Spring 2009 Issue 11

SCIENCE in SCHOOL

In this Issue:

Time travel: science fact or science fiction?

Also:

Powering the world

Why is energy so important?

Highlighting the best in science teaching and research

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.**

***Science in School* addresses science teaching both across Europe and across disciplines: highlighting the best in teaching and cutting-edge research. It covers not only biology, physics and chemistry, but also maths, earth sciences, engineering and medicine, focusing on interdisciplinary work.**

The contents include teaching materials; cutting-edge science; education projects; interviews with young scientists and inspiring teachers; European education news; reviews of books and other resources; and European events for teachers.

***Science in School* is published quarterly and is available free online; free print copies are distributed across Europe. Online articles are published in many European languages; the print version is in English.**

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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.

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Science in School is published by EIROforum (a collaboration between seven European inter-governmental scientific research organisations: www.eiroforum.org) and is based at the European Molecular Biology Laboratory (EMBL: www.embl.org) in Heidelberg, Germany.

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We welcome articles submitted by scientists, teachers and others interested in European science education. Please see the author guidelines on our website for details.

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If you are interested in reviewing articles for their suitability for publication, please read the guidelines for referees on our website.

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If you would like to review books or other resources for *Science in School*, please read the guidelines for reviewing books on our website.

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We offer articles online in many European languages. If you would like to help us by translating articles into your own language, please read the guidelines for translators on our website.

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Science in School is the **only** European journal aimed at secondary-school science teachers across Europe, and across the full spectrum of sciences. It is freely available on the web and over 20 000 full-colour printed copies are distributed each quarter.

The target readership of *Science in School* includes everyone involved in European science teaching, including:

- Secondary-school science teachers
- Scientists
- Science museums
- Curriculum authorities

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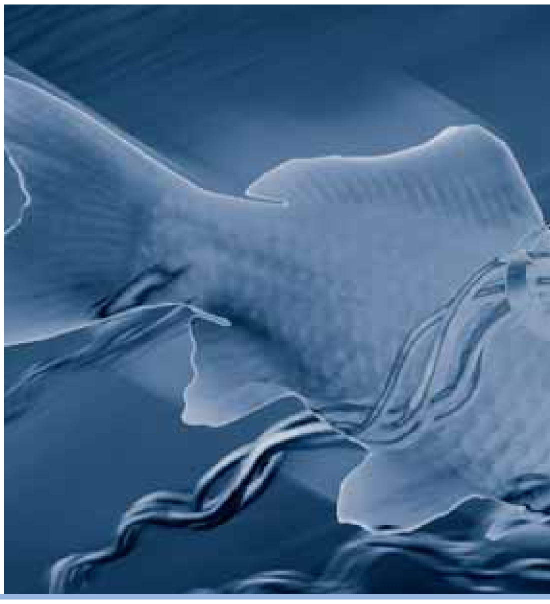
Welcome to the eleventh issue of *Science in School*



Are you curious to find out what life will be like in a hundred years' time? Or have you always fancied living in ancient Egypt? According to Jim Al-Khalili, it may one day be possible – or will it? Is time travel science fact or science fiction? Find out more in this issue's feature article.

To some people, systems biology is just as difficult to grasp as time travel. If you've been wondering what all the fuss is about, let Les Grivell explain what's behind this buzzword and how to introduce your students to this area of science.

Just as in systems biology, many science disciplines join forces to study the underlying structures of biomolecules. Dominique Cornuéjols introduces us to crystallography, while Beat Blattmann and Patrick Sticher suggest a great classroom activity to crystallise proteins just as scientists do. They've even offered to analyse your crystals in their lab and answer your students' questions in an online chat. Dominique also takes us on a protein's journey through a series of labs, where scientists try to work out its structure. Why do we need to know? Claire Ainsworth shows us how elucidating the structure of a protein can help develop a new flu vaccine.

While flu is familiar to most of us in Europe, elsewhere in the world, other pathogens cause serious problems, such as *Schistosoma* flatworms, considered by the World Health Organization as second only in importance to malaria pathogens. Alan Wilson and Stuart Haslam are studying glycoproteins produced by the worms' eggs and larvae, hoping to find the key to developing a new drug against schistosomiasis.

Health is important for our quality of life, but so too is energy; Gieljan de Vries tells us just how important. But there's a problem: we're running out of conventional fuels, and need to find alternative sources of energy. To bring them right into the classroom, why not try the classroom activities described by Dudley Shallcross, Tim Harrison, Steve Henshaw and Linda Sellou?

We all know that our use of energy affects our climate, but how much do we know about the atmospheric phe-

nomena involved? With Karen Bultitude's help, your students can investigate them in the classroom. While this setting is pretty comfortable, our profiled scientist, physicist Alison McLure, braved much more extreme weather conditions. She tells us about her very varied career, including a spell as a meteorologist in Antarctica.

Another scientist who left the bench is Christian Mellwig – read Vienna Leigh's story of how he became an enthusiastic science teacher. For teachers in primary schools, however, the idea of giving science lessons can be quite daunting. Samuel Lellouch and David Jasmin from the Pollen project have one solution – they send university students into primary schools to help teachers overcome their fears. Read up on some of the activities that you can use in your classroom, too.

If none of these articles takes your fancy, why not submit your own or encourage your students to give it a go? Science writer Rebecca Skloot tells Sonia Furtado what she believes makes a good science story – and we invite all students to enter our science writing competition. The best stories will be published in *Science in School*!

Finally, we're proud to announce the relaunch of our website (www.scienceinschool.org): explore its new dynamic features, join our discussion forum, and give us your feedback. And why not join our growing group of translators to help share our articles with online readers in your home country?

Marlene Rau
Editor of *Science in School*
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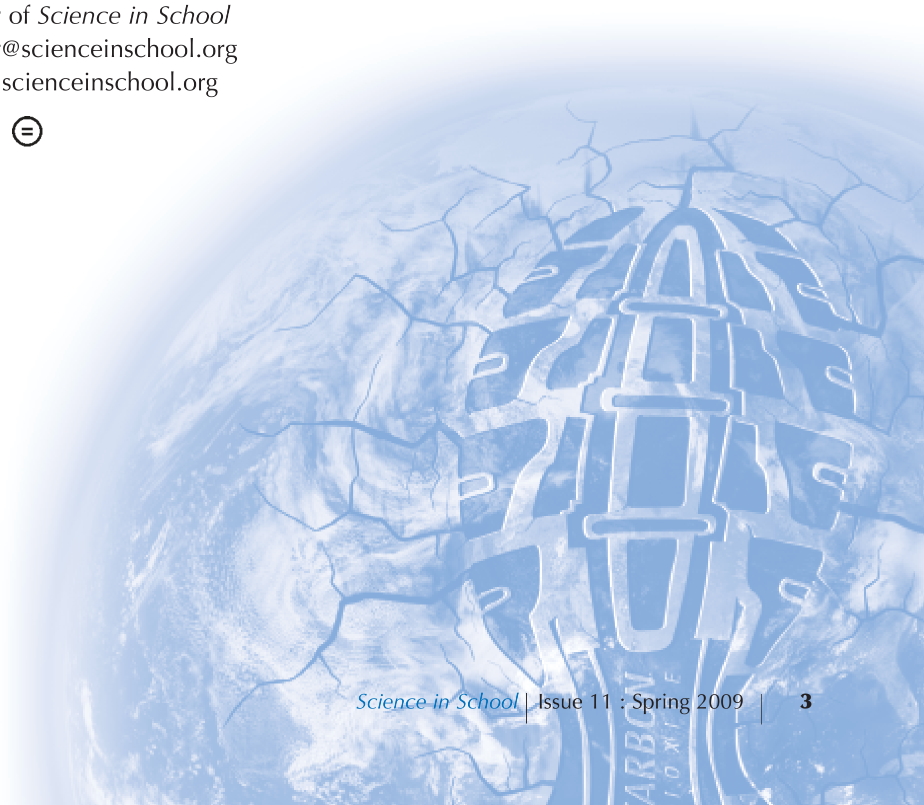


Forthcoming events

For a more extensive list, see www.scienceinschool.org/events

April – November 2009

60 cities in Germany

Exhibition train: Expedition Future, SciencExpress

The Federal Republic of Germany is 60 years old, and to celebrate, a travelling exhibition in the form of a science train will visit 60 German cities for three days each from spring to autumn, and present how science and research will change our lives in the next 10 to 15 years. Besides its 12 exhibition wagons, the train offers a lab where you can try out experiments yourself. The exhibition is aimed at a public ranging from school students to young scientists, and admission is free.

More information: www.expedition-zukunft.org

Contact: Dr Hannelore Hämmerle (haemmerle@gv.mpg.de)

May – September 2009

6 cities in Switzerland

Science Festival: Festival Science et Cité basecamp 09

This year's festival topic is the International Year of Planet Earth. Through the main travelling exhibition and a regional programme of debates, presentations, excursions and more, the Swiss earth sciences will be presented: geology, geography, crystallography, glaciology, hydrography and similar disciplines in which Earth is studied. Starting in Zürich, the festival will then move to Lugano, Neuenburg, Geneva, Chur and end in Bern. For schools, there is a special programme including teaching materials, excursions, poetry slams, a rap contest, a pool of experts ready to visit your school, and more.

More information: www.basecamp09.ch

Contact: Dr Elisabeth Veya (elisabeth.veya@science-et-cite.ch)

4 – 17 May 2009

Göteborg, Sweden

International Science Festival: Folk Forever

This year's festival theme, Folk Forever, is about civilisations across history and countries. The festival is divided into three parts: the public programme; a school programme from 4 – 15 May; and a specialist programme for invited guests. For schools, there are hands-on activities, often with preparatory or follow-up materials, and a competition for school students. Registration via email is required for the school programme.

More information: www.goteborg.com/default.aspx?id=8691

Contact: Madeleine Koncilja (madeleine.koncilja@goteborg.com)

13 May 2009

German Cancer Research Center, Heidelberg, Germany

Student Symposium: Initiative Youth and Science

The Initiative Youth and Science is organising the fifth symposium for students, to present their projects on science, technology and mathematics. There will also be lectures on astrophysics, and scientists will respond to the students' questions. Students from grade 7 (aged 12 to 14) onwards can submit their projects. In addition, all interested teachers and students from grade 7 and above are invited to attend the symposium – they are requested to register via email.

Language: German

Deadline for project submission: 16 March 2009

More information: www.explo-heidelberg.de/lernlabor/Symposium_JuWi.htm

Contact: Dr Fred Engelbrecht (engelbrecht@explo-heidelberg.de)

13 – 17 May 2009

Perugia, Italy

Science Festival: Perugia Science Fest, Wonders 09 European Science Festival, EUSCEA Annual Conference

This year, the Perugia Science Fest will host the main events organised by the European Science Events Association (EUSCEA): the Wonders09 European Science Festival, a seminar on 'How to organise a special science event', and the EUSCEA Annual Conference. At the Science Fest, school groups can take part in a wide range of workshops, exhibitions, conferences, concerts, performances and shows. They will also have the opportunity to join Wonders09. The Darwin Year and Galileo Galilei will be main topics of activities. At the end of the festival, the organisers hold science workshops in schools throughout the Umbria region to give continuity to the activities of the festival itself. The festival will also offer seminars and round tables to discuss new methods of science teaching.

More information: www.perugiasciencefest.eu

Contact: info@perugiasciencefestival.it

14 – 16 May 2009

Seville, Spain

Science Fair for Students: Feria de la Ciencia de Sevilla

Throughout the three-day Science Fair, participating students from different educational levels present science projects that were previously prepared at school. The Science Fair is also a place where national private and public institutions present their current research. This year's topics will be evolution, to commemorate the 150th anniversary of the formulation of Darwin's theories, and astronomy, to coincide with the International Year of Astronomy.

More information: http://cienciacompartida.org

Contact: sadc@cienciacompartida.org

Until 16 May 2009

throughout Europe

Competition: SESAME 2008 – 2009

SESAME is an international research project that incorporates a variety of disciplines to explore and study the ecosystem changes of the Mediterranean and the Black Seas as well as their surrounding environments. If you're a science teacher in Europe, participate in the SESAME school competition with your class! The contest is divided into two age classes:

- Ages 6 to 11 (create a travel diary about an oceanographic expedition carried by the SESAME Project)
- Ages 12 to 16 (write a newspaper published onboard a research vessel during a SESAME oceanographic expedition)

1st prize: A computer for the class

2nd prize: A world mural map (National Geographic)

3rd prize: Teaching materials about marine environment and climate change.

Submission deadline: 16 May 2009.

More information: www.sesame-ip.eu/public

Contact: Evangelos Papathanassiou (vpapath@ath.hcmr.gr), Eleni Kaberi (ekaberi@ath.hcmr.gr)

29 May 2009

Berlin, Germany

Conference: Berlin European conference on science education in primary school

On the day that the Pollen project (2006-2009) for promoting inquiry-based science teaching in primary school reaches completion, a European conference on science education will be held to discuss issues and findings, and to promote best practice in the field. Co-organised by the Freie Universität Berlin, the Berlin-Brandenburgische Akademie der Wissenschaften and the Pollen Project, this conference will address four major issues:

- Inquiry-based science education as a key approach
- Community participation and support for dissemination
- Involvement of the scientific community
- Science and cross-disciplinary teaching.

Participation is free of charge.

Language: English

Registration is via email.

More information: www.pollen-europa.net

Contact: Dr Petra Skiebe-Corrette (skiebe@zedat.fu-berlin.de), Janick Rajoharison (janick.rajoharison@inrp.fr)

June / July 2009

venues throughout the UK

Student Science Fairs: Regional CREST Fairs

Regional CREST (CREativity in Science and Technology) Fairs are organised across the UK in 12 regions. They are a wonderful opportunity for students aged 11-19 to present their projects, not only to peers, but also to the local science and educational professionals of the judging panel, and to celebrate the work that students and teachers have put into the projects over the past year. Students are also competing for the chance to attend the National CREST Final the following spring, which takes place as part of The UK Young Scientists and Engineers Fair. Any students, schools and/or parents can contact their local CREST co-ordinator to nominate a CREST project for their local regional CREST Fair.

More information: www.britishscienceassociation.org

4 June – 1 October 2009

more than 30 cities in Germany

Roadshow: MS Science 2009 (science ship)

The floating Science Center *MS Wissenschaft* will be on tour again from June through September, this year focusing on 'future'. The interactive exhibition will explore what everyday life in the future could look like and what current research is doing to achieve this. It is suitable for students aged 10 and above. School classes and groups are requested to register.

More information: www.wissenschaft-im-dialog.de/projekte/ms-wissenschaft.html

Contact: Beate Langholf (beate.langholf@w-i-d.de)

6 – 7 June 2009

Bristol, UK

Science Festival: Bristol Festival of Nature

The Festival of Nature is a public event held annually on the first weekend of June in Bristol. The Festival is an imaginative weekend of films, animal encounters, exhibitions, walks, talks, workshops and competitions for all ages and interests. It also includes a very popular food market, with genuine and healthy produce from the South West of England and beyond. A full programme of activities will be available about two months before the event. All events are free of charge.

More information: www.festivalofnature.org

Contact: info@festivalofnature.org

15 – 16 June 2009

Nottingham Trent University, UK

Student Workshop: Physics of Forensics Competition Day

This physics competition day for Year 10 students is aimed at teams of four able students, who should be accompanied by a teacher of the physics element of KS4 (for students aged 14–16). There will be an opening lecture, practical work and student presentations, which will be followed by a prize-giving session. Accompanying teachers will have the opportunity to participate in a teachers' workshop, provided by the Institute of Physics, and also to spend time with their students. The event is free of charge. Prior registration is required.

More information: www.ntu.ac.uk/cels

Contact: Georgina Westbrook (georgina.westbrook@ntu.ac.uk), Natasha Neale (natasha.neale@ntu.ac.uk)

19 – 21 June 2009

Gläsernes Labor, Berlin, Germany

Follow-up workshops: Science on Stage 2009

An important constituent of the international Science on Stage festival 2008 in Berlin, organised by Science on Stage Germany, were workshops on a variety of topics from the area of science education. The work on four of the topics will now be continued in 2009/2010.

Topics will be:

- Science in kindergarten and primary school
- Are non-formal education initiatives always beneficial?
- Solo entertainer or moderator? The science teacher of the future
- Self-perception in the teaching process.

Registration is via email.

More information: www.science-on-stage.de

Contact: info@sciencein-on-stage.de

20 – 26 June 2009

Saarbrücken, Germany

Science Festival: Science Summer 2009

Every year, Wissenschaft im Dialog organises a week of science events for the public in a different German city – this year in Saarbrücken, the capital of the Saarland. Aimed at the general public, it also offers 50 hands-on experiment stations for schoolchildren to be explored. Moreover, there will be a science film festival, science theatre for children aged 6 to 12, the *MS Science* exhibition ship, science lectures, the Researchers' Night, and much more.

More information: www.wissenschaft-im-dialog.de

Contact: Hella Grenzebach (hella.grenzebach@w-i-d.de)

21 June – 14 July 2009

XLAB, Göttingen, Germany

Student Summer Camp: International Science Camp

The XLAB Experimental Laboratory for Young People invites high-school and first-year university students aged about aged 17-20 from all over the world to participate in the XLAB International Science Camps. The courses cover current topics in physics, biology and chemistry. Thirty students will be accepted for the camp, with only two to four students from each country. The price is €1750 plus travel expenses. Financial support is possible and should be applied for by 15 March.

Application deadline: 1 March 2009

Language: English

More information: www.xlab-goettingen.de

Contact: Sciencecamp@xlab-goettingen.de

26 – 27 June 2009

Ashton Court estate, Bristol, UK

Biodiversity Survey: BioBlitz

The Bristol Natural History Consortium, supported by Bristol Science City and Defra, is running the first terrestrial BioBlitz in the west of England. It is a 30-hour race against the clock in which scientists, local naturalists, members of the public, schools and community groups work together to find and identify all the wildlife in a certain area. The BioBlitz will be held at the Ashton Court estate in Bristol. Three different sites within the estate, each with contrasting areas, have been selected. Results will be passed on to local authorities and the Bristol Regional Environmental Records Centre (BRERC).

More information: www.festivalofnature.org/education.php?pageid=275&parentid=0

Contact: Berry Goddard berry@bnhc.org.uk

Until 30 June 2009

Austria

Competition: Hands-on X-Netz

The interactive travelling Science Center Network exhibition 'Erlebnis NETZ[werk]E' (The Net[work]) Experience) has toured Austria since June 2007. To enhance the exhibition, a competition is run for Austrians up to the age of 26, who can submit ideas for interactive exhibition stands on the topic of nets/networks. Selected ideas will be realised and added to the exhibition. If the jury is convinced your idea is feasible and suitable, you will be awarded €300 as an individual or €500 as a group to run the required research on your project, plus cost of materials, and you will have three months to complete your proposed project, for which you can get help from a list of cooperation partners.

The closing date is 30 June 2009.

More information: www.science-center-net.at/x-netz

Contact: office@science-center-net.at

30 June – 1 July 2009

Europa Park, Rust, Germany

Workshops for kindergarten and primary school kids: Science Days for Kids 2009

This science festival for children aged 4-8 offers more than 30 workshops and several science shows. Organised by the Förderverein Science und Technologie eV, the event is run by scientists, teachers and secondary-school students. Registration is required – groups, classes and members of the public can take part.

Language: German

More information: www.science-days.de/kinder

Contact: Joachim Lerch (j.Lerch@science-house.de)

1 – 3 July 2009

European Molecular Biology Laboratory, Heidelberg, Germany

Training course: ELLS LearningLAB The Power of DNA Technologies

The European Learning Laboratory for the Life Sciences (ELLS) is an education facility which brings secondary-school teachers into the research lab for a unique hands-on encounter with state-of-the-art molecular biology techniques. ELLS also gives scientists a chance to work with teachers, helping to bridge the widening gap between research and schools. The three-day course is designed to enable the participating teachers to explore a range of activities, which they can practice in the lab and then take back to the classroom. The course is open to 24 European high-school science teachers and is run in English. The course, including course materials and catering, is free of charge; accommodation costs will be partially subsidised. However, participants are expected to meet their own travel costs.

More information: www.embl.de/ells

Contact: ells@embl.de

6 – 8 July 2009

Wels, Upper Austria

Science Fair: Experimentale 09

Now in its third year, the Experimentale in Upper Austria is a science fair at which all Upper Austrian schools are invited to present their best science experiments to the public, in the form of hands-on stands with activities developed and run by the students themselves. It will take place at the building site of the future 'Science Center' in Wels, which will be the largest science centre in Austria when finished.

More information: www.nawi4you.at

Contact: Guenther Vormayr (guenther.vormayr@lsr-ooe.gv.at)

6 – 13 July 2009

Davidson Institute of Science Education, Weizmann Institute of Science, Rehovot, Israel

Training course: The 4th Sheila Schwartz Family International Leading Science Teacher Seminar

The Weizmann Institute of Science is offering you the opportunity to participate in a unique eight-day seminar at a top science education institute where you will:

- Be exposed to cutting-edge research by top scientists
- Develop leadership in school science education
- Establish international collaborative initiatives with like-minded colleagues
- Advance your science teaching strategies.

Price: US$200 registration, flight expenses and accommodation

Language: English

More information: http://davidson.weizmann.ac.il/international

Contact: Dr Dvora Cohen dvora.cohen@weizmann.ac.il

15 – 17 July 2009

European Molecular Biology Laboratory, Monterotondo, Italy

Training course: ELLS LearningLAB

The European Learning Laboratory for the Life Sciences (ELLS) is an education facility which brings secondary-school teachers into the research lab for a unique hands-on encounter with state-of-the-art molecular biology techniques. ELLS also gives scientists a chance to work with teachers, helping to bridge the widening gap between research and schools. The three-day course is designed to enable the participating teachers to explore a range of activities, which they can practice in the lab and then take back to the classroom. The course is open to 24 European high-school science teachers and is run in English. The course, including course materials and catering, is free of charge; accommodation costs will be partially subsidised. However, participants are expected to meet their own travel costs.

More information: www.embl-monterotondo.it/training/ells/learninglab

Contact: ells@embl.de

22 – 25 July 2009

École Normale Supérieure, Paris, France

Science Festival Paris Montagne: [R]évolutions

Every year in summer, the Paris-Montagne association organises a science festival on the historical campus of École Normale Supérieure at the heart of Paris' Quartier Latin. About 2000 participants from beyond the borders of Paris, in particular school students, attend to freely access an area in which science has come alive for centuries. After the festival, Paris-Montagne offers an animation programme and meetings in the Parisian suburbs. Participation is free, but prior registration is recommended for some days, especially for groups.

More information: www.paris-montagne.org

Contact:

Claire (info-public@paris-montagne.org)

29 July – 9 August 2009

Andøya Rocket Range, Norway

Student Summer Camp: European Space Camp 2009

European Space Camp is a summer camp for young people aged 17-21, with a background in physics and mathematics who are interested in space and science. Participants spend a week doing technical experiments, working as real rocket scientists, learning how to exploit knowledge they already possess, as well as broadening their understanding of applied science. By working in groups, they have to use their creativity, and learn to co-operate. The program includes group work with hands-on activities related to the rocket launch, lectures and social activities. Participation is free, but participants must cover their own travel expenses.

Language: English

Registration deadline: 15 April 2009

More information: www.spacecamp.no

Contact e-mail address: salome@spacecamp.no

All year

CERN, Geneva, Switzerland

Training course: CERN high-school teacher programme

CERN, the world's largest particle physics laboratory, organises one-week courses for secondary-school physics teachers who would like to increase their knowledge of particle physics and cosmology, who want to find out more about the world of frontier research, and who wish to bring modern physics into their classrooms. The course materials are aimed at students aged 13-16. The courses cover (at an introductory level) particle physics, cosmology, detectors, accelerators and applications. Teachers have the opportunity to visit CERN's experimental installations. Each course is aimed at teachers from a particular European country and is run in the national language. The courses are free of charge, but the participants are expected to pay for their travel expenses and accommodation.

More information: http://education.web.cern.ch/education/

Contact: Mick Storr (mick.storr@cern.ch)

All year

AHHAA Science Centre, Tartu, Estonia

Workshops and Science Shows: AHHAA á la carte

AHHAA Science Centre offers scientific theatre shows and experiments for school students, and the opportunity to borrow exhibits. Teachers can visit with their class in Tartu or invite the organisers to come to their school in Estonia or abroad. There is a range of activities on chemistry, physics, geography, biology, astronomy and robotics, as well as do-it-yourself workshops. Most activities are run in Estonian, but some can also be booked in English or Russian. Different modules can be combined to suit your needs. They can serve as exciting additions to school activities or training sessions, or simply as a fun way to spend your time. The Science Centre is also happy to help organise bigger events, such as science days at schools.

More information: www.ahhaa.ee

Contact: ahhaa@ahhaa.ee

All year

Ireland

Teacher Training: Discover Primary Science

Discover Primary Science is the Irish programme to foster interest in science and engineering among children in primary schools. Participating schools carry out a range of science activities in the classroom and are also encouraged to undertake additional explorative activities and projects. Teachers who register for the programme attend a hands-on training day for which substitute cover is provided, where they learn about undertaking the activities in the classroom and receive a classroom activity pack of science activities which support the curriculum. An Award of Science Excellence is available to schools that go beyond basic participation and carry out a minimum requirement of additional explorative activities. Support is available in various ways.

