStories

Water Heroes

A comic story and associated teaching activities produced by Environment Canada to teach students about freshwater ecosystems and conservation: www.on.ec.gc.ca/greatlakeskids/water-heroes-e.html

Using comics in the science classroom

The following articles offer suggestions on how to use comics in the science classroom.

Keogh B et al. (1998). Concept cartoons: a new perspective on physics education. *Physics Education* **33**: 219-224

Tatalovic M (2009) Science comics as tools for science education and communication: a brief, exploratory study. *Journal of Science Communication* **8**: A02. Free access at: http://jcom.sissa.it/archive/08/04/Jcom0804%282009%29A02/?searchterm=None

Vilchez-Gonzales JM, Palacios, FJP (2006) Image of science in cartoons and its relationship with the image in comics. *Physics Education* **41**: 240-249

Weitkmap E, Buret F (2007). The Chemedian brings laughter to the chemistry classroom. *International Journal of Science Education* **29**: 1911-1929

Resources

If you found this article helpful, you may like to read the other 'Resources on the web' articles published in *Science in School*. See: www.scienceinschool.org/web

Born in Rijeka, Croatia, Mico Tatalovic did a bachelor's degree in biology at Oxford University, UK, and then a master's in zoology at Cambridge University. While working on Cambridge University's *BlueSci* magazine, he developed a love for science writing and went on to do a master's in science communication at Imperial College, London. Mico is currently a freelance science writer.

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