More information: www.primaryscience.ie

Contact: primaryscience@forfas.ie

All year

Schullabor Novartis, Basel, Switzerland

Workshop: 'Gentechnik Erleben' (Experience Genetic Engineering)

These workshops focus on practical laboratory work, but background information is provided for all experiments. Secondary-school students isolate plasmid DNA from bacterial cultures and digest it with restriction enzymes. The resulting DNA fragments are separated and visualised by gel electrophoresis. The workshops are for secondary-school students who already have the necessary theoretical background and are over 17 years of age. The workshops are free of charge, are in German or English (on request), and have a maximum of 20 participants. Teachers are invited to get in touch to arrange a workshop for their class.

More information: www.schullabor.ch

Contact: Gesche Standke (gesche.standke@novartis.com)

All year

various universities across Germany

Lectures for kids: Children's University (Die Kinder-Uni)

A large number of the German universities offer a programme of special lectures and events aimed at school children – many of which are on science topics. This initiative was started in 2002 by Tübingen University, and has since spread across Germany. On the website, you can find information and guidelines for students and parents, university professors and potential new organisers, as well as a list of the current lectures.

Anyone can attend, and participation is free.

More information: www.die-kinder-uni.de

Contact: Ulla Steuernagel, Ulrich Janßen (post@die-kinder-uni.de)

All year

schools and other venues in the UK

Roadshow: Cool Seas

Run by the Marine Conservation Society, the Cool Seas Roadshow visits primary and junior schools throughout the UK. It entertains and educates schoolchildren about the importance of conserving the UK's marine wildlife, using life-size inflatable models of marine animals in dynamic presentations given by a marine wildlife education specialist. The roadshow involves a full day of presentations to different classes, and costs either £175 or £350, depending on how much the school can contribute.

Each school that is visited receives printed materials and web-based resources, including an activity booklet for each student, and a poster for every classroom. The curriculum-linked, web-based resources can be viewed online. The roadshow is also suitable for public events outside school.

More information: www.mcsuk.org

Contact: info@mcsuk.org

All year

Rudolf-Virchow-Zentrum, Würzburg, Germany

Workshop for Students: The Science Reporters (ForscherReporter)

Run by the Rudolf-Virchow-Zentrum, a research institute for experimental biomedicine at Würzburg University, this project for students from grades 11 to 13 (aged 16 and above) combines hands-on science with training in science journalism. On six afternoons within one month, the students will first experiment in the lab themselves, then interview scientists and finally produce a radio feature on the topic to be uploaded to the web as a podcast. Groups of six to eight students from a school can register with their teacher. It is more convenient if you live in the area, as you have to visit the institute over several days. Participation is free.

More information: www.forscherreporter.de

Contact: Sonja Jülich (sonja.juelich@virchow.uni-wuerzburg.de)

All year

10 locations around the UK

Training courses: Science Continuing Professional Development

The national network of Science Learning Centres, set up by the UK Department for Skills and Education and the Wellcome Trust, provides continuing professional education for everyone involved in UK science education, at all levels. With nine regional centres and a national centre in York, access to innovative and inspiring courses is within reach across the UK. The centres not only deliver hundreds of courses, but also act as a focus for all the science learning activities in their region.

More information: www.sciencelearningcentres.org.uk

Contact: enquiries@national.slcs.ac.uk

All year

over 200 locations around Germany

Workshops for Students: Lernort Labor, Student Labs

The co-ordinating body for labs for school students in Germany, Lernort Labor, invites teachers to take their classes to visit these labs at universities, science institutes, science centers, museums and in industry. They provide hands-on science and can be found all across Germany.

More information: www.lernort-labor.de

Contact: office@lernort-labor.de

All year

Glasgow Science Centre, Glasgow, UK

Free teacher visits

Teachers, classroom assistants, nursery teachers and technicians are invited to visit the Glasgow Science Centre, free of charge, to explore and investigate what is on offer.

More information: www.glasgowsciencecentre.org

Contact +44 (0)871 540 1003

All year

many Scottish venues, UK

Roadshow: Science Circus

Glasgow Science Centre's outreach team brings all the fun of the science centre directly to schools and community groups throughout Scotland thanks to its lively travelling Science Circus. Science Circus activities consist of amazing live science shows and interactive exhibits delivered at your venue.

More information: www.glasgowsciencecentre.org

Contact: +44 (0)871 540 1004

All year:

Pembrokeshire, Wales, UK

Field trip: Rockpools

The Pembrokeshire Darwin Science Festival invites all primary schools in Pembrokeshire to book a rockpool ramble and identification field trip. The course is aimed at Key Stage 2 pupils (aged 8-11), takes half a day and is led by three qualified marine scientists. Cost: £250 with a bus or £170 without a bus. Maximum 30 children.

More information: www.darwincentre.com

Contact: Marten Lewis (M.B.Lewis@pembrokeshire.ac.uk)

All year

Pembrokeshire, Wales, UK

Workshops: Primary school

The Pembrokeshire Darwin Science Festival offers a double workshop visit for a maximum of 30 Key Stage 2 pupils (aged 8-11) and costs £200. The group is split into two workshops, which run simultaneously:

- Plankton/microscopy identification workshop
- Energy workshop using dynamos, solar panels and a steam engine as hands-on props.

Also available are three 90-minute workshops, each for a maximum of 20 pupils and costing £120:

- Oil-spill workshop for Key Stage 2 pupils (aged 8-11)
- Climate-change workshop for Key Stage 2 pupils (aged 8-11)
- Marine-litter workshop for Key Stage 1 pupils (aged 4-7).

More information: www.darwincentre.com

Contact: Marten Lewis (M.B.Lewis@pembrokeshire.ac.uk)

All year

Paris-Montagne, Paris, France

Science Academy

Throughout the year, Paris-Montagne runs an outreach programme in all Parisian suburbs and in the Lyon area. The science academy is for high-school students who are interested in science but not confident enough to enrol for undergraduate studies, due to social and cultural hindrances. The organisation offers students personal tutoring and the possibility to discover the world of research by meeting researchers in various fields and by carrying out their own research in real laboratories during their holidays (100 labs from three hospitals and a dozen universities and research institutes, participated in April 2008). The most dedicated participants in the programme are offered the chance to take part in a summer camp during the Paris-Montagne science festival in July, and also to attend other scientific summer camps in Europe (including Petnica, Kut Diak and Visnjan).

Since its creation in 2006, nearly 300 high-school students have participated in the science academy, and each year around 1500 participants visit the Paris-Montagne science festival.

More information: www.scienceacademie.org

All year

Portugal

School visits: MIT professors go to Portuguese secondary schools

Ciência Viva is organising short talks by MIT professors in Portuguese secondary schools, as part of a co-operation between the Massachusetts Institute of Technology and Portuguese universities in the areas of bioengineering, sustainable energy and transport systems. The students have direct contact with MIT professors and can discuss their ideas and ask questions about these important engineering areas. Schools are selected based on their motivation for participating in the programme and on the projects they have developed in the areas of science and engineering.

More information: www.cienciaviva.pt/divulgacao/mit

Contact: info@cienciaviva.pt

All year

INTECH, Hands-on Interactive Science and Discovery Centre, Winchester, UK

Free teacher visits

Teachers are invited to visit INTECH, the hands-on interactive science and discovery centre, free of charge, or to attend a teacher preview session to discover what is available for school visits and workshops.

More information: www.intech-uk.com

Contact: Angela Ryde-Weller (AngelaRydeWeller@intech-uk.com)

If you organise events or competitions that would be of interest to European science teachers and you would like to see them mentioned in *Science in School*, please email details – including date, location, title, abstract, price, language, registration deadline, website and contact email address – to editor@scienceinschool.org.

Science on Stage: recent international events

Autumn showers, shortening days, jet-lag… nothing could dampen the enthusiasm of teachers, students and journalists from around the world who took part in the Spanish and German Science on Stage events. **Sonia Furtado** reports.

On-stage performance of 'Harry Potter and the secrets of chemistry' at the Science on Stage festival, Germany

Image courtesy of Science on Stage Deutschland eV

Science in Action: Spain

Take the best projects from an international competition, add a couple of thought-provoking talks and a flight simulator, place them all in a science

Image courtesy of Ciencia en Acción

Image courtesy of Ciencia en Acción

museum for three days, and you have Ciencia en Acción[w1] (Science in Action), Spain's Science on Stage event.

On 19-21 September 2008, the authors of the best projects in the Science in Action competition gathered in Valladolid, Spain. The 80 finalists were teams of teachers, students and journalists from all over Spain, plus Portugal, Argentina, Colombia, Mexico, Peru, Salvador and Uruguay. Having made it to the final, they were now competing for the ultimate prize: to come first in their category and win €1500.

Aiming to acknowledge, promote and reward teachers who help students get involved in science, students enjoying their first contact with scientific research, and journalists who help the general public engage with science, this is certainly a multidisciplinary competition. Teams competed in 14 categories, ranging from 'physics demonstrations' to 'didactic materials' and 'science films'. Plus there was the 'Catch a Star' competition, jointly organised by the European Association for Astronomy Education[w2] and the European Southern Observatory[w3]. The winners were granted a trip to the Calar Alto observatory in Almeria, Spain, and specially commended projects were awarded telescopes.

As if the buzzing and creative atmosphere generated by these contestants were not enough, the festival organisers offered a flight simulator, as well as two original talks: Dr Jose Luis Fernández from the Universidad Autónoma de Madrid discussed economy and mathematics in 'Giacomo Casanova and subprime mortgages', and Dr Miguel Angel Alario from the Universidad Complutense de Madrid actively explored the main roles this liquid plays in our lives by asking 'Why is water different?'.

If you would like to find out more about the competition, including the entries in each category, visit the Ciencia en Accíon website[w1].

Image courtesy of Science on Stage Deutschland eV

Ultrasound project by Ulrike Bornschein at the Science on Stage festival, Germany

Image courtesy of Science on Stage Deutschland eV

Dietlind Jering, leader of the Representation of the European Commission, opens the fair at the Science on Stage festival 2008 in Berlin

Science on Stage festival, Germany

On 23-26 October 2008, the Urania exhibition hall in Berlin saw 230 teachers from 21 European countries and Canada enthusiastically take centre stage. And not only onstage, but also at stands, presenting projects for workshops, round tables and fairs. Each project was a contender at Germany's Science on Stage festival[w4], competing in one of six guiding themes: 'science in kindergarten and primary school', 'interdisciplinary teaching', 'hands-on experiments to boost motivation and cognition', 'self-perception in the teaching process', 'Are non-formal education initiatives always beneficial?', and 'Solo entertainer or moderator? The science teacher of the future'.

A jury selected teams from Hungary, Germany, Canada, Switzerland, Austria and the UK as winners of the Science on Stage award for each theme. As engaging as the competing entries were, audience participation wasn't limited to the opportunities provided by each individual project: the attending public was also called upon to vote for their favourite. The winner was 'latex motor', a motor powered by heating and cooling latex condoms and gloves, created by one of the teams selected in April to represent Austria (Hayes, 2008). And there were still more prizes! The European societies for physics (EPS), biology (ECBA) and chemistry (EuCheMS) each gave a special award to the best project on their subject.

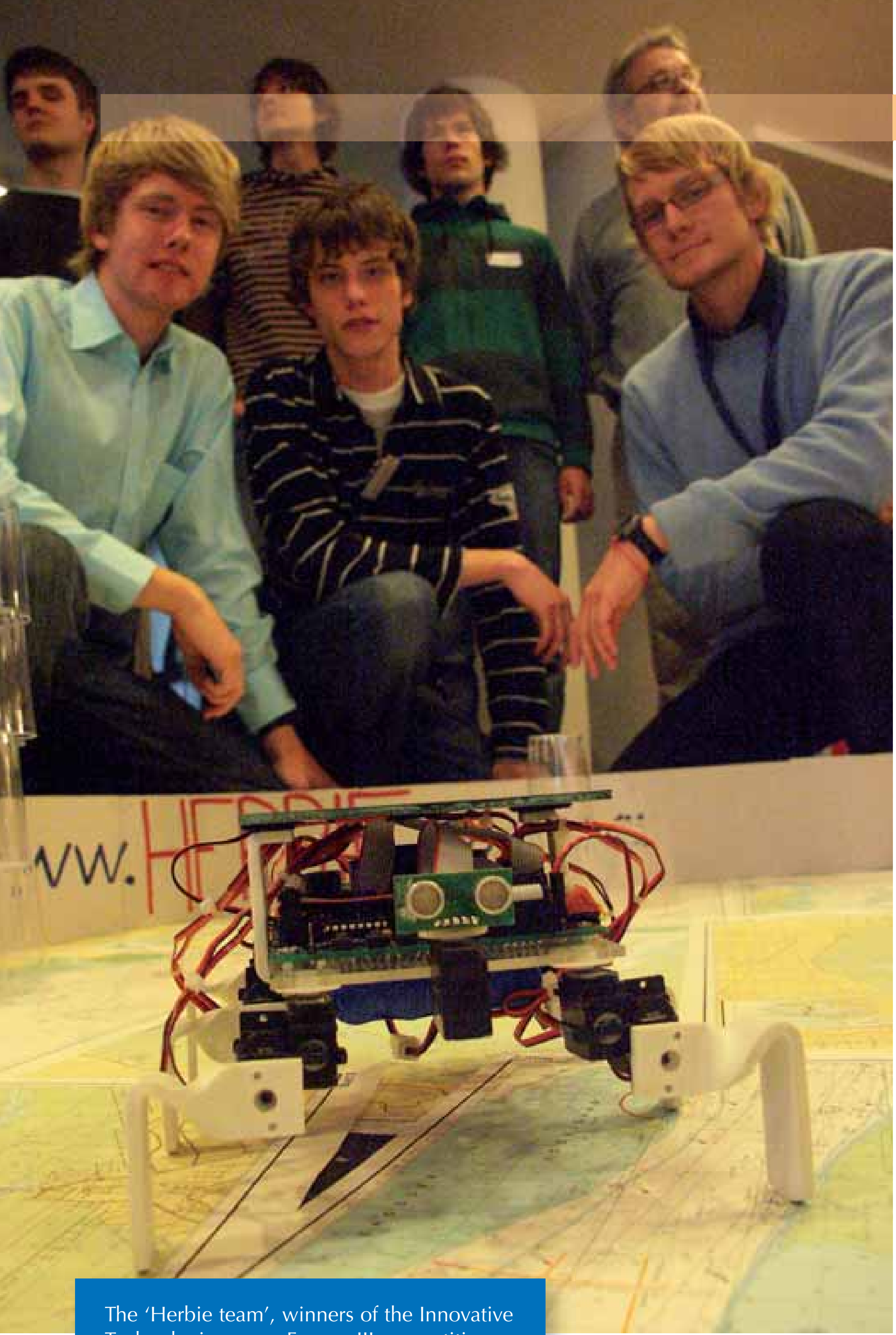
Aside from the competition, there were other matters of interest. For instance, the festival served as the platform for Science on Stage Germany to launch its new handbook, 'Teaching Science in Europe 2'. Downloadable online[w5], this handbook stems from a project involving 100 teachers from 20 countries who discussed concepts and materials for science lessons under the guidance of Science on Stage Germany. It focuses on 'science in kindergarten and primary school', 'interdisciplinary teaching (scientific and non-scientific subjects)' and 'self-perception and self-evaluation'.

The festival was so successful that the organisers plan to continue four of its workshops during 2009 and 2010, in an effort to strengthen the network of European science teachers even more. The topics of 'self-perception in the teaching process', 'Are non-formal education initiatives always beneficial?', 'Solo entertainer or moderator? The science teacher of the future' and 'science in kindergarten and primary school' will be discussed in further meetings, the first of which is scheduled for June 2009 (see events list on page 6). If you are interested, you can find more information online or contact Science on Stage Germany[w4].

Innovative Technologies move Europe III

In its 2008 edition, this international competition got European students and teachers moving to the theme of biomimetics. Students and teachers were encouraged to look to nature for inspiration – literally. The challenge was to create 'something that crawls', 'something that jumps' or 'something that flies', based on how animals do so. It was taken up by eight German teams, plus one each from the Czech Republic, the UK, Belgium and the Netherlands. At the final in Oberhausen, Germany, on 11 April 2008, a jury examined their entries, and the best crawler, jumper and flyer were awarded prizes.

Teams taking part in the 'Innovative Technologies move Europe' competition must engage in creative and



The ‘Herbie team’, winners of the Innovative Technologies move Europe III competition

Image courtesy of Science on Stage Deutschland eV

interdisciplinary problem-solving, while simultaneously mastering the technical aspects of actually building their moving ‘somethings’. To help with the latter, students were given the opportunity to talk to engineers at Lenord, Bauer & Co. – Science on Stage Germany’s partner in the competition – a company which specialises in automating motion. As well as the immediate benefits of this engagement with the engineers, i.e. help in making projects work in the best possible way, this also gave students a valuable insight into the practicalities of scientific and technological professions. As for the teachers, they were encouraged to engage in an international discussion of the concepts and methods of science teaching.

If you’ve missed the competition so far, fear not: Science on Stage Germany has collated the results from its first three editions. Released in September 2008, the ‘Innovative Technologies move Europe’ booklet, a guideline for teachers and other companies wishing to engage cooperatively in science education, is available online[w6].

The competition’s fourth edition has already started: the theme for 2009 is ‘Potentiometers – use your potential’, and contestants are invited to build a model which modulates light or sound frequencies. You’ll find additional information online[w7].

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w1 – To find out more about Ciencia en Acción, the Spanish Science on Stage event, see: www.cienciaenaccion.org

w2 – The European Association for Astronomy Education aims to improve and promote astronomical education in Europe. See: www.eaae-astro.org

w3 – The European Southern Observatory builds and operates some of the world’s most advanced ground-based astronomical telescopes. See: www.eso.org

w4 – For more information on the German Science on Stage activities, see: www.science-on-stage.de

w5 – The new handbook of Science on Stage Germany, Teaching Science in Europe 2, can be downloaded in English and German here: www.science-on-stage.de

w6 – To download the latest ‘Innovative Technologies move Europe’ handbook (in German), see: www.science-on-stage.de

w7 – To find out more about the 2009 competition ‘Innovative Technologies move Europe’ on the theme of potentiometers, see: www.schule-bewegt.de/en/wettbewerbe/2008

Time travel: science fact or science fiction?

Do you believe that time travel has no place in a serious science lesson? **Jim Al-Khalili** from the University of Surrey, UK, disagrees. He shows how the topic of time travel introduces some of the ideas behind Einstein's theories of relativity.

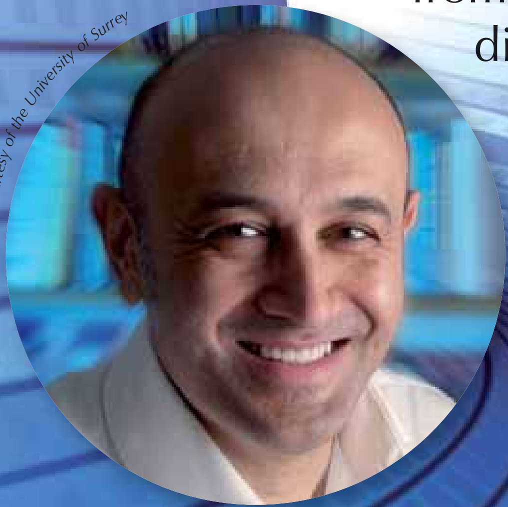

Image courtesy of the University of Surrey

Jim Al-Khalili

Image courtesy of Frank Ramspott/Matjaz Boncina/iStockphoto

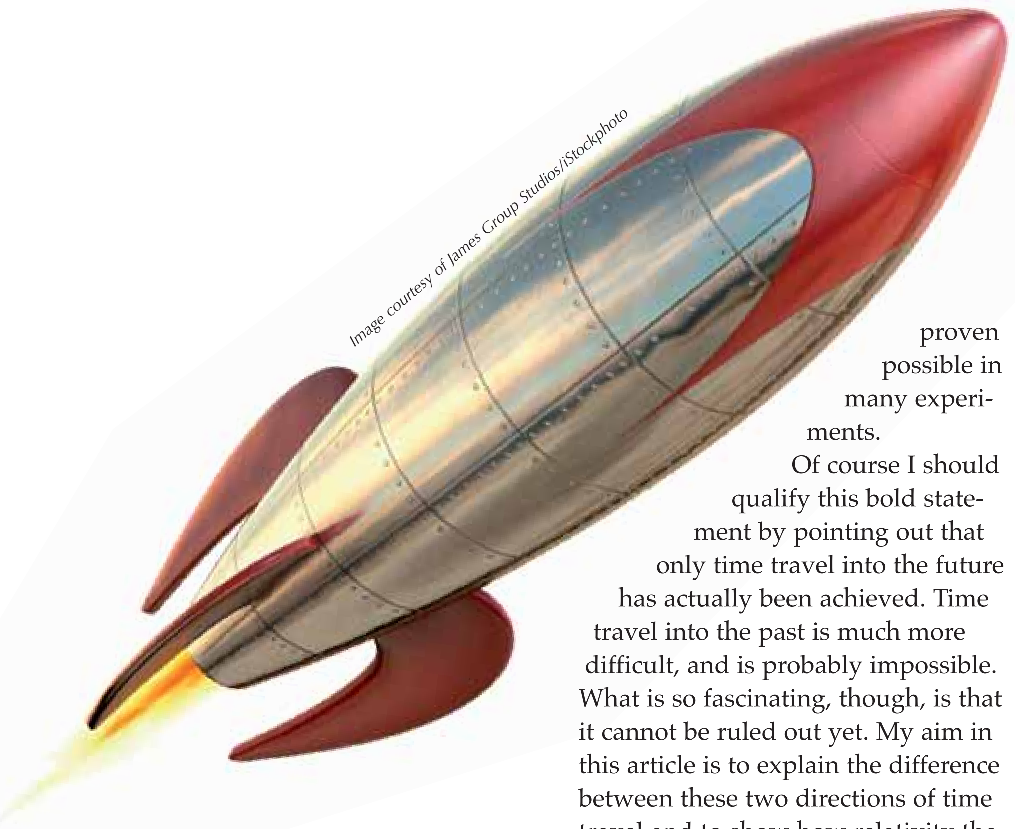

Image courtesy of James Group Studios/iStockphoto

When physicists want to get people excited about their subject, they usually turn to cosmology or particle physics. There is always going to be something exciting to say about space or the search for new particles at the Large Hadron Collider (for a discussion of the LHC, see Landua & Rau, 2008, and Landua, 2008). Of course, it is far more challenging to make electromagnetism or thermodynamics sound exciting. So is introducing a subject like time travel a little like giving in to science fiction? I would argue not. In fact, I think it is an excellent way of getting across some of the basic ideas behind Einstein's theories of relativity (yes, there are two of them). One can begin by asking the simple yet emotive question: is time travel really possible? Anyone who has watched a movie such as *The Terminator* or is a fan of *Dr Who* may worry that the concept of time travel, while great fun to contemplate, is just nonsense with no place in real science. However, not only do the laws of physics allow for time travel, but it has also been proven possible in many experiments.

Of course I should qualify this bold statement by pointing out that only time travel into the future has actually been achieved. Time travel into the past is much more difficult, and is probably impossible. What is so fascinating, though, is that it cannot be ruled out yet. My aim in this article is to explain the difference between these two directions of time travel and to show how relativity theory forced physicists to abandon common-sense notions about the nature of time itself.

Isaac Newton: the common sense approach?

Until Isaac Newton completed his work on the laws of motion in 1687, the definition of time had been considered to be the domain of philosophy rather than science. However, when Newton described how objects move under the influence of forces, time was an integral part of his mathematical description of reality, since all movement and change require the notion of time to make sense. Newton viewed time as absolute and relentless; he described it as existing entirely outside of space and independent of all processes that occur within space. This is still the view that most of us have: we think of time as flowing at a constant rate, as though there were an imaginary cosmic clock that marks off the seconds, hours and years regardless of our feelings about the passage of time. We have no influence on its rate of flow and cannot make it speed up or slow down. We feel we know what time is – but no one really does. The best definitions we have are rather silly, like saying 'time is nature's way of stopping everything happening at once!' or 'time flows by at a constant rate of one second every second'. What on earth does that mean anyway?

Was Newton right? Does such absolute time really exist? Albert Einstein showed that it doesn't.

Albert Einstein: a revolutionary

In 1905, Einstein discovered, through his study of the nature of light, that time and space are not independent but are intimately linked. His ideas became known as the special theory of relativity, which heralded a revolution in physics. It showed how and why the old notions of space and time had to be replaced with a new and unfamiliar set of concepts. Basically, relativity theory unifies time with the three dimensions of space into something called space-time. This is where the idea of time as the fourth dimension comes from.

In 1915, ten years after his work on special relativity, Einstein completed his theory of gravity, known as the general theory of relativity. Widely regarded as the most beautiful scientific theory ever discovered, it describes how the gravitational effects of matter affect space-time. This led to many exciting predictions that were subsequently shown to be correct, such as the birth of the Universe in the Big Bang and the existence of black holes.

But let us return to the topic of special relativity. Einstein showed that for anything (or anyone) travelling at speeds approaching that of light – an impressive three hundred thousand kilometres per second – time literally runs more slowly. The closer to the speed of light that a clock moves, the slower it will tick as seen by observers watching it zoom past. Nowadays, the slowing down of time is confirmed routinely in particle accelerators, such as the CERN facility in Switzerland[w1]. Many physics students get a chance to see this effect in the laboratory by observing a certain type of sub-atomic particle called a muon (pronounced 'mew-on')[w2].

Let us consider a simple example with numbers. A sprinter runs 100 metres in exactly ten seconds, according to the reliable and highly accurate timekeeping of the judges. Had he, however, carried his own very accurate stopwatch along with him, then, due to time slowing down very slightly for him, his watch would show a time of 9.999999999995 seconds. Of course, this is so close to ten seconds that we would never know the difference. However, scientists routinely need to measure times with this sort of accuracy. The difference between the runner's and the judges' watches is just five picoseconds; it is such a small time difference because the athlete is moving so much slower than light.

This is actually quite a subtle concept. If people know anything about the theory of relativity, it tends to be its insistence that all motion is relative. So why is it the sprinter's watch that runs slower, hence recording the shorter time? If all motion is relative, then we should be able to argue that it is in fact the track that is moving relative to the sprinter. So it should be the judges' trackside watches that run slower. This is true, but in reality the situation is not completely symmetrical. For one thing, the sprinter has to accelerate and decelerate and this change in speed affects the rate at which his time goes by, relative to that of the judges. Another way of understanding why the sprinter's stopwatch reads a faster time is that, for him, the distance he has to run is in fact slightly less than 100 metres. This is another consequence of the theory of relativity: that distances are shortened when you move very fast.

High-speed motion: time travel to the future

As this is beginning to sound somewhat strange, we might as well explore how it all links up with time travel. The idea of time slowing down gives us, quite literally, a means of time travel into the future. If you were to travel around our galaxy in a rocket, at close to the speed of light for, say, four years, you would get quite a shock when you returned home to Earth. If your onboard calendar said you left in January 2005 and returned in January 2009, then depending on your exact speed and how twisted your path was through the stars, you might find that on Earth, the year was 2045 and everyone had aged 40 years! They would be equally shocked to see how young you still looked considering how long you had, according to them, been away.

Inside the rocket, four years would have elapsed while Earth-bound clocks counted off 40 years. This means that you would have, for all intents and purposes, leapt 36 years into the future.

This effect has been checked and confirmed many times in different experiments to extremely high degrees of accuracy. In 1971, J. C. Hafele and Richard E. Keating placed four highly accurate atomic clocks on a jet aircraft and flew them eastwards around Earth. After the jet returned, the onboard clocks were compared with reference atomic clocks at the US Naval Observatory: the travelling clocks were a tiny fraction of a second behind the reference clocks (Hafele & Keating, 1972a, 1972b)[w3]. Even though the jet had a ground speed of up to a thousand kilometres per hour, the speed of light is a further million times greater than this, hence the very small and rather unimpressive difference between the two groups of clocks. Nevertheless, that difference is real and the clocks are so accurate that we do not doubt their readings or the conclusions we draw from them.

Time travel to the past?

Time travel to the past, it turns out, is much more difficult. To many people, it might come as a surprise that travelling forward in time is easier than travelling backward. If anything, you might think that the notion of travelling into the future is the more ridiculous. The past may well be inaccessible, but at least it is out there in some sense: it has happened. The future on the other hand, has yet to happen. How can we visit a time that has not yet happened? However, time travel to the future by high-speed motion does not require the future to be already 'out there' waiting for us.

Image courtesy of iStockphoto Frank Ramspott

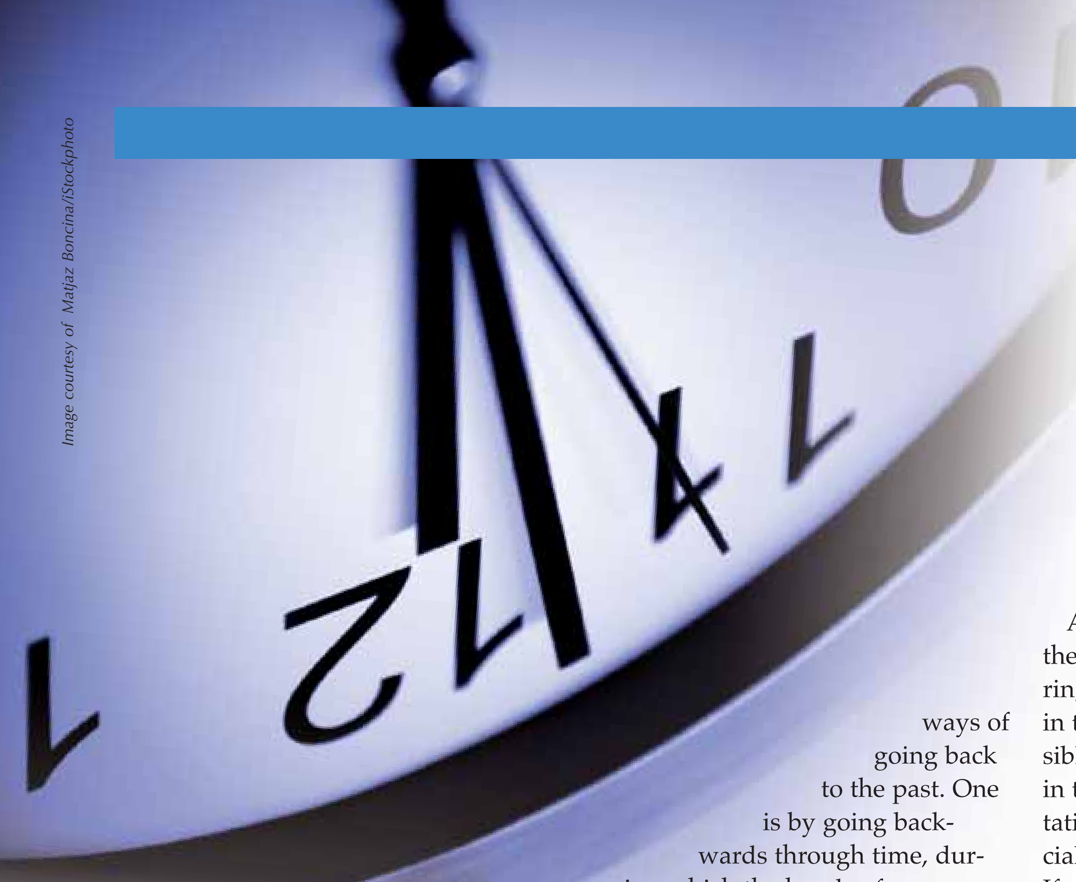

Image courtesy of Matjaz Boncina/iStockphoto

What it means is that we move out of everyone else's time frame and into one in which time moves more slowly. While we are in this state, time outside ticks by more quickly and the future unfolds at high speed. When we rejoin our original time frame, we will have reached the future more quickly than everyone else.

On the other hand, there are many mind-boggling examples of how ridiculous things would be if time travel to the past were possible. For example, what if you were to go back in time, to last year for example, and kill your younger self. What would happen then? Would you simply pop out of existence as the younger you slumps to the ground? And if you died last year, who would have killed you? I know this is a bit morbid, but it is a well-known paradox. Think about it. It seems you cannot kill your younger self because you must survive the assassination attempt to become the assassin. The thing to remember about time travel to the past is that you are allowed to meddle with history as long as things still turn out the way they do. You cannot change the past.

In principle, there would be two ways of going back to the past. One is by going backwards through time, during which the hands of your watch would move anticlockwise. This would require faster-than-light speeds which relativity theory tells us are impossible, and so is not the sort of time travel I am discussing here. The other way is by travelling what appears to you to be forward in time (your watch runs forwards) but by moving along a warped path through space-time that takes you back to your past (like looping the loop on a roller coaster). Such a loop is known in physics as a *closed time-like curve* and has been the subject of intense theoretical research during the past decade. Perhaps surprisingly, it has been known for half a century that Einstein's equations of general relativity allow such closed time-like curves: the American mathematician Kurt Gödel showed in 1949 that this type of time travel into the past was theoretically possible.

So what is all the fuss about? Time travel to the future has been done and time travel to the past, while difficult, has not been ruled out by theory. What are we waiting for? Why haven't we built a time machine yet? The problem is that, apart from the fact that closed time-like curves in space-time are exceedingly difficult to create, we do not really understand them theoretically. As things stand at the beginning of the 21st century, general relativity tells us that we cannot rule out time travel, but many physicists are hoping that a better understanding of the mathematics involved will eventually lead to the conclusion that time loops are impossible.

At the moment, we cannot rule out the possibility that a naturally occurring time machine exists somewhere in the Universe. It is theoretically possible for space-time to be so warped in the presence of a very strong gravitational field that, under certain special conditions, a time loop is created. If we stumbled across such an entity, known as a wormhole, during future space travel it might provide us with a permanent link to the past.

For now, the best way to rule out the existence of time loops is to ask where all the time travellers from the future are. If future generations ever succeeded in building a time machine then surely there would be many people wanting to visit the 21st century and we should see these visitors among us today. So just to keep the debate alive, below are five possible reasons why we should not expect to see any time travellers:

1. Time travel to the past is forbidden by some as-yet-undiscovered laws of physics. Physicists hope to discover a new theory that goes beyond general relativity and which explains why time loops are forbidden. We already have two possible candidates for such a theory, known as superstring theory and membrane theory. But neither is properly understood yet.
2. There are no naturally occurring time machines, such as wormholes, so the only way to travel back in time is to build one. But it turns out that this would only take us as far back as the moment it was switched on (because that would be the earliest moment in time that could be accessed). So we cannot

see any time travellers from the future because time machines have not been invented yet.

3. Naturally occurring time machines exist and people do use them to travel back to the 21st century, but – an idea taken seriously by many theoretical physicists – our universe is just one of an infinite number of parallel universes. Thus time travel to the past slides the traveller into a parallel world. There are so many of these that our universe is just not one of the lucky few that have been visited.

If you are not convinced by these reasons, then I might interest you in a couple of more mundane possibilities:

4. Expecting to see time travellers among us presupposes that they would want to visit this century. Maybe for them, there are much nicer and safer periods to visit.
5. Time travellers from the future are among us but they keep a low profile!

If I were a betting man I would say that time travel to the past will soon be shown to be impossible even in theory. Getting to the future, on the other hand, just requires us to build a fast enough rocket. Beware, though, that if you reach the future, there is no coming back.

Jim Al-Khalili is a physics professor and the Professor of the Public Engagement in Science at the University of Surrey, where he has taught a course on relativity to undergraduates for the past 12 years. He appears regularly on TV and radio.

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w1 – For more information about CERN, the world's largest particle physics laboratory, see: www.cern.ch

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REVIEW

What do we know about time travel? Is it possible to travel to the future,or to the past? To what extent has it been tested, and what were the results? This article gives short but very exciting answers to these questions.

The article is very useful to introduce relativity and associated topics of modern physics to the students. Teachers can use it to discuss issues such as the nature of time and its meaning, or the exciting topic of time travel. It allows for a combination of physics with philosophy.

Taking the article as a starting point, teachers can then discuss further problems of time travel, such as the difficulty of accelerating a 70 kg human to the speed of light.

Alessandro Iscra, Italy

Sugary insights into worm parasite infections

Image courtesy of Percherie; image source: Wikimedia Commons

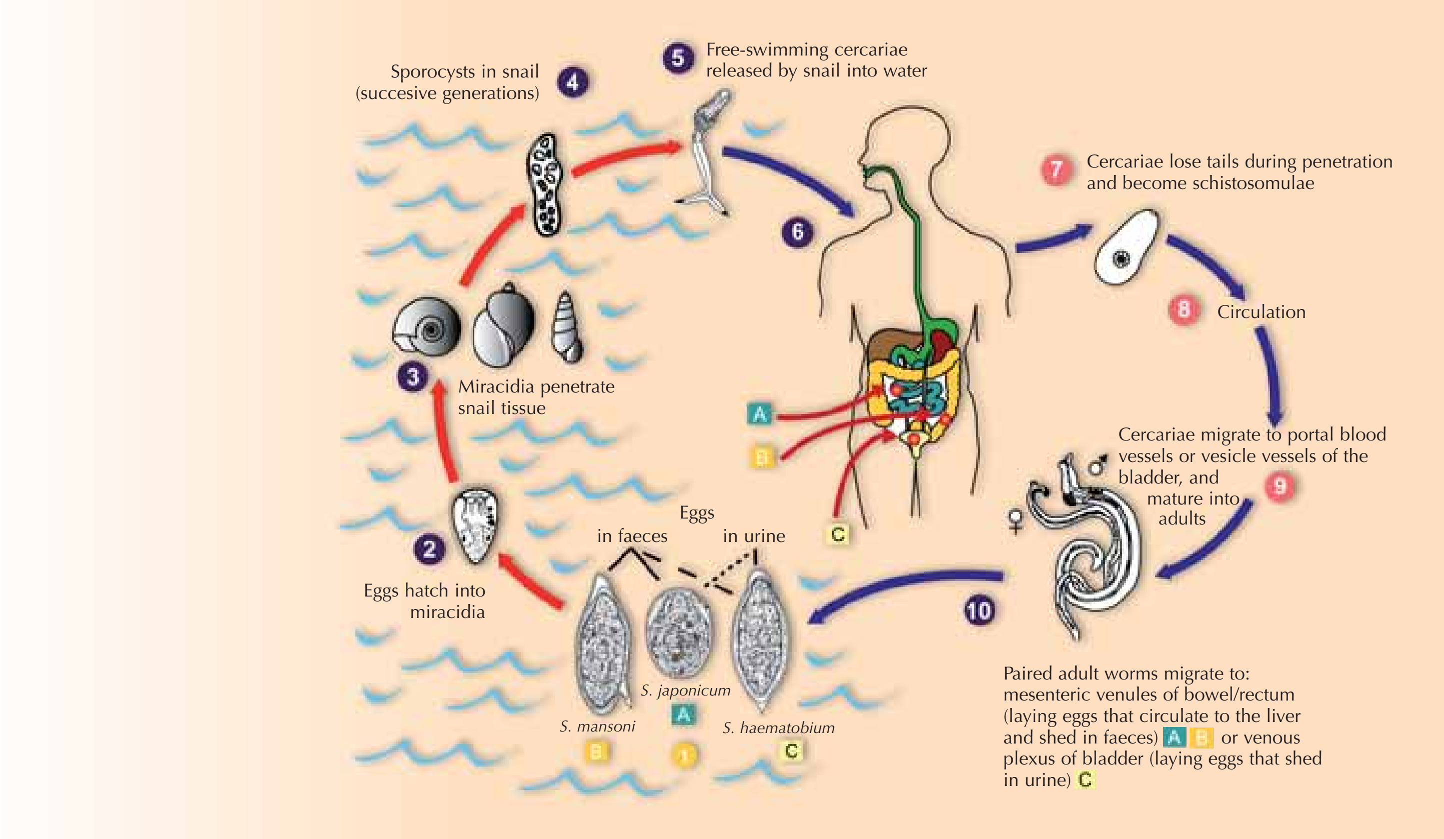
The geographic distribution of schistosomiasis

Schistosomiasis is a major parasitic disease (also known as bilharzia) which infects humans and domestic livestock, and is caused by several species of flatworm in the genus *Schistosoma*. The World Health Organization estimates that as many as 200 million people are infected in parts of South America, Africa and Asia. Approximately 280 000 people die from schistosomiasis each year in sub-Saharan Africa and millions more are chronically ill. Typical symptoms include abdominal pain, diarrhoea, fever, anaemia and fatigue; the stunting of children's growth and cognitive development is another consequence of infection. Schistosomiasis thus remains an important public health problem in developing countries.

The flatworms pass through a number of stages (see life cycle on page 21): eggs, free-swimming larvae (miracidia), sporocysts, a second free-swimming larval stage (the cercaria) and finally the adult worms. An entire life cycle takes a minimum of 12 weeks.

Worm eggs are released into water when human faeces or urine enter rivers or other water bodies. Freshwater snails of various genera act as intermediate hosts of the flatworms, and the presence of suitable snail species determines the distribution of the disease. Contact with water causes the eggs to hatch in a matter of minutes into miracidia, which enter the snail by penetrating its foot, after which the larvae are known as sporocysts. The sporocysts undergo asexual reproduction within the snail to produce thousands of cercariae, the aquatic stage that infects humans by penetrating the skin. A single snail can shed cercariae for

Schistosomiasis is the second most socioeconomically devastating parasitic disease after malaria. **Alan Wilson** and **Stuart Haslam** investigate new ways to combat the parasite – taking advantage of its sugar coating.



Original image courtesy of Public Health Image Library

Life cycle of the human flatworm parasite *Schistosoma*

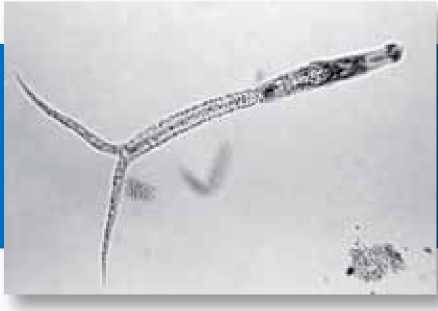
weeks, and this represents a major amplification step in the life cycle of the parasite: one miracidium gives rise to tens of thousands of cercariae before the infection is spent. The most common way of acquiring schistosomiasis is by wading or swimming in lakes or other water bodies that are infested with infected snails. Non-human hosts include other mammals, as well as birds and crocodiles.

Within the human host, the larvae migrate through the blood circulatory system to the hepatic portal blood vessels between the intestine and liver (in the case of *Schistosoma mansoni* or *S. japonicum*) or vesical veins of the bladder (in the case of *S. haematobium*). There, they feed on red blood cells, develop to adulthood and mate. The centimetre-long male then grasps the longer and thinner female in his ventral groove, where she will remain, and, using a combination of oral and ventral suckers, transports her against the blood flow to the smaller blood vessels of the host. Here she pushes forward, poking out at the front of the male's groove, to deposit hundreds of eggs per day into the blood vessels. Once established, the adult worms can live for decades in the hostile environment of the host bloodstream, potentially open to immune attack. Finally, the eggs must escape into the intestine or the bladder, to be shed to the external environment in faeces or urine, continuing the life cycle.

The adult and larval worms are comparatively harmless to their human host, but the eggs can cause severe disease. The severity of the tissue damage caused by the eggs is positively correlated both to the num-

Images courtesy of Public Health Image Library

A *Schistosoma haematobium* egg, magnified 500x



A schistosomal cercaria, magnified approximately 150x

Cercariae of *Schistosoma mansoni*

ber of worms that a person accumulates, and to the intensity of the human immune response to the eggs: too strong an inflammatory response ultimately leads to more tissue damage, too little to tissue necrosis by egg products. Moreover, a large proportion of the eggs do not escape from the host. Instead, in *S. mansoni and S. japonicum* infections, they are carried in the blood circulation to lodge in the liver. As a result, fibrous layers of cells from the immune system (known as granulomas) form around the eggs – and it is this response rather than the worms themselves that causes the life-threatening syndrome. *S. haematobium* eggs are equally dangerous, causing fibrosis – the formation of excess fibrous connective tissue – in the bladder wall.

We were interested in how the parasite enters and leaves the human body. In both the cercarial stage penetrating the host's skin and the egg escaping through the gut or bladder wall, the parasite releases secretions to help it move through the host's body. The cercariae possess a series of specialised gland cells. These release a mixture of proteins that have been shown to help the larvae pass through the tough stratum corneum – the outermost layer of the skin – then cross the dermis and finally penetrate a blood vessel. The secretions from the eggs are released by a specialised tissue, the envelope, which lies beneath the egg shell and completely surrounds the growing miracidium larva inside. These secretions help the eggs to leave a blood vessel and passively cross the tissues to reach the lumen of the intestine or bladder. They are too big to cross capillary beds, so if they break free in the blood vessels they travel downstream to the next organ – the liver, in the case of *S. mansoni*.

In the long term, the cercarial secretions could be a suitable target for a drug to treat schistosomiasis or for a vaccine to prevent it. But to develop an effective drug, scientists need to know how the secretions work and what they consist of. We characterised the proteins in both the cercarial and egg secretions of *S. mansoni* using mass spectrometry (see box) and showed that they have a relatively simple composition. Cercarial secretions contain several enzymes that degrade proteins (called proteases), plus a series of proteins and glycoproteins that may function by modifying the host's immune response. The proteins secreted by the eggs also have protein-degrading activity, although we do not know exactly how they work, because the amino-acid sequence of the principal components is unlike that of any other proteins for which we know the function.

Unusually for a parasite, both the egg and cercarial secretions are very immunogenic – they provoke strong antibody responses from the host immune system. But what makes the secretions so immunogenic? Studies on human, primate and rodent responses to the infection (Kariuki et al., 2008) have revealed that the vast bulk of antibodies directed against both larval and egg secretions recognise the carbohydrate (glycan) rather than the protein part of the secreted glycoproteins. So what are glycoproteins? And what is the role of the glycans in the biology of the parasites?

The central dogma of modern biology states that DNA encodes the basic template of life, and that the information in the DNA code is first translated into mRNA and finally into proteins which carry out many of the fundamental tasks both in and between the billions of cells which make up a living organism as complex as a human being. But to say that there are just three key types of molecules in living systems is an over-simplification. It is estimated that more than half of all proteins in humans are modified by the addition of sugar molecules, forming glycoproteins. These glycoproteins play a major role in the way that molecules and cells recognise each other, and therefore in the many interactions that determine how diseases are spread or combated.

Every cell in the human body (indeed, in all eukaryotes) is coated with a sugar-rich layer called the glycocalyx. Acting as identity tags, glycans on the outside of the glycocalyx interact with a variety of receptors (recognition molecules) on the mem-

Image courtesy of Public Health Image Library

Boys wading in a stream in Puerto Rico despite the sign on the bank 'Danger – there is bilharzia'

branes of surrounding cells and thereby help to control the social (correct) and anti-social (errant) behaviour of our cells. The worm parasite appears to exploit this glycan recognition process to manipulate the host's immune system and allow the worm to complete its life cycle. By characterising the detailed structure of the important worm glycans, we want to understand more about how these interactions take place.

Our analytical method of choice to derive the glycan structures is mass spectrometry (see box on page 24), as it is exquisitely sensitive (data can be obtained from very tiny amounts of material, such as 1 femtomole = 1 billionth of a millionth (10^{-15}) of a mole), and it can be used to study very complex mixtures. In a mass spectrometry experiment, energy is transferred to the purified worm glycans, for example by pulsing them with a laser beam. This energy transfer makes them ionised and charged. Once they have a charge, they can be made to 'fly' through the analytical section of the mass spectrometer. There, the different glycans are separated by their mass-to-charge ratio. From this information, the structure of the glycans can be deduced in terms of their monosaccharide composition and in terms of how they are linked together. Our mass spectrometry analyses revealed that both the cercarial and egg secretions contain very similar, highly immunogenic glycan structures.

In the case of the non-motile egg, it is as though the egg were trying to attract attention to itself. This led us to think that the parasite egg actually relies on the host immune response, which produces factors such as proteases, to help it escape from the blood vessels to the gut lumen or the bladder. Why the eggs would take the risk of being attacked by the immune system – when they have their own proteases – remains unclear.

In the case of the mobile cercaria, we propose a 'smokescreen hypothesis': we think that cercaria 'deliberately' attract attention to their secreted glycoproteins to distract the host's immune response away from protein targets of the larva which are more vital to its survival. Armed with a detailed knowledge of the parasite glycan structures, we hope to design new anti-parasite drugs or vaccines in the future.

Acknowledgements

This work was funded by the Biotechnology and Biological Sciences Research Council (BBSRC) and the Wellcome Trust, with additional funds from the UNDP/World Bank/World Health Organization Special Programme for Research and Training in Tropical Diseases.

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BACKGROUND

Mass spectrometry

Mass spectrometry is an analytical method used to determine the elemental composition of a sample or molecule. It can be used for both qualitative and quantitative measurements. Not only is it an important method for protein analysis, it is also widely used in space missions to characterise the composition of heavenly bodies. The principle consists of ionising the molecules or molecule fragments in the sample and then measuring their mass-to-charge ratios.

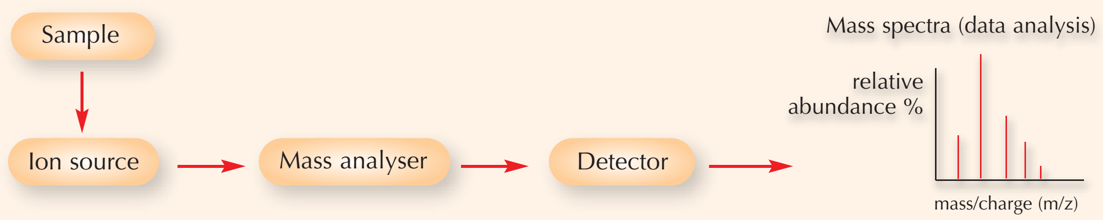
The machine used for this method, a mass spectrometer, is generally composed of three sections (see image below):

The ion source, in which the sample is split into gas phase ions.

The mass analyser, where electromagnetic fields are applied to separate the ions by their mass-to-charge ratio. These fields exert forces on the ions; the electric field may speed up or slow down a charged particle, and its direction may be altered by the magnetic field. The magnitude of the deflection of the moving ion's trajectory depends on its mass-to-charge ratio: according to Newton's second law of motion, lighter ions are deflected by the magnetic force more than heavier ions.

The detector, which records and quantifies the ions' mass-to-charge ratio.

This information is then used to determine the chemical element composition of the original sample.



A schematic representation of a mass spectrometer

Resources

Jang-Lee J, Curwen RS, Ashton PD, Tissot B, Mathieson W, Panico M, Dell A, Wilson RA, Haslam SM (2007) Glycomics analysis of *Schistosoma mansoni* egg and cercarial secretions. *Molecular and Cellular Proteomics* **6**: 1485-1499. doi:10.1074/mcp.M700004-MCP200

For more information about schistosomiasis, see: www.york.ac.uk/res/schisto/background.htm

For more information about mass spectrometry, see: www3.imperial.ac.uk/lifesciences/research/molecularbiosciences/massspec

Professor R. Alan Wilson has been researching the biology, physiology and molecular biology of the human blood fluke *Schistosoma* and the immune responses of the mammalian host for many years. Over the past two decades, he has worked on mechanisms by which mammals can become immune to schistosomiasis. More recently, he has developed lab techniques to identify the surface-membrane or secreted proteins of *Schistosoma* that might serve as targets of those protective responses. He is currently involved in annotation and analysis of the *S. mansoni* genome, and associated extensive transcript databases.

Dr Stuart Haslam obtained his first degree and PhD from the University of Leeds, UK. He then moved to Imperial College, London, UK, to conduct research on nematode parasite glycosylation, using high-sensitivity mass spectrometric analysis. He also does structural analysis of glycoconjugates (glycans linked with other chemical species) from diverse biological origins ranging from bacteria to humans, including the analysis of several cancer-derived cell lines.

Outmanoeuvering influenza's tricks

Catching the influenza virus can be more than just a nuisance: these pathogens have caused the most deadly pandemic in recent history. **Claire Ainsworth** investigates how scientists are working to prevent it happening again.

It seems like a constant battle – no sooner have you downloaded a security upgrade for your computer than a hacker somewhere finds another weak point. Once again, your machine is open to attack by viruses, spyware and other malicious programs, until the next upgrade patches the flaw.

The cells in our bodies face similar problems: they too have a multitude of security systems to prevent their biochemistry from being hijacked by viruses. But these systems are not perfect, and many viruses have evolved sneaky strategies to hack into them. A group of scientists from the FLUPOL[w1] EU initiative are trying to understand these strategies to develop a security upgrade for the human body. They have laid bare one of the tactics used by the influenza virus, paving the way for new drugs to combat future flu pandemics.

Influenza is a grave concern for governments and health organisations around the world. Although common

Stephen Cusack and Darren Hart

Image courtesy of EMBL Photolab

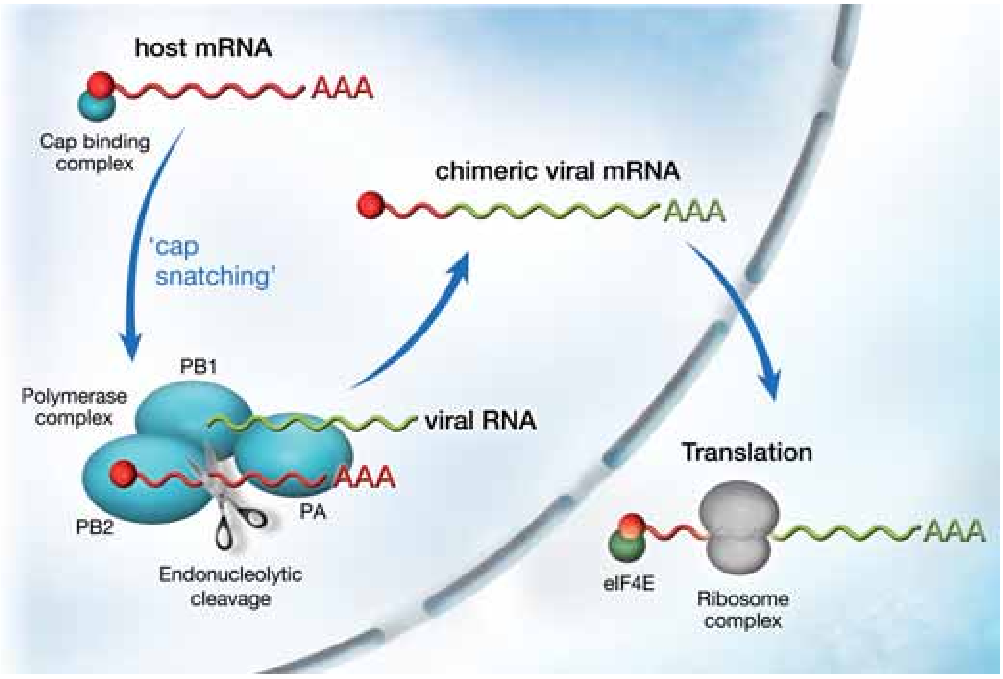
human strains of the virus are rarely deadly to healthy people, they can prove fatal to the elderly or to those with other illnesses or weakened immune systems. Worse, new strains of the virus are constantly evolving and could prove to be more virulent than their predecessors. The most worrying threat of all is the potential for bird flu – the influenza virus that infects birds – to develop the ability to infect humans easily. In the past, viruses that have made this leap have been extraordinarily deadly. For example, the 1918 influenza pandemic (from Greek *pan*: all, and *demos*: people; an epidemic of infectious disease that spreads through populations across a large region, such as a continent, or even worldwide), also originated in birds and killed between 50 and 100 million people as it swept around the world. It was the deadliest pandemic in recent history.

In the past few years, fears have been mounting over a strain of bird flu called H5N1 (see also Niekoop & Rienks, 2006), which has already infected and killed a few hundred people worldwide. Should it eventually acquire the ability to spread from human to human, we could face a new, deadly pandemic. Flu vaccines do exist, but those that work against one flu strain often have a limited effect against others. Vaccines against new strains take a long time to produce, and so may come too late to curtail a new pandemic. New ways to halt the spread of the virus are badly needed.

When the influenza virus infects a host cell, its goal is to produce many copies of itself that go on to attack even more cells. A viral enzyme composed of three subunits, called polymerase, is the key to this process. It copies the genetic material of the virus and steers the host cell machinery towards the synthesis of viral proteins. It does this by a process known as 'cap snatching' (see image below). The cap is a short extra piece of RNA, which must be present at the beginning of all messenger RNAs (mRNAs). It is required to direct the cell's protein-synthesis machinery to its starting point, so that it can synthesise a new protein according to the information laid down in the mRNA. The viral polymerase steals the cap from host-cell RNA molecules: it binds to host-cell mRNA via its cap, cuts the cap off and adds it to the beginning of the virus' own mRNA. But exactly how the polymerase achieves this, and which of the three subunits does what, has remained controversial. The biochemistry of the viral polymerase is probably very different from human proteins, which makes it an attractive target for drugs aimed at reducing the spread of infection in the body, since this difference lowers the risk of damaging human proteins as a side effect.

Moreover, learning about the polymerase is crucial for understanding how influenza leaps between species. Several of the mutations that enable bird flu to adapt to life in a human host occur within its polymerase protein, so it will be essential to find out what they do. This is no easy task, and demands a wide range of expertise. The FLUPOL EU initiative was formed to meet this

Image courtesy of Petra Riedinger

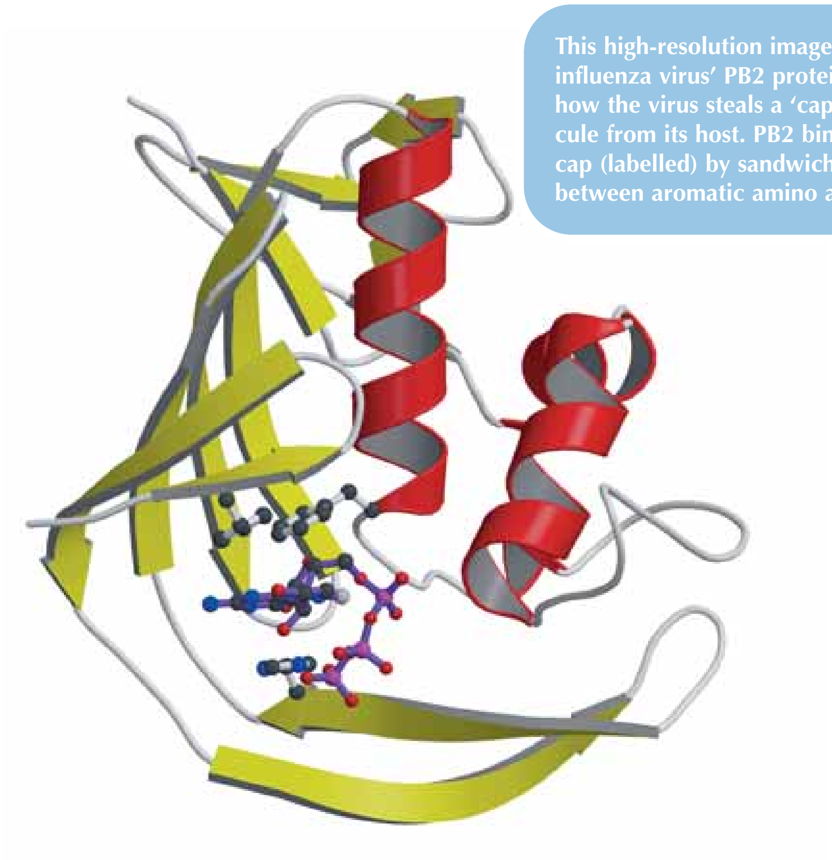


The RNA of the influenza virus steals the cap of host mRNA with the help of protein PB2, which makes part of the polymerase complex. With the cap attached, the viral RNA can be translated into proteins by ribosomes in the cytoplasm and more copies of the virus are produced

challenge: Stephen Cusack's and Darren Hart's groups at the EMBL outstation in Grenoble[w2], France, together with colleagues from the Grenoble Unit of Virus Host Cell Interactions[w3], have joined forces with other European teams in Madrid, Lyon, London and Marburg. "We have a multidisciplinary approach to studying this enzyme, from bioinformatics via structure to mouse models of interspecies transmission," says Stephen.

The polymerase, however, does not yield its secrets easily. For many years, it was impossible to get any detailed information on its three-dimensional structure. To do this, researchers need to produce the polymerase's constituent proteins in a soluble form and get them to form crystals. By shining X-rays on the crystals, they are able to deduce the structures of these proteins and better understand how they work. For an introduction to crystallography, see the article by Dominique Cornuéjols in this issue (pages 70-76). You can also try your hand at crystallising proteins in the classroom (Blattmann & Sticher 2009, pages 30-36 in this issue).

For a long time, no-one managed to get the all-important crystals. Whenever they tried, researchers found that the proteins either formed useless, insoluble lumps, or that they could not produce enough soluble protein to work on. Frustratingly, the scientists were unable to resort to their usual strategy for solving this problem: chopping the proteins up into their individual working parts, called domains, in the hope that these might be soluble. This method relies on being able to identify the domains in advance. Biologists usually do so by comparing the amino-acid sequence of the target protein with those of other proteins whose structures are known. But the flu polymerase is unlike any other known protein, so such an approach was impossible.



This high-resolution image of the influenza virus' PB2 protein shows how the virus steals a 'cap' molecule from its host. PB2 binds the cap (labelled) by sandwiching it between aromatic amino acids

Image courtesy of Petra Riedinger

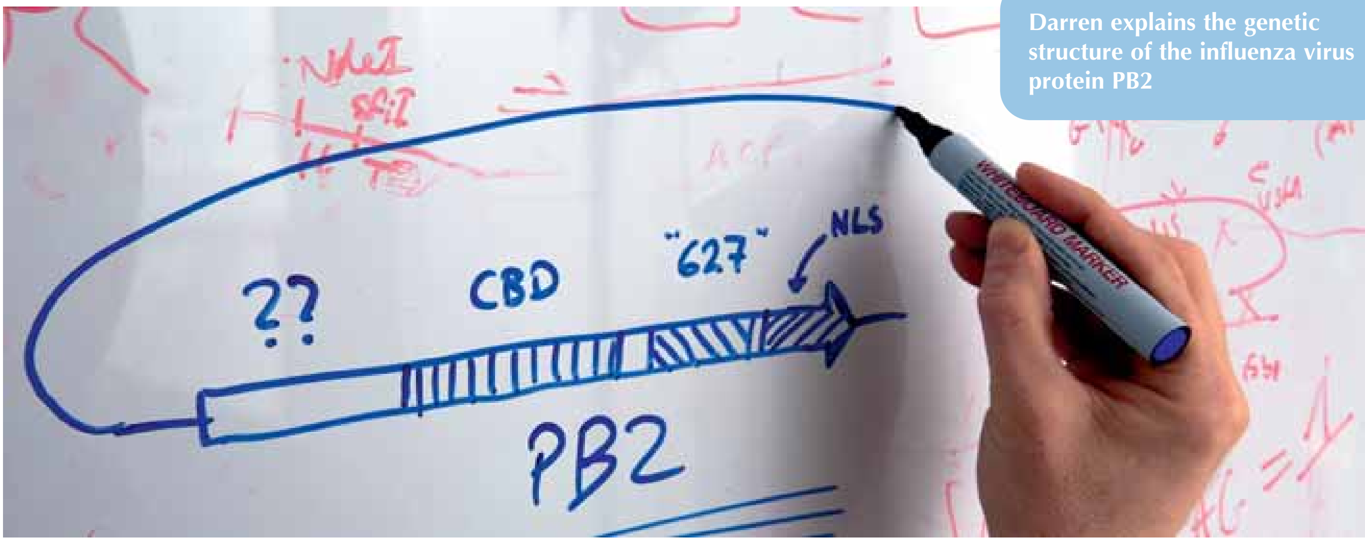
The solution came in the form of a new automated system Darren invented. Called ESPRIT (Expression of Soluble Proteins by Random Incremental Truncation), this system allows scientists to screen all the possible fragments of a protein for suitable soluble domains quickly and easily. In 2007, Darren and Stephen used ESPRIT to obtain the first soluble fragment of PB2, one of the three subunits (PA, PB1, PB2) that combine to form influenza's polymerase (Tarendeau et al., 2007). Having determined the structure of this fragment, they discovered how it helps the PB2 subunit hitchhike into the cell's nucleus, where it assembles with the other two subunits to form the functional polymerase.

Stephen and Darren were particularly interested in another region of PB2 which plays a key role in cap snatching. The PB2 subunit binds to host-cell mRNAs via the cap, and then the polymerase's PB1 subunit cuts the cap off and adds it to the beginning of the viral mRNA. The capped viral mRNA can then be recognised by the host-cell machinery, allowing viral proteins to be made at the expense of host-cell proteins. Without a cap, an mRNA cannot be turned into protein. So drugs that block PB2's cap-binding activity could stop the flu virus reproducing.

Until now, however, little was known about how PB2 worked. "This has been studied for many years, but no one was sure exactly where the cap binding domain was," says Stephen.

Thanks to ESPRIT, Darren, Stephen and colleagues found a PB2 fragment that bound to the cap. With the help of the high-throughput crystallisation facility at EMBL Grenoble, and the intense synchrotron X-ray beamlines at the European Synchrotron Radiation Facility (ESRF)[w4] (see

Image courtesy of EMBL Photolab



Darren explains the genetic structure of the influenza virus protein PB2

Cornuéjols, 2009, pages 70-76) in this issue), they determined the structure of the PB2 cap-binding domain when bound to the cap. This revealed that the domain contained a structure never seen before. "It's completely unlike any other protein in its fold," says Stephen.

But although the structure was entirely new, the way the domain interacted with the cap uses the same basic idea as other cap-binding proteins: the central interaction is a 'sandwich' with two PB2 amino acids stacking either side of the cap (see image on page 27). "It's a nice example of convergent evolution, where proteins from completely different origins come up with the same solution," says Darren.

To prove that their fragment was indeed the culprit cap-stealer, Darren and Stephen created fragments containing mutations of the amino acids which sandwich the cap. Sure enough, most of the fragments with mutations didn't interact with the cap. What's more, as shown by FLUPOL collaborators at the Centro Nacional de Biotecnologia in Madrid[w5], the same mutations blocked the ability of the whole polymerase to make new viruses. "We were able to display the critical importance of this for the virus as a whole," says Stephen (Guilligay et al., 2008).

Now that the structure is known, scientists can use it to design relatively simple, small molecules that block PB2's action. "If you can inhibit cap-snatching, you can kill the virus," says Stephen. He and Darren are now gearing up to look for potential drugs that do just that. They are using the structure to actively design an inhibitor, but they are also exploiting their ability to produce large amounts of the PB2 fragment to search vast chemical compound collections for other molecules PB2 may bind to – potential PB2 inhibitors. "We are the first people to be able to make enough of this fragment to take this brute-force approach for identifying small molecule inhibitors," says Darren.

Recently, researchers at the UVHCI and in Stephen's group discovered that part of the PA subunit, the third viral polymerase's subunit, is responsible for cleaving the cap off the host mRNA (Dias et al., 2009). The results came as a big surprise, because everybody thought that the cleaving activity resides in a different part of the polymerase. So with PA, another promising antiviral drug target has been found.

The researchers produced crystals of the crucial PA domain and examined them with the powerful X-ray beams of the ESRF in Grenoble. The high-resolution images they obtained reveal the individual amino acids that constitute the active site responsible for separating the cap from the RNA. A hollow canyon in the centre of the PA domain captures the long mRNA strand, and the metal complexes at the top edges of the canyon cut off the cap. Further experiments at ESRF confirmed that these metal complexes contain manganese, providing an important hint for drug development, since it will be essential to take the metal ions into account for designing improved inhibitors. The trick will be to exploit the knowledge about the structure of the viral polymerase subunit's active sites – which either are responsible for ligand binding or have enzymatic activity – to design small molecule inhibitors which can specifically block the sites and therefore virus reproduction.

Their findings have given scientists a close-to-complete picture of the cap-snatching mechanism, and the researchers are now in the process of using ESPRIT to crack the rest of the flu polymerase's structure in the hope that, in the near future, they will uncover new ways of countering influenza's dirty tricks.

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Web references

w1 – For more information on the EU FLUPOL initiative, see: www.flupol.eu

w2 – You can find the website of the European Molecular Biology Laboratory (EMBL) outstation in Grenoble here: www.embl.fr

w3 – To find out more about the Unit of Virus Host Cell Interactions in Grenoble, see: www.uvhci.fr

w4 – For more information on the European Synchrotron Radiation Facility (ESRF) in Grenoble, see: www.esrf.eu

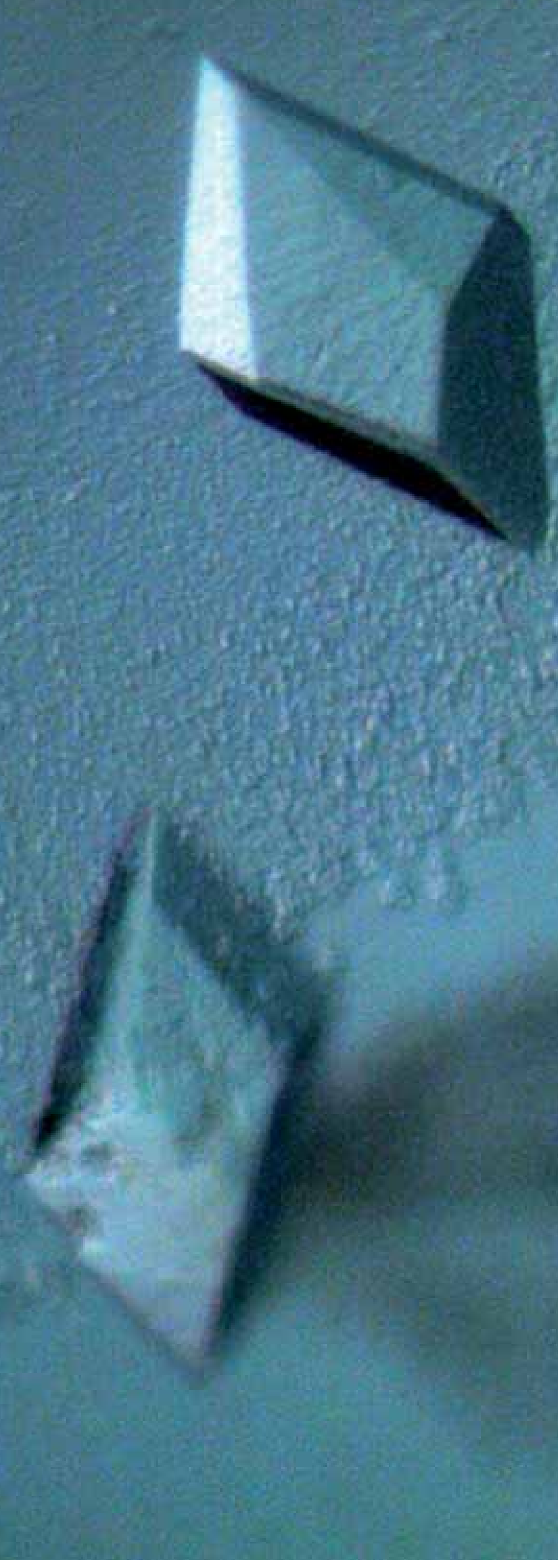
w5 – To learn more about the Centro Nacional de Biotecnologia in Madrid, see: www.cnb.uam.es

Influenza medication

Image courtesy of EMBL Photolab

Growing crystals from protein

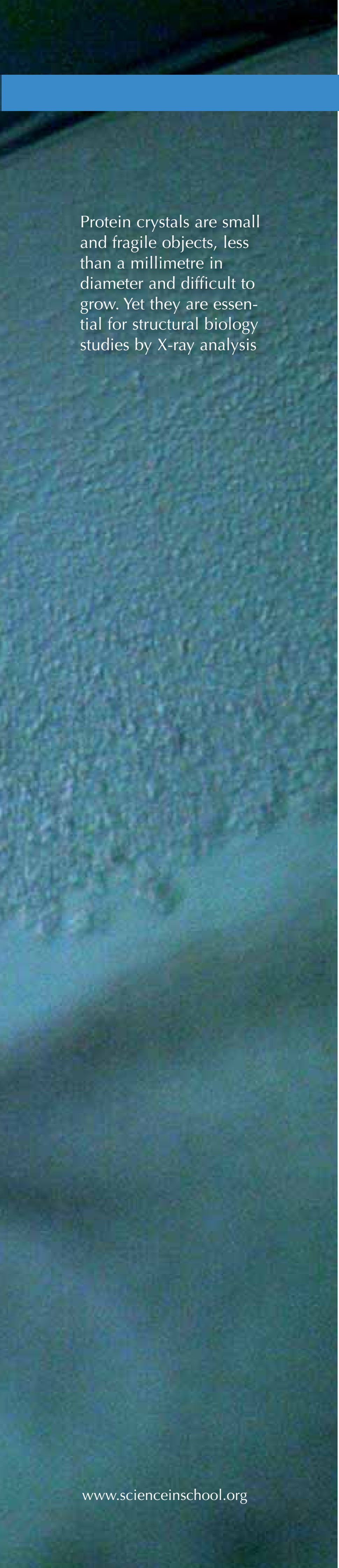
Beat Blattmann and **Patrick Sticher** from the University of Zürich, Switzerland, explain the science behind protein crystallography and provide a protocol for growing your own crystals from protein – an essential method used by scientists to determine protein structures.



In 1959, Max Perutz and John Kendrew published an article on the three-dimensional structure of whale myoglobin, which is a small protein responsible for the transport of oxygen in whale cells. By investigating the protein's structure, the two scientists wanted to understand the oxygen-carrying mechanism at the molecular level. They grew crystals from this protein and managed to determine its structure by analysing the X-ray diffraction pattern of the crystal. A number of myoglobins from other species had been tested before with little success, until Perutz and Kendrew obtained a useable diffraction pattern with whale myoglobin crystals. This pioneering work was awarded the Nobel Prize in Chemistry in 1962[w1]. Fifty years later, however, it is still a challenge to obtain protein crystals for structural studies.

What are proteins?

Proteins are the largest group of non-aqueous components in living cells. Almost every biochemical reaction requires a specific protein, called an enzyme. Other types of proteins have mechanical and structural functions (e.g. collagen in connective tissue), or mediate cell signalling (e.g. hormone receptors), immune responses (e.g. antibodies) or the transport of small molecules (e.g. ion channels). The variety is immense: more than 20 000 different proteins are known to exist in humans alone.



Protein crystals are small and fragile objects, less than a millimetre in diameter and difficult to grow. Yet they are essential for structural biology studies by X-ray analysis

Image courtesy of Gaby Sennhauser, University of Zürich

Despite this variety, all proteins share an identical structural principle. They consist of 20 different building blocks, called amino acids, which are arranged in a linear chain connected by covalent bonds between adjacent amino acids (see figure below). The length of the protein chain varies from a few dozen to thousands of amino acids. In cells, each protein is assembled using the information encoded in its corresponding gene. The assembly is performed by a ribosome, which is a complex molecular machinery consisting of proteins and RNA.

Proteins are folded into distinct three-dimensional structures

Under natural conditions, the linear chains of amino acids spontaneously fold into distinct three-dimensional structures. Stretches of amino acids form typical secondary structural elements. The most prominent elements are α-helices and β-sheets (see figure below), which are typically stabilised by hydrogen bonds between individual amino-acid residues. The entire protein forms a tertiary structure consisting of a variety of such structure elements.

Structure is function: what does the three-dimensional structure of a protein tell us?

The function of a particular protein depends on its three-dimensional structure. Only when the protein is folded, the specific amino acids of the protein are close enough to enable the formation of an *active site*. These sites can catalyse biochemical reactions, as in the case of enzymes, or form a specific binding site, as in the case of antibodies. Investigating the structural details of a protein is of great importance to understand how fundamental processes of life function at a molecular level: this is the research area of structural biologists. One of the major challenges in structural biology today is the elucidation of the structure, function and interaction of huge macromolecular complexes and membrane proteins[w2]. Due to their complexity, these proteins are experimentally extremely challenging, and every time the structure of a protein is determined, it is a major achievement. Nevertheless, since they are involved in fundamental biological processes, there is a great interest in better understanding their structure and function, and scientists keep trying to crystallise them.

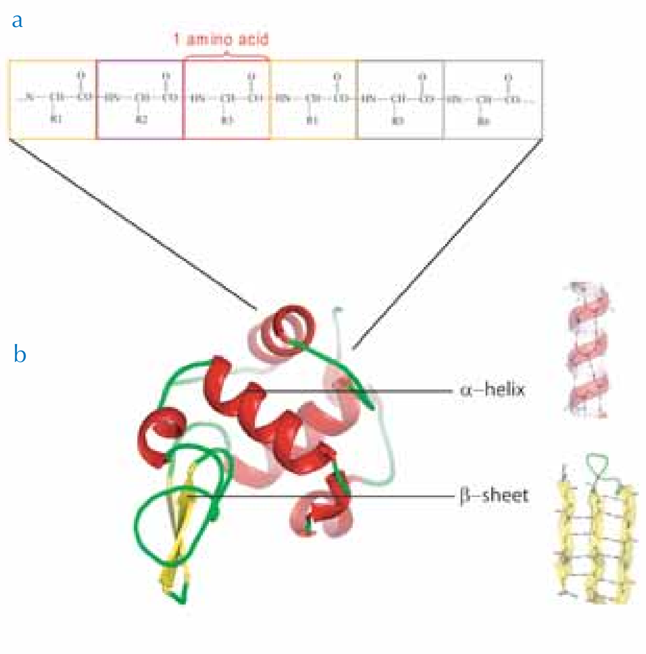
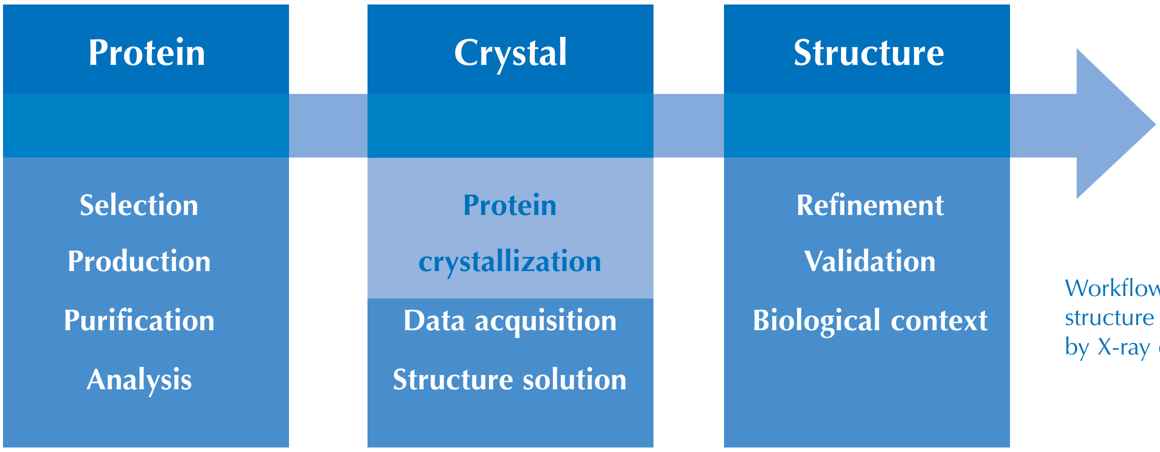


Image courtesy of Marc Leibundgut, ETH Zürich, and www.pdb.org

a. Proteins are built from amino acids, which are covalently linked to form a linear chain

b. Proteins are folded to a three-dimensional structure that determines their function. Small stretches of the amino-acid chain form typical folds. Two prominent structural elements are α-helices and β-sheets

Image courtesy of Beat Blattmann and Patrick Sticher



Workflow for protein structure determination by X-ray diffraction

Proteins are too small for direct observation

Proteins are tiny structures, measuring only a few nanometres (1 nm = 1 millionth of a mm). Particles that size cannot be observed even with the strongest light microscope, which has a maximum resolution of 1 micrometre (1 m = 1 thousandth of a mm).

Three major technologies are available to make protein structures 'visible':

- X-ray diffraction of protein crystals
- Nuclear magnetic resonance (NMR)
- Electron crystallography

As more than 90% of all protein structures deposited in the publicly accessible protein database of biological macromolecules[w3] have been determined by X-ray diffraction, we will concentrate on this method. To learn more about the history of crystallography and the journey of a

Crystals grow from an aqueous protein solution, which is brought into supersaturation. Crystallisation proceeds in two phases, nucleation and growth. After nucleation, it is important to reach what is known as the 'metastable zone', in which the best conditions are found for the growth of large well-ordered crystals. Two competing processes decrease the protein concentration in the supersaturated state: (I) crystallisation, (II) precipitation

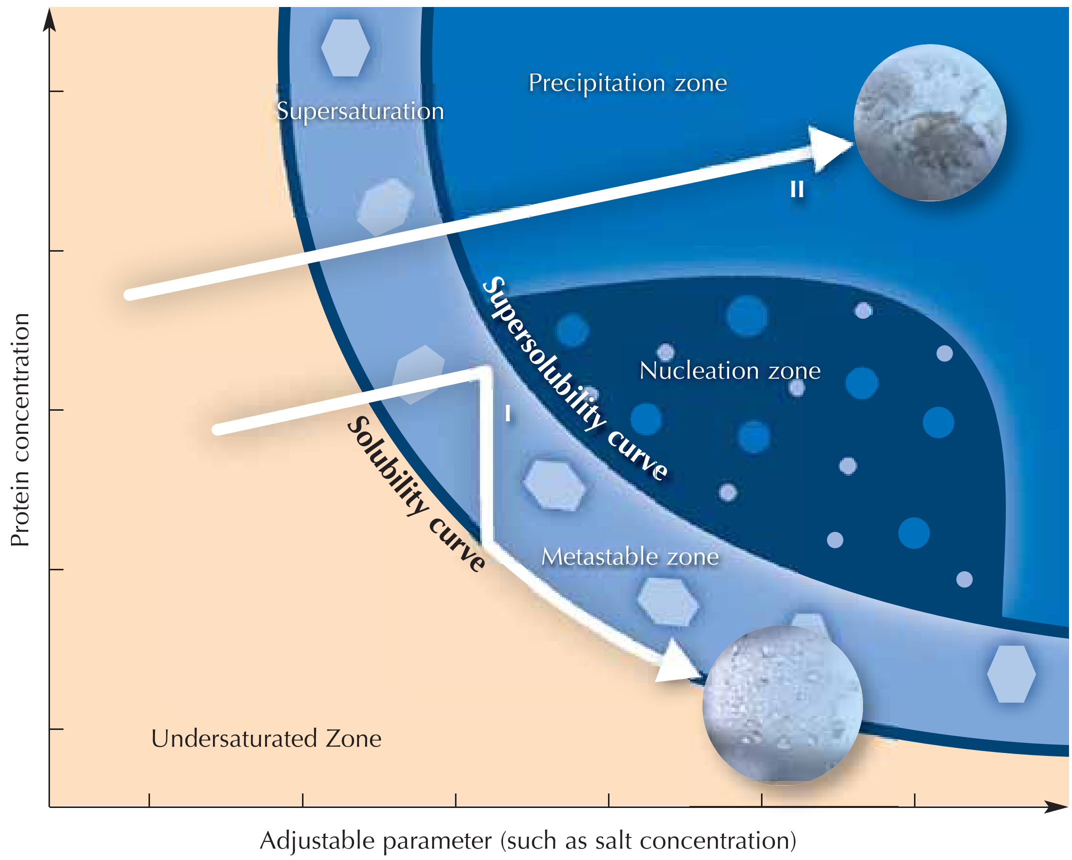


Image courtesy of Nicola Graf

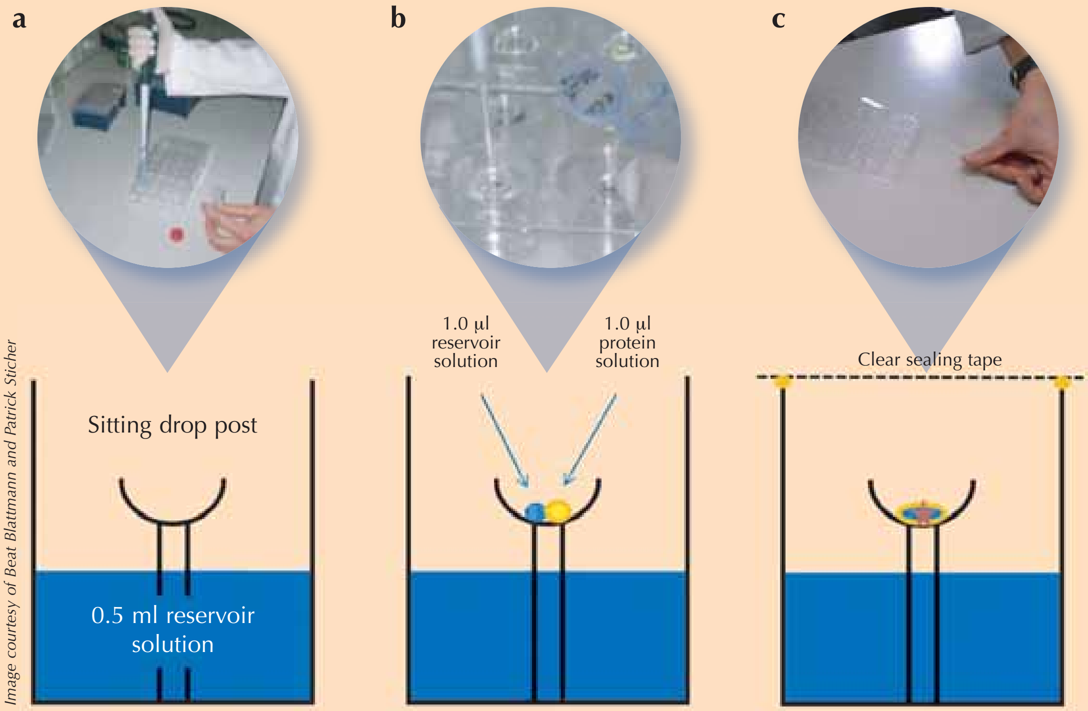


Image courtesy of Beat Blattmann and Patrick Sticher

The vapour diffusion method is the most frequently used technique to grow protein crystals.

a. A small amount of a crystallisation solution is put into a small reservoir.

b. A drop of protein solution and a drop of crystallisation solution are placed onto the sitting drop post in the chamber.

c. The chamber is sealed to start the crystallisation process

protein from lab to lab, until its structure is solved, see the article by Dominique Cornuéjols in this issue (pages 70-76).

Crystallising proteins is a tricky task, because it is difficult to determine the right conditions under which each new protein will crystallise – sometimes, it even seems impossible. So to ensure reproducible crystal quality (i.e. that equally good crystals can be grown again), scientists use controlled experimental set-ups to crystallise their proteins. The most frequently used method in protein crystallography is the vapour diffusion method (see image above): in this method, a small amount of a crystallisation solution is added to the reservoir of the crystallisation chamber. A drop of protein solution and a drop of the crystallisation solution are pipetted onto the sitting drop post that is located in the centre of this chamber.

Immediately after adding all solutions, the chamber is sealed to avoid evaporation. Since the concentration of salt ions is higher in the crystallisation solution than in the mixture on the sitting drop post, solvent molecules will move from the protein drop to the reservoir by vapour diffusion in the gas phase. During this process, the solubility of the protein in the drop decreases. The protein solution in the drop eventually becomes supersaturated, which is a thermodynamically unstable state. This causes some of the protein in the drop either to form crystal nuclei that finally grow into larger protein crystals (see image on page 32), or to precipitate as amorphous protein which is useless for X-ray analysis. Crystallisation and precipitation are competing processes, so it is extremely important to find the optimal conditions favouring crystallisation.

Lysozyme crystals in the classroom

In this practical activity, students learn more about modern X-ray crystallography by determining the optimal crystallisation conditions for a protein. They investigate the formation of lysozyme crystals as a function of pH and salt concentration.

Lysozyme

Lysozyme is a protein belonging to a family of antibacterial enzymes which damage bacterial cell walls. In humans, it is abundant in a number of secretions, such as tears, saliva and mucus. Large amounts of lysozyme can also be found in chicken egg whites.

Equipment and materials

- One or two Cryschem™ crystallisation plates (Hampton Research) per class
- Crystal clear sealing tape (5 cm) (Hampton Research)
- 1 ml and 1 l manual pipettes
- A microscope to observe the crystals
- Storage space at 20 °C

Chemicals

- Lysozyme (SigmaAldrich Product #62971, BioChemika grade – lysozyme from a different source will probably also do, but this one has been thoroughly tested with the protocol, so it is recommended, to be on the safe side)
- Sodium chloride (NaCl) (table salt from the supermarket will do)
- Citric acid
- Sodium acetate
- Sodium phosphate, monobasic
- Sodium hydroxide solution
- Glacial acetic acid
- Deionised water (DI-water)

Stock solutions

The following aqueous stock solutions should be prepared in advance by the teacher:

- 50 mg/ml lysozyme stock solution in water
- 3 M sodium chloride
  Dissolve 17.53 g NaCl in 100 ml DI-water.

		1	2	3	4	5	6
		2.0 ml of 3M NaCl stock solution (end conc. 0.6 M) 7.0 ml DI-water	3.0 ml of 3M NaCl stock solution (end conc. 0.9 M) 6.0 ml DI-water	4.0 ml of 3M NaCl stock solution (end conc. 1.2 M) 5.0 ml DI-water	5.0 ml of 3M NaCl stock solution (end conc. 1.5 M) 4.0 ml DI-water	6.0 ml of 3M NaCl stock solution (end conc. 1.8 M) 3.0 ml DI-water	7.0 ml of 3M NaCl stock solution (end conc. 2.1 M) 2.0 ml DI-water
A	1.0 ml sodium citrate (end conc. 0.1 M), pH 3.5	A1	A2	A3	A4	A5	A6
B	1.0 ml sodium acetate (end conc. 0.1 M), pH 4.5	B1	B2	B3	B4	B5	B6
C	1.0 ml sodium acetate (end conc. 0.1 M), pH 5.5	C1	C2	C3	C4	C5	C6
D	1.0 ml sodium citrate (end conc. 0.1 M), pH 6.5	D1	D2	D3	D4	D5	D6

pH increases from 3.5 to 6.5

NaCl end concentration increases from 0.6 to 2.1 M

Pipetting scheme for the crystal growth experiment

- 1 M sodium citrate, pH 3.5
  Dissolve 19.24 g citric acid in 100 ml DI-water. Adjust the pH with sodium hydroxide solution to pH 3.5.
- 1 M sodium acetate, pH 4.5
  Dissolve 13.6 g sodium acetate in 100 ml DI-water. Adjust the pH with glacial acetic acid to pH 4.5.
- 1 M sodium acetate, pH 5.5
  Dissolve 13.6 g sodium acetate in 100 ml DI-water. Adjust the pH with glacial acetic acid to pH 5.5.
- 1 M sodium phosphate, pH 6.5
  Dissolve 15.6 g sodium phosphate in 100 ml DI-water. Adjust the pH with sodium hydroxide solution to pH 6.5.

Crystal growth experiment

1. From the stock solutions, prepare the 24 reservoir solutions for the crystallisation experiments according to the table on the left. The students can be split into small groups, each preparing some of the 24 different solutions. All groups can use the same stock solutions.
2. Using the table for reference, pipette 0.5 ml of the corresponding reservoir solution into each of the 24 reservoir wells of a Cryschem™ plate ('a' in figure on page 33). The table on the left summarises the conditions in each well and shows the position of the wells on the plate.
3. Pipette 1 µl of the reservoir solution into the crystallisation cup on the sitting drop post in each well ('b' in figure on page 33).
4. Add 1 µl of lysozyme stock solution to each 1 µl reservoir solution drop ('b' in figure on page 33).
5. Immediately after adding the drops of protein solution, close the crystallisation vessel with crystal clear sealing tape to prevent evaporation from the vessel ('c' in figure on page 33).
6. Store the plate at 20 °C. The crystals will start to grow immediately in some wells, and growth can be observed directly under the microscope at 1-2 hour intervals. The plates may be stored until the next lesson for final analysis. After about 1-2 weeks, crystals will have grown to their final size. A sealed plate will keep up to a year, sometimes even longer.
7. Analyse the size, number and distribution of lysozyme crystals. The crystals may be too small to be observed with the naked eye, so a good magnifying glass or – even better – a microscope would be very useful.
8. By comparing the results from the 24 reservoirs, determine the optimal conditions for crystallisation.

Have your crystals measured by X-ray

When your class has successfully grown protein crystals, please contact Dr Patrick Sticher at sticher@bioc.uzh.ch. The Swiss NCCR (National Center of Competence in Research) Structural Biology[w2] has offered to produce an X-ray diffraction image for the first 10 school classes that successfully grow protein crystals using this protocol. X-ray measurements can be made either directly from school samples, or, if shipment is a problem, by reproducing the optimised crystallisation conditions found in your class and measuring those crystals. Together with the diffraction image, the scientists offer to send additional information on what they would do next with this information to obtain the actual structure, and a certificate if required.

Chat with scientists

Students can chat online with the scientists via Skype[w4], after performing their own experiments. To make an appointment, email Patrick Sticher (sticher@bioc.uzh.ch) to chat with him using the Skype account 'proteincrystallography'.

Download additional teaching material

A set of Powerpoint® slides, images and further experiments are available online[w5].

Suppliers

The following suppliers[w6] provide the required materials and chemicals:

Hampton Research:

- Cryschem™ 24-1 SBS plate, Cat. No. HR1-002 (We recommend using this type of plate. One plate costs about US$3.)
- Crystal Clear Sealing Tape (5 cm), Cat. No. HR4-511

Gilson Inc:

- 1 ml and 1 μl manual pipettes

Sigma Aldrich:

- Lysozyme, Product #62971
- Sodium chloride, Product #71380
- Citric acid, Product #27488
- Sodium acetate, Product #71190
- Sodium phosphate, monobasic, Product #71502

REVIEW

This article provides a good introduction to the study of protein crystals by X-ray diffraction. As such, it provides an interesting comprehension exercise for biology, chemistry and physics – showing good links between the three sciences. It can be used to discuss how to look at the very small, and why we need to study things at this level. The article also provides good background reading for teachers who are not aware of the use of diffraction as an analytical tool.

The practical looks like it will take a little time to set up and obtain results, but the offer of having the results analysed at a university gives it a different dimension to other practicals.

Mark Robertson, UK

References

Cornuéjols D (2009) Biological crystals: at the interface between physics, chemistry and biology. *Science in School* **11**: 70-76. www.scienceinschool.org/2009/issue11/crystallography

Web references

w1 – Additional information about the 1962 Nobel laureates in chemistry and their pioneering work can be found on the website of the Nobel Prize Committee: http://nobelprize.org/nobel_prizes/chemistry/laureates/1962/

w2 – The Swiss National Center of Excellence in Research (NCCR) Structural Biology is a consortium of scientists dedicated to the elucidation of structure-function relationships of membrane proteins and supra-molecular complexes: www.structuralbiology.uzh.ch

Selected research highlights can be found here:

www.structuralbiology.uzh.ch/research004.asp

w3 – New structures of biological macromolecules (proteins and nucleic acids) are deposited in the Protein DataBank (PDB). The website offers a number of interesting teaching resources:

www.pdb.org

Another valuable resource for protein information is:

www.proteopedia.org

w4 – To download and install Skype, see: www.skype.com

w5 – Additional teaching resources are available here: www.structuralbiology.uzh.ch/teacher

Login: crystallization, Password: xraybeam2008

This site will be updated regularly.

w6 – The websites of suppliers are as follows:

Hampton Research: www.Hamptonresearch.com

Gilson Inc.: www.gilson.com

Sigma-Aldrich: www.sigmaaldrich.com

Resources

Abad-Zapatero C (2002) *Crystals and Life: A Personal Journey*. La Jolla, CA, USA: International University Line. ISBN: 978-0972077408

Here are some recommended protocols for growing non-protein crystals with younger students:

www.msm.cam.ac.uk/phase-trans/2002/crystal/a.html

www.waynesthisandthat.com/crystals.htm

http://chemistry.about.com/od/growingcrystals/Growing_Crystals.htm

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Beat Blattmann is a chemist in charge of the high-throughput crystallisation facility at the NCCR Structural Biology. This system allows 5000 crystallisation conditions to be tested per day.

Patrick Sticher has a PhD in microbiology. He is the scientific officer of the NCCR and is responsible for education, technology transfer and programme coordination.

SET-Routes

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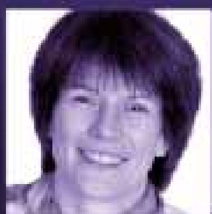
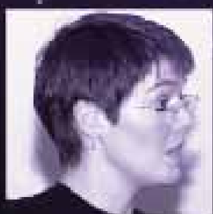


The Insight Lectures will be freely available as webcasts at www.set-routes.org or on DVD from 1 June 2009.



SET-Routes is an EU-funded network of women scientists from PhD students to institute directors, working in some of the most challenging areas of science. Its goal is to awaken young girls' interest in science and to encourage young women graduates to pursue careers in science, engineering and technology – SET.

Fuelling interest: climate change experiments

Image courtesy of alohaspirit / iStockphoto

Dudley Shallcross, **Tim Harrison**, **Steve Henshaw** and **Linda Sellou** offer chemistry and physics experiments harnessing alternative energy sources, such as non-fossil fuels.

Discussions of climate change in the science classroom can be very wide-ranging, but will probably involve different sources of energy and their consequences. Relevant topics are likely to include different fuels that can be used, how effective they are and how they are produced, and alternatives to combustion. We suggest a couple of laboratory activities to support physics and chemistry lessons on climate change.

1) Measuring fuel efficiency

Unburned fuel evaporating into the atmosphere, during either storage or combustion, is an air pollutant, and also plays a role in determining the lifetime of greenhouse gases. One way to limit the damage is to use alcohols instead of more standard hydrocarbon fuels such as petrol and diesel.

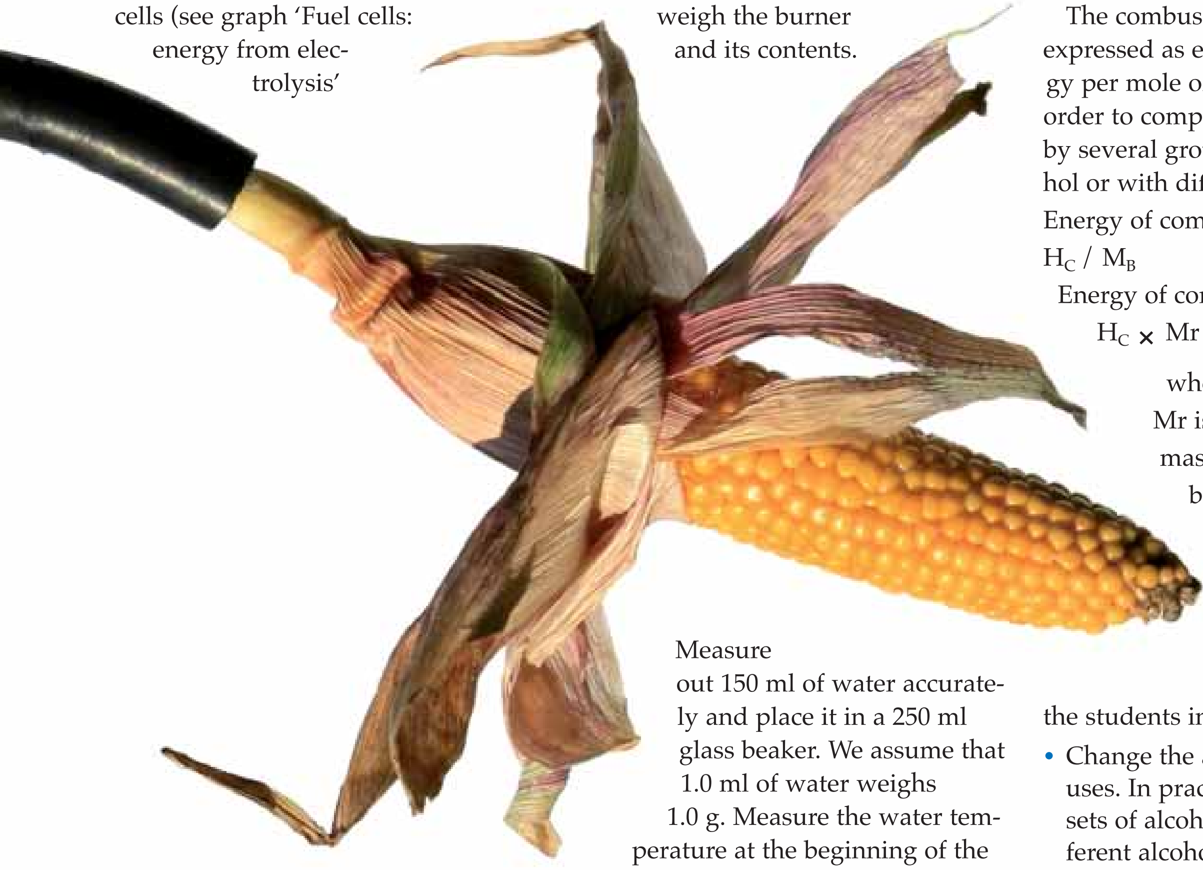
Hydrocarbons in the atmosphere are oxidised by the hydroxyl radical (•OH) to form predominantly alcohols and carbonyls. Levels of atmospheric •OH are important, as these radicals remove greenhouse gases that contain the C-H bond, such as CH_4. Computer simulations have shown that releasing alcohols into the atmosphere has a less damaging effect than releasing hydrocarbons, because fewer oxidation steps take place, removing smaller amounts of •OH. Therefore, using alcohols instead of hydrocarbons as fuels has a positive effect on both air quality and the removal of greenhouse gases. Moreover, the smaller alcohols released into the atmosphere can be removed, to a small extent, by physical processes such as dry (taken up by a surface) and wet (rain, fogs, aerosols) deposition, whereas their hydrocarbon counterparts cannot.

Alcohols are used in fuel cells (see graph 'Fuel cells: energy from electrolysis' on page 42) which have a wide range of potential applications, for example in short-range vehicles.

Of course, a good fuel is not only environmentally friendly – it must also be an efficient source of energy. The following experiment allows students to determine the energy released by burning different types of alcohols, and to compare their effectiveness with that of more standard fuels.

Alcohol burners are the small burners made of glass, complete with a wick, which usually come with children's chemistry sets and are readily available from schools equipment companies. They can be used to determine the energy released in the combustion of shorter primary alcohols such as methanol, ethanol, propan-1-ol, butan-1-ol and pentan-1-ol.

The students can set up the experiment (see image on page 40), in which the alcohol burner is filled with a known alcohol. First, weigh the burner and its contents.



Measure out 150 ml of water accurately and place it in a 250 ml glass beaker. We assume that 1.0 ml of water weighs 1.0 g. Measure the water temperature at the beginning of the experiment and clamp the beaker above the burner, leaving a space of about 5 cm between the wick and the base of the beaker. Ignite the burner and place it centrally under the water container until the temperature has risen by 30 to 40 °C. Determine the temperature rise by recording the final temperature of the water. Weigh the final mass of the alcohol burner and its contents. It is at this stage that the students will not remember if they originally weighed the alcohol burner with the lid on or off! Calculate the mass of alcohol burned (M_B).

The energy released in the combustion, used to raise the water temperature, can be calculated using equation (1)

$$H_C = -c \times M_{water} \times T_R \qquad (1)$$

where:

H_C = heat of combustion [kJ]

c = the specific heat capacity of water = 4.187 kJ kg^{-1} °C^{-1}

M_{water} = mass of water [kg]

T_R = temperature rise of water [°C]

The combustion energy can then be expressed as energy per gram or energy per mole of the alcohol burnt, in order to compare the results obtained by several groups with the same alcohol or with different alcohols.

Energy of combustion per gram =

$$H_C / M_B \qquad (2)$$

Energy of combustion per mole =

$$H_C \times Mr / M_B \qquad (3)$$

where:

Mr is the relative molecular mass of the alcohol being burnt,

M_B is the mass of the burnt alcohol.

Further investigations that can be carried out by the students include:

- Change the alcohol that the burner uses. In practice, it is best to have sets of alcohol burners that use different alcohols, as it is very difficult to replace the alcohol in a wet wick.

  An alternative to comparing several different alcohols is to compare just one alcohol with a night light (a small wax candle in a metal holder)
- Change the material that the beaker is made from, for example to copper or a galvanised steel food can
- Change the thickness of the material that the water container is made from
- Compare an insulated container (made from a heatproof material!) with a glass beaker
- Compare the open glass beaker being heated to one with a lid fitted

Alcohol burner set up under a beaker to which a known volume of water is to be added

Close-up of an alcohol burner

Images courtesy of Bristol ChemLabS

on top, through which the thermometer is placed.

- Does it make a difference whether the water in the container is stirred or not?

Table 1: Heats of combustion for small primary alcohols (*Handbook of chemistry and physics*, 57th edition, CRC Press) and some common fuels (Wikipedia, http://en.wikipedia.org/wiki/Heat_of_combustion, accessed 17/03/09)

Name of alcohol/fuel	Standard heat of combustion [MJ/kg]
Peat (damp)	6.0
Peat (dry)	15.0
Wood	15.0
Coal (Lignite)	15.0
Methanol	22.7
Coal (Anthracite)	27.0
Ethanol	29.7
Carbon	32.8
Propan-1-ol	33.6
Butan-1-ol	36.2
Pentan-1-ol	37.7
Diesel	44.8
Paraffin	46.0
Kerosene	46.2
Gasoline	47.3
Butane	49.5
Propane	50.4
Ethane	51.9
Natural gas (average, varies depending on source country)	54.0
Methane	55.5
Hydrogen	141.8

- Does the height at which the beaker is clamped above the flame make any difference to the amount of heat absorbed by the water?
- Does it make a difference to have boards / heatproof mats placed around the burner to reduce draughts?
- Does the length of wick that is exposed make any difference?

Note that it is too dangerous to use petrol or diesel in these burners. Even without testing conventional fuels or different alcohols to compare the energies released by 'green' fuels, these experiments can be used to discuss experimental error and accuracy of measurement in general. It will be obvious from comparing the classroom experimental results with the textbook data or those available on Wikipedia[w1] (see table) that there are significant errors.

2) Producing biofuels from vegetable oil

Biofuels are solid, liquid or gaseous fuels derived from relatively recently dead biological material, as opposed to fossil fuels, which are derived from long-dead biological material.

Whereas burning fossil fuels releases CO_2 which has been trapped for a long time, burning biofuels should only release CO_2 that has been recently captured from the atmosphere during photosynthesis and converted to fuel. In theory, the process should therefore be carbon neutral. The production of biofuels, however, also generates CO_2; the life-cycle emission (amount of CO_2 generated during production, use and waste disposal) of some first-generation biofuels even exceeds that of traditional fossil fuels.

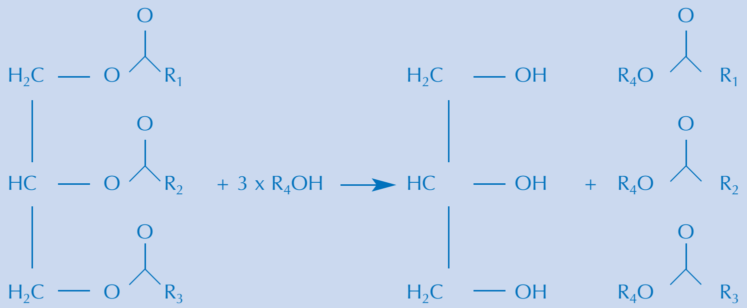
So far, three generations of biofuels have been developed: first-generation biofuels are made from sugar, starch, vegetable oil, or animal fats. Besides having sub-optimal emission levels, first-generation biofuels have other important limitations: there is a threshold above which their production threatens food supplies and biodiversity. Moreover, they are more expensive than existing fossil fuels.

This led to the development of second-generation biofuels, which can supply a larger proportion of our fuel supply sustainably, affordably and with greater environmental benefits. They use a variety of non-food crops, including waste biomass, the stalks of wheat, corn, and wood.

Still, land-based biofuels occupy land that could otherwise be used to grow food. Algae fuel, also called oilgae, is being developed as a third-generation biofuel to avoid this problem. These fuels can be produced in a low-input, high-yield manner, since algae produce 30 times more energy per acre than land crops such as soybeans.

Theoretically, biofuels can be produced from any biological carbon source, although the most common sources are photosynthetic plants and plant-derived materials. One advantage of many biofuels over most other

Image courtesy of Bristol ChemLabS



Transesterification of vegetable oil triglycerides

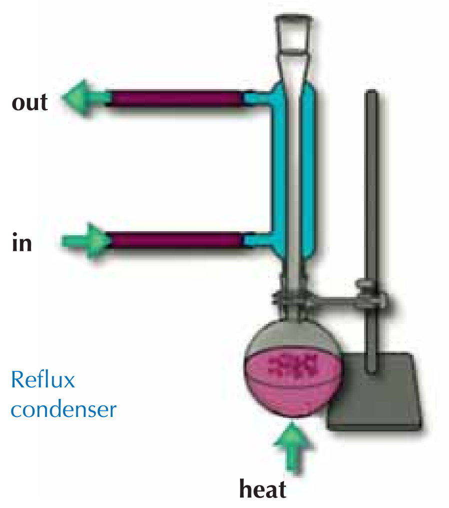


Image courtesy of Bristol ChemLabS

Electricity generated from gin in a mini fuel cell

fuel types is that they are biodegradable, and so relatively harmless to the environment if spilled.

There are a number of ways to make biofuels from a range of vegetable oils, but the reaction is essentially the same. A biofuel is made by alkaline hydrolysis of the triglycerides in a vegetable oil (see image above), and the following re-esterification of the triglycerides to the methyl ester. In practice, both steps can take place in the same preparation, provided a mixture of methanol in alkali is used, as is done commercially. This mixture contains the methoxide ion. During hydrolysis, a fatty acid is liberated from the triglyceride. Together with the methoxide ion, the methyl ester of the fatty acid is then formed.

Glycerol (propan-1,2,3-triol) is a waste product of this last reaction. The disposal or use of the glycerol is one of the challenges for this growing industry.

For the experiment described below, you can either use a boiling tube or a reflux method involving Quickfit™ laboratory glassware.

In the simpler preparation without a reflux, 12-13 ml of a vegetable oil of choice are put into a boiling tube with 2 ml of potassium hydroxide in methanol (5% w/w). The liquids are mixed without shaking to prevent trapping air and foaming. The mixture is left to stand in a water bath at 60ºC. The reaction rate can be followed by measuring the viscosity: you can time how long it takes for a small ball bearing (readily available, symmetric shape, smooth and dense) to drop through a defined depth of the mixture in the tube every 5 minutes at regular intervals for up to 2 hours. The larger triglyceride is broken down to smaller subunits (see image above), which will then have a smaller mass than the compound from which they are formed. Since the viscosity of a liquid is directly proportional to the mass of its molecules, the reaction will lead to a less viscous mixture. Furthermore, you can leave a sample for a whole day in these conditions to qualitatively observe the extent of hydrolysis.

Although the biofuel produced in this experiment still contains the glycerol formed as a waste product of the reaction, the change in viscosity can nevertheless be observed. If using a reflux condenser for the reaction, the biofuel can be separated from the glycerol by solvent extraction.

The biofuel produced by either method can then, for example, be used to run a small diesel engine.

Note: if using vegetable oil that has already been used for cooking, please remember to filter out any food residues first!

3) Fuel cells: energy from electrolysis

Both the previous experiments are based on the release of energy through combustion. While this is one way of oxidising a fuel to release energy, it is not the only way. Fuels can also be oxidised by electrolysis, as demonstrated in the following experiment.

Fuel cells produce electricity from a reaction between a fuel such as an alcohol or hydrogen at the anode, and an oxidising agent such as oxygen or chlorine at the cathode. The fuel and the oxidising agent react in the presence of an electrolyte. The reactants flow into the cell, and the reaction products flow out of it, while the electrolyte remains within it. A fuel cell works by catalysis, separating the component electrons and protons of the reactant fuel, and forcing the electrons to travel through a circuit, hence converting them to electrical power.

A fuel cell is different from a chemical battery because its reactants can be replenished (representing a thermodynamically open system), whereas the chemicals being consumed in a battery are not, as it is sealed (thermodynamically closed). A fuel cell will continue to work as long as its reactants are replaced.

A typical fuel cell produces a voltage from 0.6 V to 0.7 V at full rated load. However, fuel cells can be combined in series and parallel circuits; series yield higher voltage, while parallel allows a stronger current to be drawn. Such a design is called a fuel cell stack. Furthermore, the cell surface area can be increased to allow stronger current from each cell.

Fuel cells are very useful as power sources in remote locations, such as spacecraft, remote weather stations, large parks and rural locations. In the future, they could also power vehicles.

There are several demonstration fuel cells available for purchase[w2] (for about €20 each), to show the principle to students. The one we use is an alcohol/air fuel cell (see image on page 41), which consists of two parts: an adapted plastic beaker with a conductive pad connected to a terminal (the anode), and an insert containing the catalyst. A defined volume of a source of alcohol (such as antifreeze), or of an alcohol itself (such as propan-1-ol) is mixed with 55 ml of alkali (such as sodium hydroxide) as an electrolyte, and put into the plastic beaker. The insert is put into the beaker to complete the cell. Air can pass through the insert into the alkaline alcohol mixture.

The chemical reaction that generates a current is the oxidation of the alcohol by the oxygen in the air – to a carbonyl or a carboxylic acid, depending on the degree of oxidation. The reaction is catalysed by platinised graphite in a pad at the base of the beaker.

At the cathode:

$4e^- + O_2 + 2H_2O \rightarrow 4\ OH^-$

At the anode:

$CH_3CH_2OH + 2OH^- \rightarrow CH_3CHO + 2H_2O + 2e^-$

The aldehyde CH_3CHO is also capable of being oxidised to a carboxylic acid, so it can continue to release an electric current. Incidentally, an alternative fuel for this particular type of fuel cell, which gives a greater voltage than an alcohol, is sodium tetrahydroborate (III) (sodium borohydride, $NaBH_4$). According to the manufacturer, only minute quantities (about 20 mg of $NaBH_4$) are required to run the fuel cell for one hour. Note $NaBH_4$ is toxic, harmful and an irritant.

The voltage produced by the fuel cell can easily be measured using a cheap multimeter.

These are some of the investigations that can be carried out by students using the fuel cells:

- Different types of alcohol may be used, as long as they are water-soluble: these include the alcohol series from methanol to pentan-1-ol, the secondary or tertiary isomers of these alcohols (where they exist) and different sources of alcohol, such as methylated spirits, car windscreen wash, antifreeze or even alcoholic drinks like vodka or gin. What effect does the type of alcohol have on the voltage produced?
- Students can investigate the effect of changing the initial concentration of alkali on the output voltage. They may also analyse whether the type of alkali used, for example sodium versus potassium hydroxide, makes any difference to the voltage produced by the fuel cell.
- Investigating the change in concentration of the alkali or the alcohol while the fuel cell is running can also be interesting.
- The whole setup can be placed in a cooled/heated water bath to change the temperature at which the reaction takes place. By measuring the output current, the effect of temperature on the rate of reaction can be investigated.

Suggestions for further experiments can be found in a couple of books or online[w3].

Acknowledgement

The authors wish to thank Will Davey at Sheffield University for the basis of the biofuel production experiment.

Web references

w1 – For heat of combustion tables of various fuels and organic compounds on Wikipedia, see: http://en.wikipedia.org/wiki/Heat_of_combustion#Heat_of_combustion_tables

w2 – One of many suppliers specialising in fuel cell technology for both industry and education is h-tec: www.h-tec.com

w3 – h-tec has also published a book on using fuel cells in the classroom:

Voigt C, Hoeller S, Kueter U (2005) *Fuel Cell Technology for Classroom Instruction (Basic Principles, Experiments, Work Sheets)*. Luebeck, Germany: h-tec

A collection of safe, inexpensive, educational and fun projects focusing on fuel cell technology is:

Harper G (2008) *101 Fuel Cell Projects for the Evil Genius*. New York, USA: McGraw-Hill Professional

For further experiments using fuel cells, see: www.ectechnic.co.uk/exps.html

Resources

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

Dudley Shallcross is the professor in atmospheric chemistry, Tim Harrison is the school teacher fellow and Linda Sellou and Steve Henshaw are both postdoctoral teaching assistants at the School of Chemistry, University of Bristol, UK. The school teacher fellowship is a position for a secondary-school teacher that was created to bridge the gap between secondary schools and universities, and to use the resources of the School of Chemistry to promote chemistry regionally, nationally and internationally. For more information about modelling climate change or about the post of school teacher fellow, please contact Dudley Shallcross (d.e.shallcross@bristol.ac.uk) or Tim Harrison (t.g.harrison@bristol.ac.uk).

Image courtesy of sbayram / iStockphoto; earth image courtesy of NASA

Catch them young: university meets primary school

Teaching science at primary school can be a challenge. At *La main à la pâte*, Samuel Lellouch and David Jasmin send university students to support primary-school teachers. Why not try two of their activities in your classroom?

Image courtesy of Fabrice Krot, La Maison des Sciences

Image courtesy of letty17 / iStockphoto

Guillermo is an engineering student at the prestigious Ecole Polytechnique in Saint Etienne, France. He is supporting Pascale, a teacher delivering a unit on electricity to six-year-olds (French CP level) in a local primary school. At the end of the class, they review the activities:

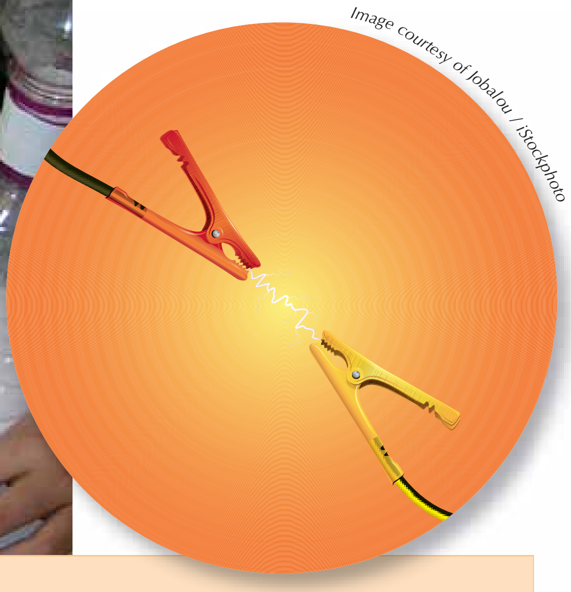
"Have you seen the diagrams the children made today? Their progress is amazing!" comments Pascale. "Next week we'll learn about the switch. Can you come and help? It would be great if we could work together again."

"Sure. I can provide diagrams, help you prepare the materials and guide the children's ideas," says Guillermo. "The switch is quite a difficult topic for six-year-olds. Perhaps we could introduce it by asking them how they could turn off a light bulb without disconnecting the wires."

★ ★ ★

As part of a project called *La main à la pâte*[w1], between 1500 and 2000 science or engineering students in France coach primary-school classes (children aged 3-11) during science lessons. The project was launched in 1996 by physics Nobel Prize winner Georges Charpak and the Académie des Sciences to promote investigation and inquiry-based science teaching in primary schools. Although it began in France, the project now runs in more than 20 partner countries. There are *La main à la pâte* mirror websites in German[w2], Spanish[w3], Serbian[w4],

Pupils performing the sand timer activity



Arabian[w5] and Chinese[w6], as well as an international web portal, Teaching Science[w7]. With versions in English, French and Spanish, this portal includes links to many of *La main à la pâte*'s partner projects in countries such as Belgium, Sweden, Turkey and Switzerland.

While an inquiry-based approach makes science more enjoyable for children, as well as helping them develop important skills and acquire scientific knowledge, it can be time-consuming. Particularly at first, preparing and running the sessions can be a lot of work: finding materials, organising experimental work, and guiding individual groups or children. Moreover, many primary-school teachers do not feel confident

BACKGROUND

A win-win situation

The children learn about their own abilities to perform scientific experiments, and have the opportunity to compare their approach with that of a 'real' science student. In addition, the inquiry-based approach allows children to enjoy teamwork as well as the experimental activities themselves: this is a real source of motivation and shared joy.

The primary-school teachers may realise that science is not as difficult as they thought and, with the students' coaching, they can familiarise themselves with inquiry-based approaches similar to those used in scientific research. This is especially important because these teachers are more often trained in arts than in science – according to the French ministry of education, 80% of primary-school teachers do not have a scientific background. It is also satisfying for teachers to see how motivated and concentrated the children are in a concrete experimental situation.

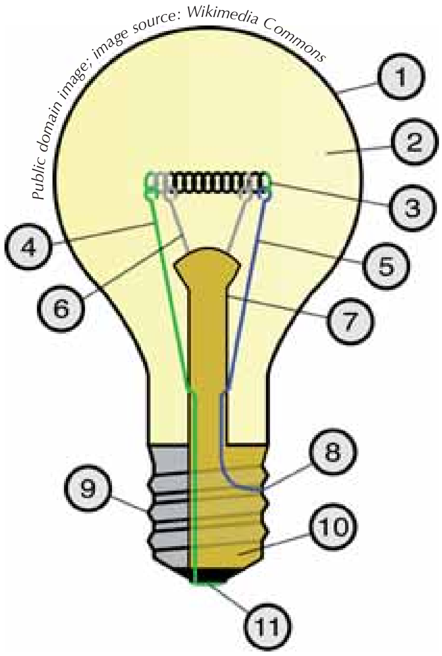
The science and engineering students have the opportunity to give children a realistic idea of their job in particular and of science in general, while at the same time gaining an interesting insight into the world of teaching. Moreover, they face the sometimes difficult task of adapting their knowledge to a particular audience: children aged 3-11 can cause disconcerting situations, posing a real challenge to the students.

BACKGROUND

Pollen: scientific coaching at a European level

Pollen is a European project which aims to stimulate and support inquiry-based science education in European primary schools. Within the project, 12 seed cities for science in 12 EU countries have been selected to involve the whole community (including families, scientific partners, city halls, and cultural centres) in enhancing science teaching at primary-school level.

Teachers and scientists outside seed cities can get involved by forming local partnerships to become part of Pollen. They can also contribute to the online resources[w9], which are freely available.



1. Glass bulb
2. Inert gas
3. Tungsten filament
4. Contact wire (goes to foot)
5. Contact wire (goes to base)
6. Support wires
7. Glass mount/support
8. Base contact
9. Screw threads
10. Insulation
11. Electrical foot contact

enough to run scientific activities in lessons.

Students like Guillermo help overcome such difficulties. Coming from engineering schools, technical universities and university science departments all over France, they volunteer to help teachers use an inquiry-based approach in the classroom. For at least seven consecutive weeks, third-year students spend half a day per week at a primary school. Each student helps a teacher to prepare the lesson – 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.

To allow more students and teachers to participate in such partnerships, as of 2009 the French ministry of education and ministry of research and higher education have joined this project, developing it into ASTEP[w8]: supporting teachers through the involvement of scientists in primary education.

Furthermore, *La main à la pâte* is the French co-ordinator of the European Pollen project[w9] (see box), which also promotes an inquiry-based approach, but with a stronger emphasis on community participation. Saint-Etienne, the French Pollen seed city, has concentrated on strengthening the links between primary schools and its university. Based on this experience, they have created a guide and a training unit for scientists and teachers, both of which are available online in French and English[w10].

Below are two teaching activities developed by teachers and students involved in the *La main à la pâte* and Pollen projects. Details of many more activities are available on the *La main à la pâte*[w1] and Pollen[w9] websites.

How can the bear's nose be switched on?

This activity, discussed by Pascale and Guillermo, is a teaching unit in six sessions to introduce the notion of the electric switch to children aged 3 – 6[w11]. It can provide some ideas for teaching children about electricity, a topic that is often neglected in primary schools because teachers find it difficult to know how to approach it in class.

In the next section you will find the basic background knowledge required for the teacher and the class to work on this unit, while subsequent sections outline the activity itself. Further background information developed by *La main à la pâte* for teaching electricity at primary-school level can be downloaded from the *Science in School* website[w12].

Background knowledge for teacher and class

The key is to know what a simple electric circuit is. It consists of a con-

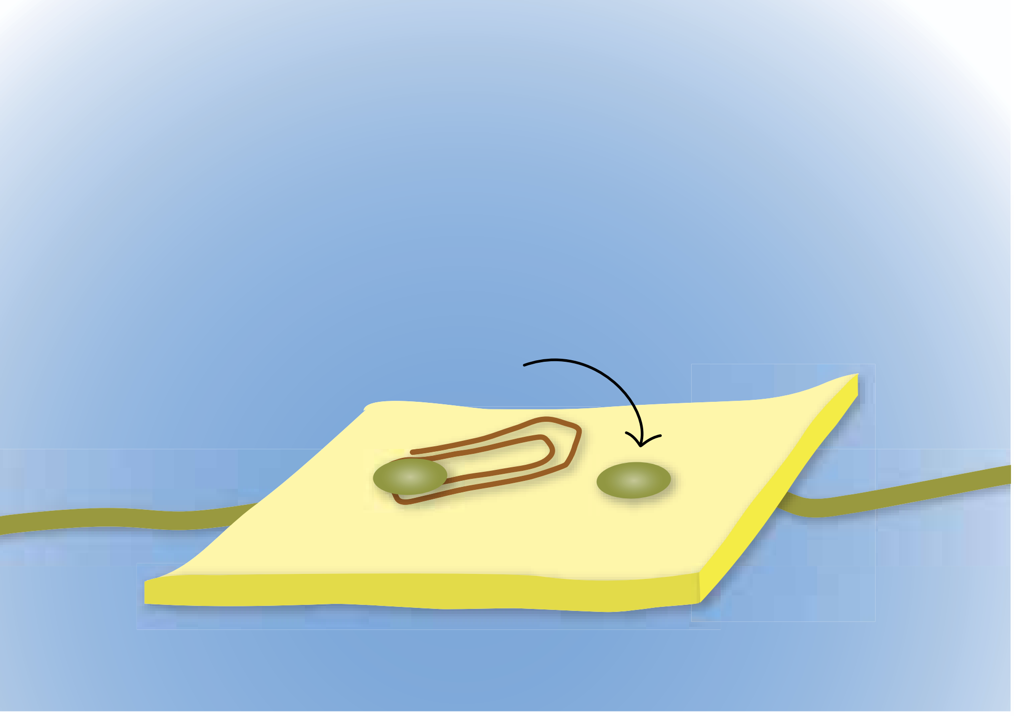


Image courtesy of Nicola Graf

A switch made with a paperclip and two split pins

Image courtesy of Jean Jannon / Pixelio

A split pin

tinuous series of conductive objects, including a battery, electric cables and a light bulb. All these objects must be in contact with each other, one after the other, forming a closed loop – an uninterrupted circuit. Of course you can't see what's inside the battery, and it's dangerous to take it apart since it will generally contain harmful chemicals, but a functioning battery is built to ensure circuit continuity, allowing electricity to flow. If the circuit is cut at some point, the battery can no longer ensure the flow of electricity.

To understand that the circuit really forms a loop, the class can initially take a close look at a light bulb without a socket and with broken glass. They can see that it contains two different contacts (the base contact and the electrical foot contact; see image on page 46), and they can then trace the path followed by the electricity from one of the contacts through the filament to the other contact.

Unfortunately, at primary-school level there is no experiment to visualise which direction the electricity flows in, since you'd have to be able to watch the tiny electrons. The important thing at this level is that electricity can move only if the circuit contains a working battery and forms a closed loop. How do you know if electricity is flowing through the circuit? At primary-school level, the only way is to see if a light bulb in this circuit is glowing or not.

A crocodile clip

Public domain image; image source: Wikimedia Commons

If electricity is flowing through the circuit, the electrical current will travel through the filament; because of the filament's electrical resistance, it will become white-hot and generate light and heat. The filament is always inside a glass receptacle containing a vacuum or an inert (noble) gas, to prevent it from reacting with the oxygen in the air (i.e., burning).

When introducing the switch, the main thing is that pupils understand that it is a moveable element of an electric circuit which, depending on its position, can either ensure or interrupt the continuous flow of electricity. Once this concept has been established, any item which fulfils this function is a valid switch, even if it's only a paperclip with two split pins (see images above), or – for smaller children – a crocodile clip (see image below) with which they can open and close the simple electric circuit they made.

Equipment and materials

- Light bulb screwed/fixed into a base
- Connecting cables
- Battery
- Pocket torch
- Undecorated papier maché bear head with a light bulb as its nose (or similar inspiring setup)
- Materials to decorate the head (colours, etc.)

The electrical supplies can be purchased from local material companies, if they're not yet available at the school.

Procedure

Each step takes about 45 minutes. The following is just a proposed summary of the teaching unit. The pupils should focus on a familiar object to begin with, starting with a real-life use of battery and bulb, such as a pocket torch. After that, they can work in a more formal way with a battery and a bulb as a model for that object.

Step 1

- Switch on a pocket torch.
- Discuss with the pupils: Which elements are required to turn on a pocket torch?
  The answer is: a battery, a switch, and a light bulb.

Step 2

- Discuss with the pupils: How can the bulb be switched on and off outside the torch?
- Take the bulb out of the torch.
- Light the bulb with a simple battery.
- Let the pupils draw the setup and try it out experimentally.
- Discuss with the pupils: What is/are the element(s) that generate light within the light bulb?
  The answer is: the filament.

Step 3

Discuss with the pupils: How can we connect the bulb when the battery is far away?

The answer should involve connecting each pole of the battery to one of the bulb's contacts by adding two cables, which can be secured with crocodile clips, for example (see image below).

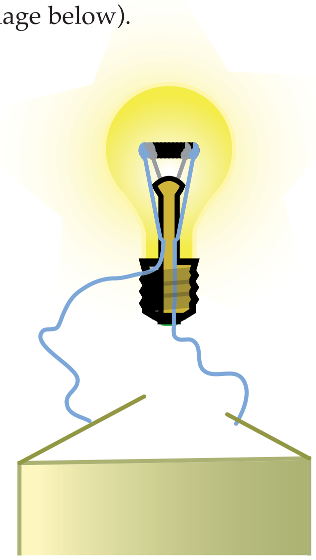


Image courtesy of Nicola Graf

Step 4

- Show pupils the papier maché bear with its light bulb nose.
- Let the pupils imagine the electrical circuit that would be necessary to switch on the bear's nose and ask them to draw it from scratch.

Step 5

- Gather all pupils and select several drawings of the electrical circuit.
- Discuss with the pupils: What changes would these circuits need in order to work?
  To help pupils propose the changes, the teacher can compare the different diagrams and the class can select some diagrams to try out experimentally until they find the correct solution.

Images courtesy of Magali Courbin, La main à la pâte

Step 6

Decorate the bear head.

Step 7

Assemble the electric circuit inside the bear's head, and use the switch to light up the bear's nose!

Image courtesy of Magali Courbin, La main à la pâte

The decorated bear's head with its light bulb nose switched on

Sand timer races

Below is a selection of activities from one of the Pollen teaching units. This teaching unit for pupils aged 3-6 deals with two essential quantities in physics: time and speed (for a more complex notion of 'time', see Al-Khalili, 2009, pages 15-19 in this issue). It enables the children to familiarise themselves with ideas such as 'faster than', 'slower than' and 'at the same time as'. This teaching unit focuses on the inquiry-based method of experiment and discussion, and in it children study, use, produce and compare sand timers. They also learn to make the connection between the volume of sand (or in this case, semolina) in a sand timer and the timer's running time. To view the whole unit, visit the Pollen website[w13].

I – Preparing the sand timers (for the teacher)

Materials per sand timer

- Two plastic bottles, one with a screw cap and one without
- Semolina (flows more steadily than sand)
- An awl or similar sharp object
- Sticky tape

Procedure

1. Punch a hole into the screw cap using the awl. Make sure the hole is more or less the same size for each sand timer you make.
2. Take the bottle to which the screw cap belongs, and pour semolina into it (you will need different levels of semolina in different bottles – see part II).
3. Close the bottle with the pierced screw cap.
4. Turn the other bottle upside down and attach the two bottles at the neck, using sticky tape, to make a sand timer.

Note: For some of the exercises, the pupils themselves must fill the sand timers and glue the two bottles together (see parts III and IV).

Image courtesy of Fabrice Krot, La Maison des Sciences

II – Compare the time required for three sand timers to finish (20 minutes)

Materials for each group of four pupils:

Three plastic bottle sand timers filled with three different levels of semolina and marked in different colours: red for the emptiest, blue for the middle one, and black for the fullest.

Procedure

1. Divide the class into groups of four pupils each.
2. Three of the pupils have one sand timer each, and the fourth is the note-taker.
3. Instruct the pupils to turn the sand timers over, and rank them according to how fast they finish.
4. Repeat the experiment three times, with the pupils changing roles.
5. Discuss: Why didn't the sand timer with the least semolina (red) always finish first?
6. Conclude: The three sand timers have to be turned over at the same time.

1st	2nd	3rd
X (red)	X (blue)	X (black)
X (red)	X (blue)	X (black)
X (blue)	X (red)	X (black)

Table 1: Example of a written record by a group of four children. Column 1: sand timer that finishes first. Column 2: sand timer that finishes second. Column 3: sand timer that finishes third. The colour of the X represents the colour the sand timer was marked in

7. Decide to always use the same method to compare the sand timers:
   - One 'measuring' pupil with no sand timer counts to three.
   - On the count of three, the other pupils in the group turn over the sand timers.
   - When one sand timer has run out, the person who turned it over raises his or her hand and says the name of the sand timer colour, for instance: "Red!"
   - The 'measurer' notes the order in which the sand timers finish.
8. Repeat the experiment three or four times.
9. Is the finishing order now always the same? Why / why not?

III – How can we adjust the time that a sand timer takes to finish? (20 minutes)

Materials for each child

- 3 empty sand timers marked in red, blue and black
- Semolina
- A sheet to record the finishing order

Procedure

1. Divide the class into small groups.
2. Hand out charts telling pupils the order in which the sand timers should finish (for instance red, then blue, then black).
3. Instruct the pupils: fill up the three sand timers to achieve the results provided in the chart.
4. Check and record the results.
5. The pupils should learn that the more semolina their sand timer has, the longer it will take to finish.

IV – Predicting the order in which the sand timers will finish according to semolina volumes (20 minutes)

Materials for each child

- 3 empty plastic bottle sand timers marked in different colours
- Semolina
- A funnel (can be made by rolling up paper)
- A small jar
- Filling level instructions (e.g. 1 jar of semolina for the red sand timer, 2 for the black and 3 for the blue)

OO > X (black)	OOO > X (blue)	O > X (red)

Table 2: Example of filling level instructions for three sand timers. O = one jar of semolina

A worksheet with results tables (see below)

Procedure

1. Divide the class into small groups.
2. Instruct the pupils to fill the sand timers as indicated in the instructions.
3. Ask pupils: What order will the sand timers finish in? Write down the results you think you will achieve on the worksheet (see below).
   Perform the experiment.
4. Write down the actual results (see example below).

Group: Chloé, Marion and Maureen

Fill all of the sand timers correctly and arrange them from the fastest to the slowest.

The results I expect

1st	2nd	3rd
X	X	X
O	OO	OOO

The actual results

1st	2nd	3rd
X	X	X

Table 3: Example of a worksheet to note down expected results for three sand timers and the results

6. Compare the expected results with the predictions.

V – Arrange three sand timers by comparing them in pairs (15 minutes)

Materials for each child

- 3 sand timers containing nearly identical semolina volumes
- A results table (see above)

Procedure

1. Instruct the pupils: You have three sand timers. You are allowed to turn over two at a time. Put them in order, from the fastest to the slowest!

Image courtesy of Fabrice Krot, La Maison des Sciences

Pupils performing the sand timer activity

2. Conclusion:
   If the black hourglass runs out faster than the red one, and the blue one runs out faster than the black one, then the blue hourglass runs out faster than the red one.

Web references

w1 – To find out more about *La main à la pâte*, see: www.lamap.fr

w2 – For the German mirror website of *La main à la pâte*, see: www.sonnentaler.net/info

w3 – The Spanish version of *La main à la pâte* can be found here: www.indagala.org

w4 – To find out more about *La main à la pâte* in Serbian, see: http://rukautestu.vin.bg.ac.yu

w5 – For the Arabic website of *La main à la pâte*, see: http://lamap.bibalex.org

w6 – The Chinese version of *La main à la pâte* can be found here: http://lamap.handsbrain.com

w7 – The Teaching Science web portal, a joint project between the International Council for Science (ICSU) and the Inter-Academy Panel for international affairs (IAP), in collaboration with *La main à la pâte*, with links to international partner projects, can be found here: www.icsu.org/1_icsuinscience/CAPA_TeachSci_1.html

w8 – For more information on the French ASTEP programme (supporting teachers through the involvement of scientists in primary education), see: www.astep.fr

w9 – For more information about Pollen, including many more learning units, see the Pollen project website: www.pollen-europa.net

w10 – For a guide and training unit for scientists and teachers in French and English, see: www.astep.fr or www.pollen-europa.net

REVIEW

Inspectors aside, outside visitors are welcome in school science lessons – in addition to being a fresh face, they can bring another kind of expertise to bear. Undergraduate science students have a good chance of relating to schoolchildren simply by virtue of not being the regular class teacher. University students can also be a powerful antidote to the 'boffin' stereotype, at a time when formative attitudes to science in general and scientists in particular are being developed. A visiting university student would be welcomed too by the teacher, who in primary schools is unlikely to have a science background him/herself. The visitor will be someone who can probably make the experiments work, and has a better chance of dealing adequately with the awkward science questions pupils are likely to supply!

Numerous organisations are keen to involve schoolchildren under their understanding of science mandate. Hopefully this article will encourage you to make contact so that soon you will also be welcoming these visitors into your classrooms, through initiatives such as the European-wide Pollen project or their national equivalent, for example the 'Researchers in Residence' scheme or 'Student Associates' scheme in the UK.

The article details two hands-on investigative activities suitable for most primary-school science classrooms. One is about electricity, often not covered in primary schools using practical work; the other is about fair testing and good experimental technique. The first may include apparatus less commonly found as class sets in primary schools. The sand timer activity makes good use of a simple homemade piece of apparatus, enabling a variety of questions to be asked and predictions tested. Both activities are highly suitable for 'how and why' discussions with school pupils. They have been tried and tested with the help of university students in the classroom, and their successful deployment should encourage primary-school teachers to try a more investigative hands-on approach to science lessons – either with or without visiting help.

Ian Francis, UK

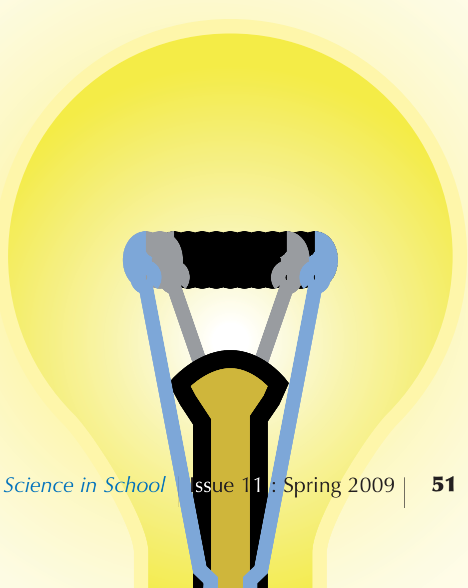
w11 – The French-language version of the teaching activity 'How can the bear's nose be switched on?' ('Le nez de l'ours – Réaliser un montage qui permette d'allumer une ampoule') can be found on the *La main à la pâte* website (www.lamap.fr) or here http://tinyurl.com/lenezdelours

w12 – Further information about teaching electricity at primary school can be downloaded here: www.scienceinschoool.org/2009/issue11/pollen

w13 – The sand timer teaching unit is available in English on the Pollen website (www.pollen-europa.net) or here: http://tinyurl.com/hourglassrace
Additionally, there are a number of examples based on the sand timer activity in the Pollen methodological guide: www.pollen-europa.net or http://tinyurl.com/guideforteachers

David Jasmin has a PhD in physics and has been working in science education and science popularization since 1995. He has contributed as a research engineer to *La main à la pâte* since 1997 and is head of this programme since 2005. Besides, he is the scientific coordinator of the Pollen project. He is also the author and editor of various books on primary school science education.

Samuel Lellouch is a second-year engineering student at the Ecole Polytechnique in Saint Etienne, one of the most prestigious engineering 'Grande Ecoles' in France. In 2007/2008, he spent six months supporting primary school teachers in class in a low-income suburb in Paris.



Take the weather with you

Karen Bultitude introduces a set of simple, fun and memorable demonstrations using everyday ingredients to explain meteorological phenomena.

Image courtesy of Bryngelzon/iStockphoto

Understanding our impact on the environment is increasingly important, with both scientific and societal implications now covered in various parts of most school curricula. With so much talk about climate change, it is useful to learn about some of the atmospheric phenomena that actually make up our climate. The following demonstrations help clarify some aspects of these phenomena and bring the concepts to life in an engaging and memorable way. They were developed as part of the British Council's ZeroCarbonCity[w1] campaign to support teachers and scientists throughout the world in explaining basic concepts of environmental science. The demonstrations can be used in a variety of ways: individually, to emphasise particular concepts during class; as a collection, for example as a workshop or demonstration lecture; or as set tasks for students to complete themselves. Further suggestions for activities related to environmental sciences can be found online[w2].

Cloud in a bottle

Create your very own mini-cloud.

Materials

- A 500 ml colourless plastic bottle with cap
- Water
- A teaspoon
- A match

Instructions

1. Place approximately one teaspoonful of water into the plastic bottle and swirl it around inside the bottle.
2. Light the match and make sure it is burning well, then drop it into the bottle.
3. Quickly screw the cap on tightly, then squeeze the bottle with your hand five or six times, after which you should see a cloud form in the bottle, then disappear when you squeeze it.
4. Pass the bottle around the class, instructing them to squeeze and release the bottle themselves to see the cloud.

You can also watch a video of the activity online[w3].

How does it work?

Clouds are formed when water vapour in the air cools down due to the expansion of the rising air mass, and then condenses to droplets on condensation nuclei such as dust particles, ice or salt. In this demonstration, the condensation nuclei are provided by the smoke from the match, which contains particles of uncombusted hydrocarbons. The temperature is changed by squeezing the bottle: the amount of air within is constant, but squeezing the plastic bottle lowers the volume of the gas, raising the temperature slightly. When you stop squeezing the bottle, the volume increases, thereby causing a slight lowering of the air temperature inside. If the air inside the bottle has a relatively high humidity (which is ensured by adding the teaspoonful of water at the beginning) then the temperature drop is sufficient to cause the water to condense on the dust particles, forming a cloud.

Links to atmospheric phenomena

Next time you see a fantastic sunset over an urban area, take a moment to think about what is causing the beautiful colours: its origin actually lies in the tiny smoke particles and other pollutants that have been emitted into the atmosphere. Just like in the plastic bottle, these smoke particles encourage water droplets to condense around them, forming clouds. The scattering of the Sun's rays amongst the clouds is what creates the beautiful sunset. There are some concerns that air pollution will therefore have a detrimental effect on the weather, since more air pollution leads to increased cloud formation, which could in turn lead to more rain in certain areas and a significant change to wider weather patterns (floods in some areas; droughts in others).

Whirling orb

This is a beautiful and fascinating demonstration of turbulent weather effects.

Materials

- A small clear plastic bottle (the more rounded the bottle, the better), including a tight-fitting lid
- Liquid hand wash (soap) that contains glycol stearate
- Food colouring
- Water (from a tap)

Instructions

1. Fill the bottle about one-quarter full with the hand wash, then add a few drops of food colouring.
2. The demonstration won't work if the mixture foams: turn on the tap so that only a trickle of water is coming out, then carefully fill the bottle up to the very top.
3. Screw the lid onto the bottle, and swirl the bottle around a few times (with the lid pointing upwards). If any foam forms, take the lid off and trickle some more water into the bottle, letting the foam run over the edge. Put the lid back on (tightly).
4. Move the bottle around: you will be able to see turbulence patterns (streaks and swirls) in the liquid.

How does it work?

Moving the bottle around causes the soap and water mixture inside to move. The glycerol stearate makes the

Images courtesy of Jonathan Sanderson

The whirling orb in action

Images courtesy of Elin Roberts and Jonathan Sanderson

Making a teabag rocket

patterns of flow visible, so you can see the directions in which different parts of the mixture are moving. Smooth lines forming in the liquid indicate laminar flow, which occurs when the liquid is moved slowly. If you make the liquid move faster (or change the direction suddenly) then the observed lines of fluid become more complex: this is turbulent flow.

Links to atmospheric phenomena

The Earth's atmosphere is a kind of fluid that moves much like the liquid inside the whirling orb. Winds interact with the spinning atmosphere and create complex circulation patterns. Understanding the general circulation of the atmosphere is fundamental to the work of many different areas of climate change science – for example, in understanding and reducing the effects of both hurricanes and pollution.

Teabag rocket

This is a good visual demonstration of thermals – rising currents of warm air.

Materials

- A traditional-style teabag
- Matches
- A saucer or plate

Instructions

1. Undo the teabag, removing the staple and string and disposing of the contents (the tea). Open up the teabag so it is a long cylinder of paper.
2. Stand the open teabag upright on the saucer or plate.
3. Use the match to light the top of the teabag.
4. Watch as the flame burns down the teabag: just before it reaches the saucer, the teabag will lift off. The flame will go out, but the teabag will keep on rising.

Tips for success

This demonstration works best in a still room where there are no air currents, away from windows or air conditioning.

Be careful to ensure that you use the right sort of teabag – it must fold out to produce the long cylinder of paper. Teabags without a string attached usually won't work.

How does it work?

The burning teabag heats up the air immediately above it. Hot air rises, so the warmer air will gradually rise up above the teabag, creating a rising current of warm air – a thermal. When the teabag has burnt down far enough, the lift from the thermal will be enough to overcome the force of gravity keeping the teabag on the saucer, and so it will lift up.

Links to atmospheric phenomena

Thermals are the basis for various weather patterns. The Sun heats up the land, causing thermals to spiral upwards. Thunderstorms are giant thermal systems, and the vortex formation associated with tornados and hurricanes is also based on thermals. As an effect of global warming, more thunderstorms are expected to occur.

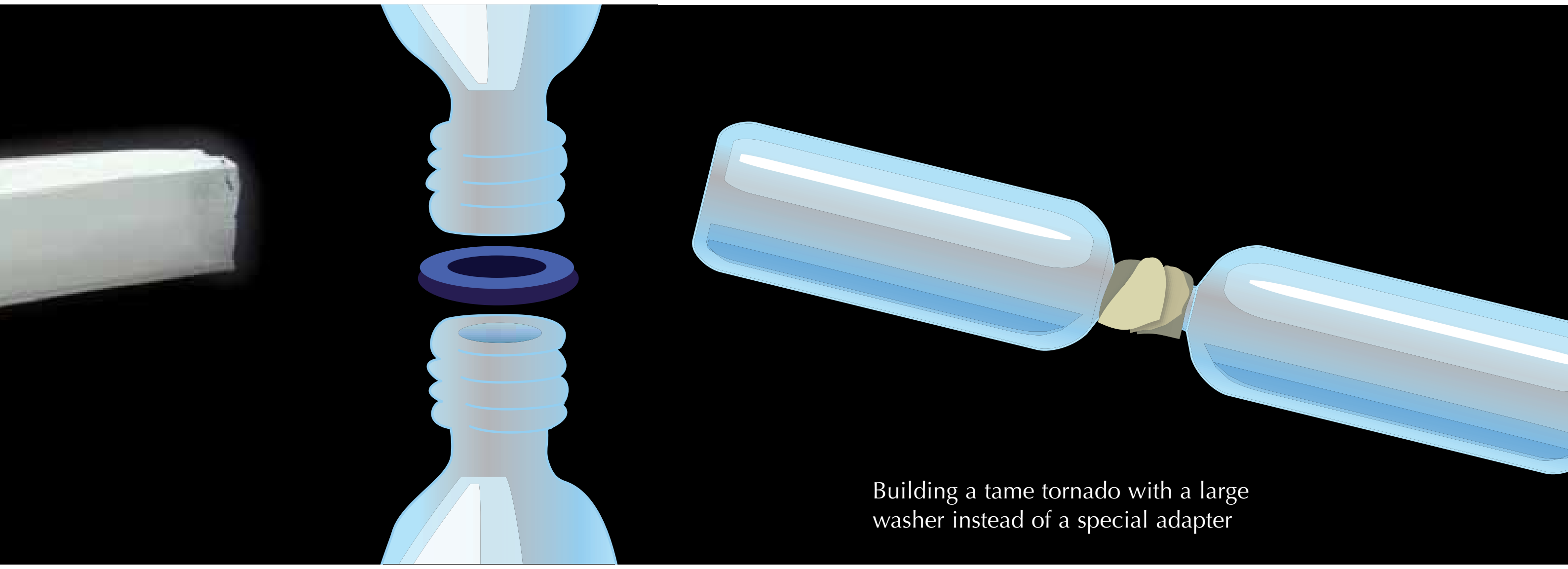
Tame tornado

This is a good visual demonstration of how tornadoes form.

Materials

- Two large (~2 l) empty soft drink bottles (must have rounded necks)
- A 'tornado tube' adapter (available from many science centres and museums or online[w4])
  If you can't find a tornado adapter, try placing a large washer (either metal or stiff rubber sealing ring) between the two bottles and fastening it all together with tape – the idea is to join the two bottles together so that the water can flow between them and they remain rigid (see images on page 55).

Images courtesy of Nicola Graf



Building a tame tornado with a large washer instead of a special adapter

Instructions

1. Fill one of the soft drink bottles with water until it is approximately half full.
2. Screw the 'tornado tube' adapter into the empty bottle.
3. Invert the empty bottle and screw the opposite thread of the 'tornado tube' adapter into the water-filled bottle.
4. Turn the whole contraption upside-down.
5. Grasp the top and middle of the contraption and spin it in a circular motion – either clockwise or counter-clockwise.
6. Once a vortex (whirlpool) forms in the upper bottle, stop spinning – you should see the vortex form throughout the liquid, and continue as long as there is liquid in the upper bottle.

You can also watch a video of the activity online[w5].

Tips for success

- If the vortex doesn't work straight away, try reducing the size and increasing the speed of the circles you are making. Make sure that the bottles are held vertically and your circles are centred about the long axis of the contraption (it is common to make the mistake of twisting the contraption around the point where the bottles are joined together).
- Make sure you replace the plastic bottles if they get too bent out of shape – they need to be round to make a proper vortex.
- Leakage problems are common. Try using cling film or plumber's (PTFE, polytetrafluoroethylene) tape to better seal the adapter around the bottles.

How does it work?

This demonstration produces a vortex similar to those observed in cyclones, tornadoes and whirlpools. As the water spins around the bottle, there is a downward pull formed due to the water passing through the opening into the empty bottle below. The initial small rotation caused by spinning the bottles gains speed as the water is sucked through the opening. As the rotation speeds up, the vortex forms.

Links to atmospheric phenomena

One of the predicted impacts of climate change is global warming: warmer air temperatures mean that thunderstorms are more likely to form, and tornadoes are formed in thunderstorms, where air starts moving in a circle. Updrafts and downdrafts within the thunderstorm force the rotating column of air to become vertical, creating the tornado. An increased number of thunderstorms is therefore likely to cause more hurricanes and tornadoes to form throughout the world.

Web references

w1 – Further information about the British Council's ZeroCarbonCity campaign is available here: www.britishcouncil.org/zerocarboncity.htm

w2 – The full set of ten demonstrations, including a Russian translation, is available here: www.scu.uwe.ac.uk/index.php?q=node/180

w3 – To watch a video of the cloud in a bottle, see: www.physics.org/interact/physics-to-go/cloud-in-a-bottle/index.html

w4 – For an international supplier of 'tornado tube' adapters, see: www.101gear.com

w5 – To watch a video of the tame tornado, see: www.physics.org/interact/

Image courtesy of CDH_Design / iStockphoto

Building a tame tornado with a 'tornado tube' adapter

REVIEW

This article provides fun physics experiments with a link to the teaching of environmental sciences and particularly of meteorological phenomena, which are surprisingly not too large in scale to be simulated in a classroom.

The proposed demonstrations are simple, cheap and attractive, and at the same time don't require special equipment, can be proposed to students of different ages, and can be expanded at different levels.

I recommend this article to science teachers from primary to secondary school. The experiments are suitable as warm-up activities to address various topics within physics and earth science curricula, such as: states of matter, phase transitions, gases, fluid dynamics, Earth's atmosphere (temperature, pressure, humidity, clouds, general circulation, cyclones and tornadoes, for example), air pollution and climate change. It can also be used to start a discussion on climate change and sustainable development.

Comprehension questions:

1) Which of the following is not an example of a condensation nucleus:

   a) dust particle b) gas molecule c) ice crystal d) salt particle

2) Thermals are:

   a) sinking currents of warm air b) rising currents of cold air c) sinking currents of cold air d) rising currents of warm air

The article is also suitable for interdisciplinary activities involving science and English.

Activity	Related topics within the science curriculum	School level
Cloud in a bottle	The water cycle	Primary/secondary
	States of matter and phase transitions (heat transfer, thermodynamics, chemical bonding)	Primary/secondary
	Water physics (specific heat capacity, heat of fusion, heat of vaporisation)	Secondary
	Atmospheric physics: humidity (absolute and relative), temperature (adiabatic heat gradient), pressure, dew point, clouds (formation classification)	Secondary
Whirling orb and tame tornado	Earth's rotation and Coriolis effect (ocean currents)	Secondary (earth science)
	Ocean currents, atmospheric currents and energy exchanges on Earth	
	General circulation of the atmosphere, winds, cyclones and anticyclones	
	Cyclones: hurricanes, tornados, mid-latitude cyclones	
Teabag rocket	Energy, heat and temperature	Secondary
	Heat transfer and thermodynamics	
	Gas physics	
	Density	
	Atmospheric physics	
	Fluid dynamics	

Guilia Realdon, Italy

Images courtesy of Elin Roberts and Jonathan Sanderson

physics-to-go/tame-tornado/index.html

w6 – For more information on the STEM Directories, see: www.stemdirectories.org.uk

Resources

Climate Challenge is an online game with associated support resources developed by the BBC: www.bbc.co.uk/sn/hottopics/climatechange/climate_challenge

Oxfam have developed a week of activities about climate change to be run with children ages 9-11: www.oxfam.org.uk/education/resources/climate_chaos

NASA has an excellent range of animations available relating to climate change: www.nasa.gov/centers/goddard/earthandsun/climate_change.html

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Dr Karen Bultitude is a senior Lecturer at the University of the West of England, Bristol, UK. She has delivered the demonstrations outlined here (including training teachers and scientists in their use) in numerous countries including Russia, Bulgaria, Latvia, Costa Rica and Greece. She is a member of the consortium which delivers the UK-wide STEM Directories[w6], a government-funded initiative to provide STEM (science, technology, engineering & mathematics) teachers and lecturers with a reliable and comprehensive overview and signposts to enrichment and enhancement activities across the UK.

Powering the world

Energy – why is it so important, where do we get it and how much do we use? **Gieljan de Vries** from the Dutch FOM-Institute for Plasma Physics Rijnhuizen[w1] investigates.

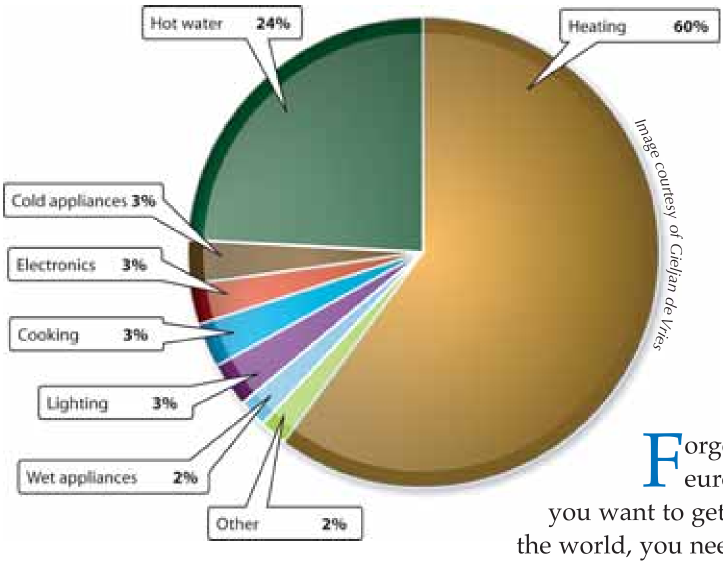


Image courtesy of Gieljan de Vries

Energy use of the average British household. Heating rooms and water takes up most of the energy. Lighting takes up only 3% of the power requirements, so installing energy-saving fluorescent lamps has a limited impact. Preventing heat loss by better building insulation saves a lot more energy. Data source: Department of Trade and Industry, UK

Forget the dollar, the euro, and the yen. If you want to get anything done in the world, you need to spend *energy*. Moving a car, powering a computer or creating something in a factory – all these things require energy. So what is energy, and how does it shape our world?

Physicists define energy as the ability to do work. That's a pretty abstract definition, because the concept of energy applies to so many different situations and materials. Pick any task, and you can calculate the total amount of energy in joules (J) that is needed to complete it, or the power (energy per second) that a process consumes in watts (W; equal to J/s). It turns out that every aspect of our lives has an energy price we have to pay.

Humans use energy all the time. Just sitting there, your body needs around 100 W of power. Energy powers muscles such as your heart and enables biochemical reactions in your organs. Of course, people do more than just sit around. Walking up the stairs or lifting boxes, we can produce around 100 W of useful power for hours on end. However, to do so, our muscles will consume 300-400 W – three to four times the energy they produce. A European household of three to four people continuously consumes an average of about 400 W by running heaters, powering electrical devices and so on. It would take

Image courtesy of gilleslougassi / iStockphoto

twelve people on treadmills (four per shift in three shifts of eight hours) to provide that much power.

Twenty thousand hours of work

Luckily, we don't have to resort to slave labour to generate energy. Instead, roughly 81% of our energy needs are met by the chemical energy contained in fossil fuels: oil, gas and coal. It's basically solar energy, absorbed by growing plants millions of years ago. After the plants die and become buried under new layers of earth, the underground heat and pressure turn the dead cells into long, energy-rich molecules.

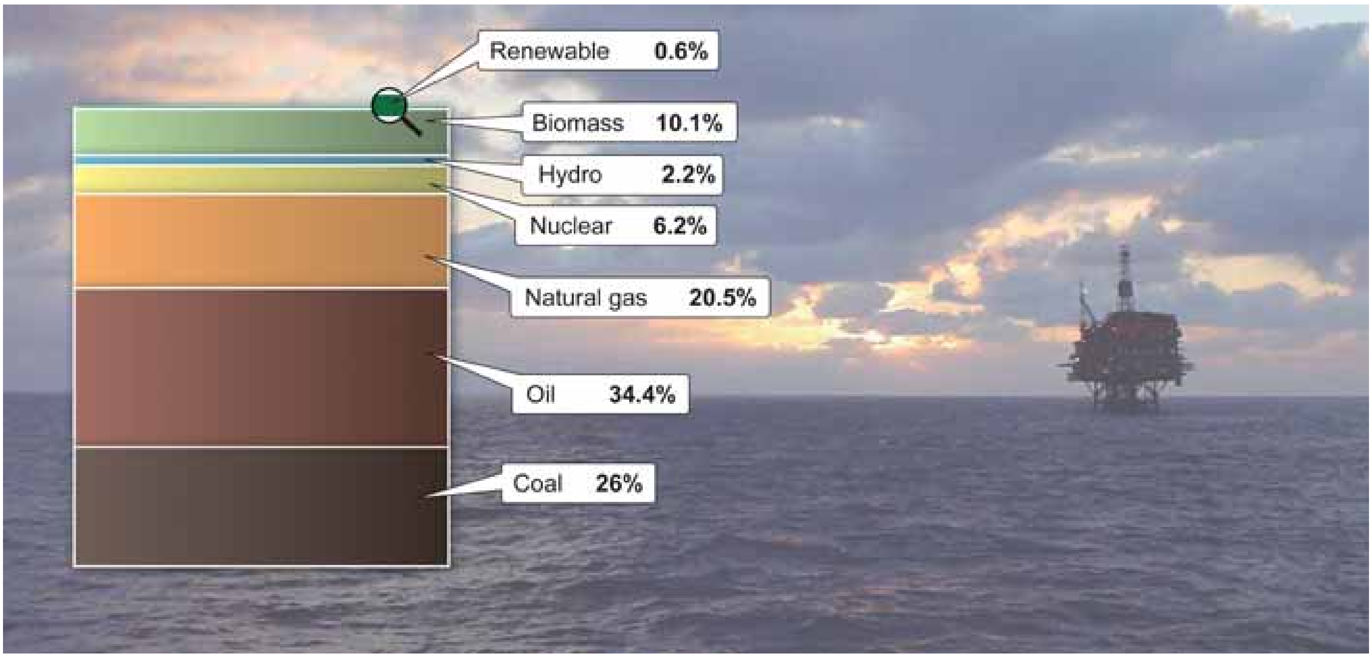
Coal, oil and gas are used in roughly equal quantities to generate the world's energy needs, but oil has perhaps the most visible use of the three: all kinds of transportation are utterly reliant on the fuels produced from it. Burning a standard barrel of oil, holding 159 litres, will release around 6100 MJ (million joule) of energy. Not only is that a lot of energy, it's also unbelievably cheap. Even though the price for a barrel of oil has fluctuated between €30 and €150 in the past year, a human would have to perform hard labour for 22 000 hours to release the amount of energy contained in one barrel. That's 11 years spent on a treadmill every workday from 9 am to 5 pm. Good luck finding anyone who would work that long and hard for that kind of money!

Back to our average energy use: we need more than the 100 W each person minimally consumes or the 400 W powering our house to maintain our way of life – consider the energy used to produce and transport household appliances in the first place. It turns out that a nation's households are responsible for about a quarter of its energy use, with transportation and industry each responsible for another third. Businesses, infrastructure and agriculture fill out the list of energy consumers.

A lake of oil

Let's put things into perspective: in 2006, the European Union used 49.2 TJ (terajoule) of energy. That's

Image courtesy of Gieljan de Vries



Global energy use in 2006. Almost 81% of all the energy we consumed was generated from fossil fuels. The biomass slice isn't quite renewable: it consists mainly of felling tropical rainforests and burning the trees. Without the tree roots, rain washes away the fertile layer of topsoil, so no new trees can grow. Finally, note the small part that renewable sources such as windmills or solar cells ('renewable') currently play. These sources are only just starting to take their place on the energy stage.
Data source: International Energy Agency Key World Energy Statistics 2008

BACKGROUND

Big numbers

When talking about the energy consumption of everyone on Earth, the numbers go through the roof. Here's a small list to help you keep track of things. From left to right, you'll find a number, what it's called, a shorthand scientific notation for the number of zeroes after the leading digit, and finally the prefix normally used.

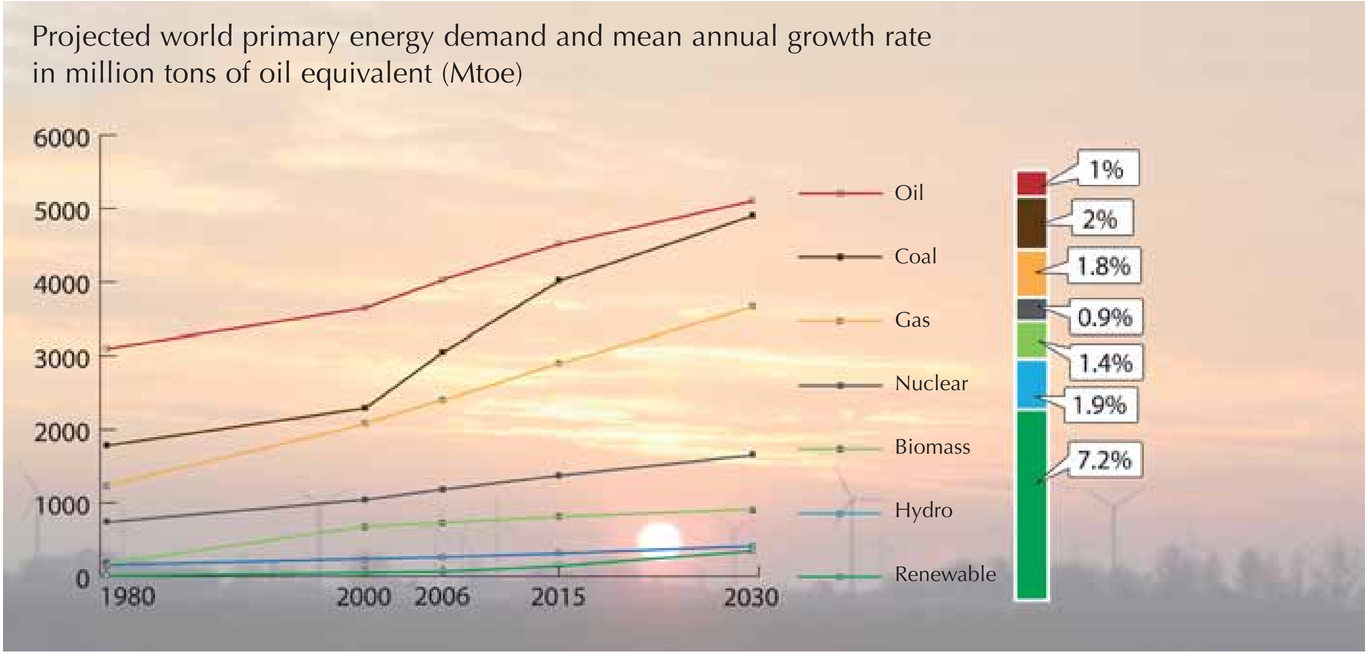
Number	Name	Shorthand	Prefix
1 000 000	a million	106	mega (M)
1 000 000 000	a billion	109	giga (G)
1 000 000 000 000	a trillion	1012	tera (T)
1 000 000 000 000 000	a quadrillion	1015	peta (P)
1 000 000 000 000 000 000	a quitillion	1018	exa (E)

For example, in 2005 the total energy consumption of everyone on Earth was the equivalent of 7 912 million tons of oils. These 6.5 billion, or 6.5 x 109, people used 331 259 616 terajoules (TJ), roughly 331.26 x 1018 = 331.26 exajoules (EJ).

49 million million joule, a truly staggering amount. Even spread out over 500 million Europeans, our yearly energy consumption is huge: 95 800 MJ for each of us (about 16 barrels of oil). For the whole of Europe, we would have had to burn the equivalent of 1176 million tons of crude oil to release that much energy, enough to fill a lake 20 metres deep and 20 by 30 kilometres wide. And that's just to satisfy the annual European demand for energy. That year, the USA used the equivalent of 2340 million tons of oil and China burned up 1717 million tons. China's energy use has increased spectacularly since their fast economic growth began. But counted per citizen, China is still not a wasteful energy user: each Chinese citizen uses the equivalent of 1.3 tons of oil per year. A US citizen, however, uses 7.4 tons of oil, and a European averages at 3.7 tons per year.

Every year, a fleet of 3500 oil tankers, some of them 400 meters

Image courtesy of Gieljan de Vries



A growing need for energy. The International Energy Agency, a Paris-based energy think tank, models future energy use. In their World Energy Outlook 2008, they calculated how much energy will be produced from various sources in 2015 and 2030. The percentage bar on the right shows how much the contribution of every source grows annually from 2006 to 2030. Coal is becoming ever more important, and sustainable energy sources show the highest growth rate – but they have a long way to go. Data source: International Energy Agency World Energy Outlook 2008

Image courtesy of mevans/ iStockphoto

long, ships 2000 million tons of oil across the globe. That's not all of the oil we use, because pipelines transport another part of the load. In 2006, the world used 3481 million tons of oil, providing 43% of the worldwide energy demand.

Those numbers are huge and they're not coming down. According to rough estimates, in 2100 the world will need four times the amount of energy it is using today. In the course of this century, China, India and other developing nations are expected both to grow in population size and to bring their energy consumption per citizen up to European levels. That's four billion people who are going to need as much energy as the average European uses right now. And we can't blame them.

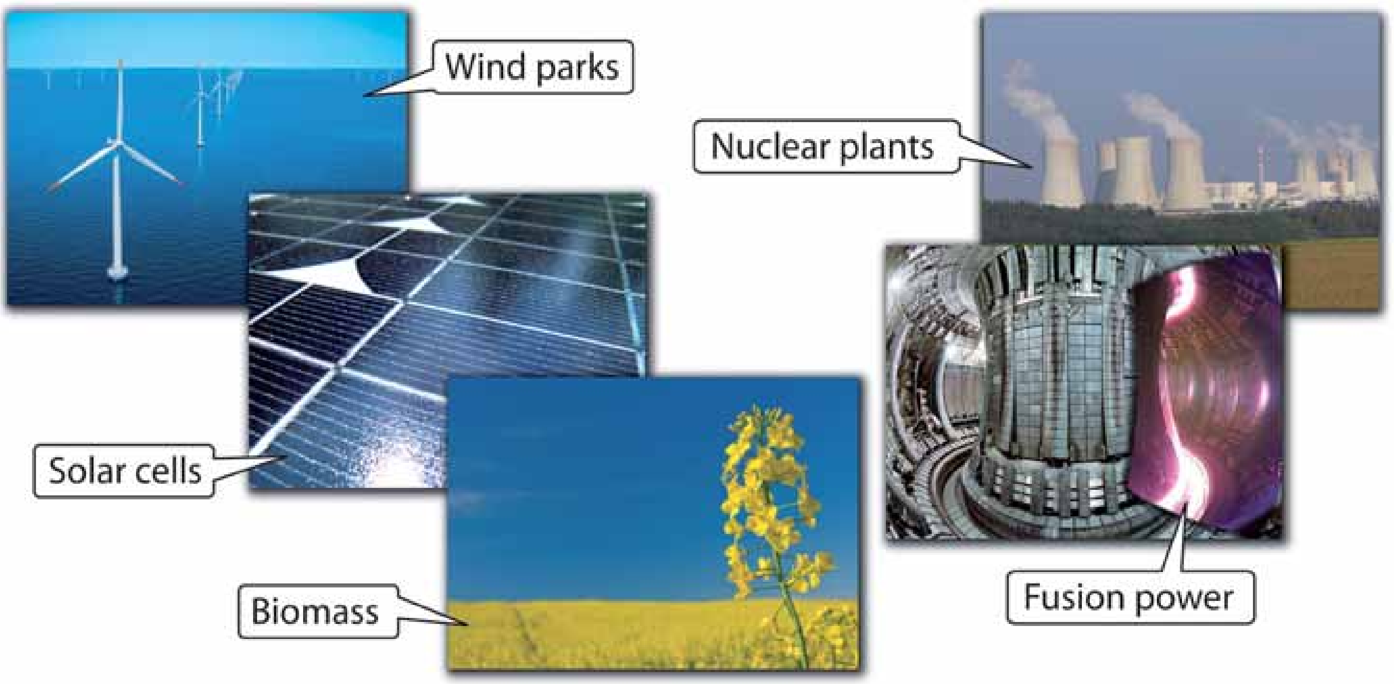
Energy is linked to the standard of living

For most of the world, energy is not something you want to use less of, but something very desirable to fulfil basic needs. Easy access to electricity and drinking water is everyday reality to most of us. For two-thirds of humanity, it's a precious, unaffordable luxury. Without electric lights, there's only so much work you can do in one day. Without the energy needed to purify and transport water, people in developing countries need to walk miles to the nearest clean well. Walk, because they often lack bicycles or well-constructed roads to speed up travel.

You can only improve your standard of living if you have energy to spend. Electric lights allow for longer workdays, diesel fuel powers heavy machinery for building roads, constructing buildings or aiding in farming. With enough energy, factories can produce consumer goods, and trucks running on fossil fuels can transport them. Energy makes life easier.

We only have to look at the poorest of countries to see that our lifestyle absolutely depends on easily available energy: we need energy to manage our water supply, but it also enables irrigation and the production of chemical fertilisers, which help feed the population. We use energy to heat or cool our homes and for easy transportation. Energy keeps factories and cities running, providing jobs for millions of people. Where energy becomes scarce, these things we take for granted become expensive – the perks of the rich. The reverse is also true: a country that can make more

Public domain image; image source: Wikimedia Commons



Five sustainable sources of energy. You can collect energy that is spread out across the globe from wind, sunlight and plants. Nuclear fission plants are much more compact, but have the problem of radioactive waste. Fusion energy, a technology that's expected to generate clean, almost inexhaustible energy by mimicking the power source of the Sun, is now being explored. It's expected to feed electricity into the grid by around 2050

energy available to its population can improve their general quality of life. Of course, energy isn't a miracle cure for problems in Africa, but not having energy does make them that much harder to solve.

Wanted: new sources of energy

The world demands more energy. In the short term, this means more use of fossil fuels. Polluting coal plants, previously unpopular, are now built to the tune of one every week in China. The demand for oil alone is projected to rise by 47% by 2030, and companies search the harshest of environments, such as the deep sea or the arctic, for natural gas to fuel power plants and factories. According to the International Energy Agency (IEA), these investments will keep the share of fossil fuels around 81% of the energy mix. In absolute terms, the total energy requirements – and, because of that, the demand for fossil fuels – is expected to rise by almost a half in 2030.

One day, the fossil reserves will run out. Coal mines can last roughly another 200 years at the current rate of use. Oil production, some fear, has already peaked: the IEA is afraid that existing oil fields are producing less and less each year, and too few new fields are being discovered to stop the slow decrease in production. We're going to need sustainable forms of energy if we want to prevent conflict over the diminishing reserves. Besides, the way fossil fuels increase climate change through the greenhouse effect is very worrying, and calls for sustainable sources of energy.

Fortunately, work is already underway to change the way we power our world. Energy harvested from sunlight, wind and hydro-power, and even the heat from Earth's core are slowly adding to fossil fuels. Promising energy sources, such as nuclear fusion, are being investigated by scientists (see Warrick, 2006). Have we started to develop these sources on time? Or will the future be energy-starved? *Science in School* will investigate alternative sources of energy in upcoming issues. Read carefully – these technologies are going to change the world. To test alternative energy sources in the classroom, see Dudley Shallcross and colleagues' article in this issue (Shallcross et al., 2009).

References

Shallcross D, Harrison T, Henshaw S, Sellou L (2009) Fuelling interest: climate change experiments. *Science in School* **11**: 38-43. www.scienceinschool.org/2009/issue11/climate

Warrick C (2006) Fusion – ace in the energy pack? *Science in School* **1**: 52-55. www.scienceinschool.org/2006/issue1/fusion

Web references

w1 – The website of the Dutch FOM-Institute for Plasma Physics Rijnhuizen can be found here: www.rijnhuizen.nl

Resources

Background reading

The article 'Future Global Energy Prosperity: The Terawatt Challenge' by Richard E. Smalley of Rice University can be downloaded from the Rice University website (http://cohesion.rice.edu) or here: www.tinyurl.com/dg256

The Hirsch report (Peaking of World Oil Production: Impacts, Mitigation, and Risk Management), created by request for the US Department of Energy and published in February 2005, can be downloaded from the Atlantic Council website (www.acus.org) or here: www.tinyurl.com/8yebs

Energy statistics

The International Energy Agency (IEA) provides energy and population statistics. Choose a country or region, then click on 'Indicators': www.iea.org/Textbase/stats/index.asp

The IEA's Key World Energy Statistics can be downloaded here: www.iea.org/Textbase/publications/free_new_Desc.asp?PUBS_ID=1199

BP has provided a Statistical Review of World Energy in 2008:

www.bp.com/productlanding.do?categoryId=6929&contentId=7044622

The following report summarises the energy subsidies in the European Union in 2004:

www.eea.europa.eu/publications/technical_report_2004_1

Gieljan de Vries (born in 1978) studied physics at the Dutch Utrecht University and discovered that his great passion was talking to people about science. First as a science journalist, then as public information officer of Rijnhuizen, the Dutch centre for research in fusion energy, Gieljan got to know the world of energy and discovered how dependent our way of life is on easily accessible energy.

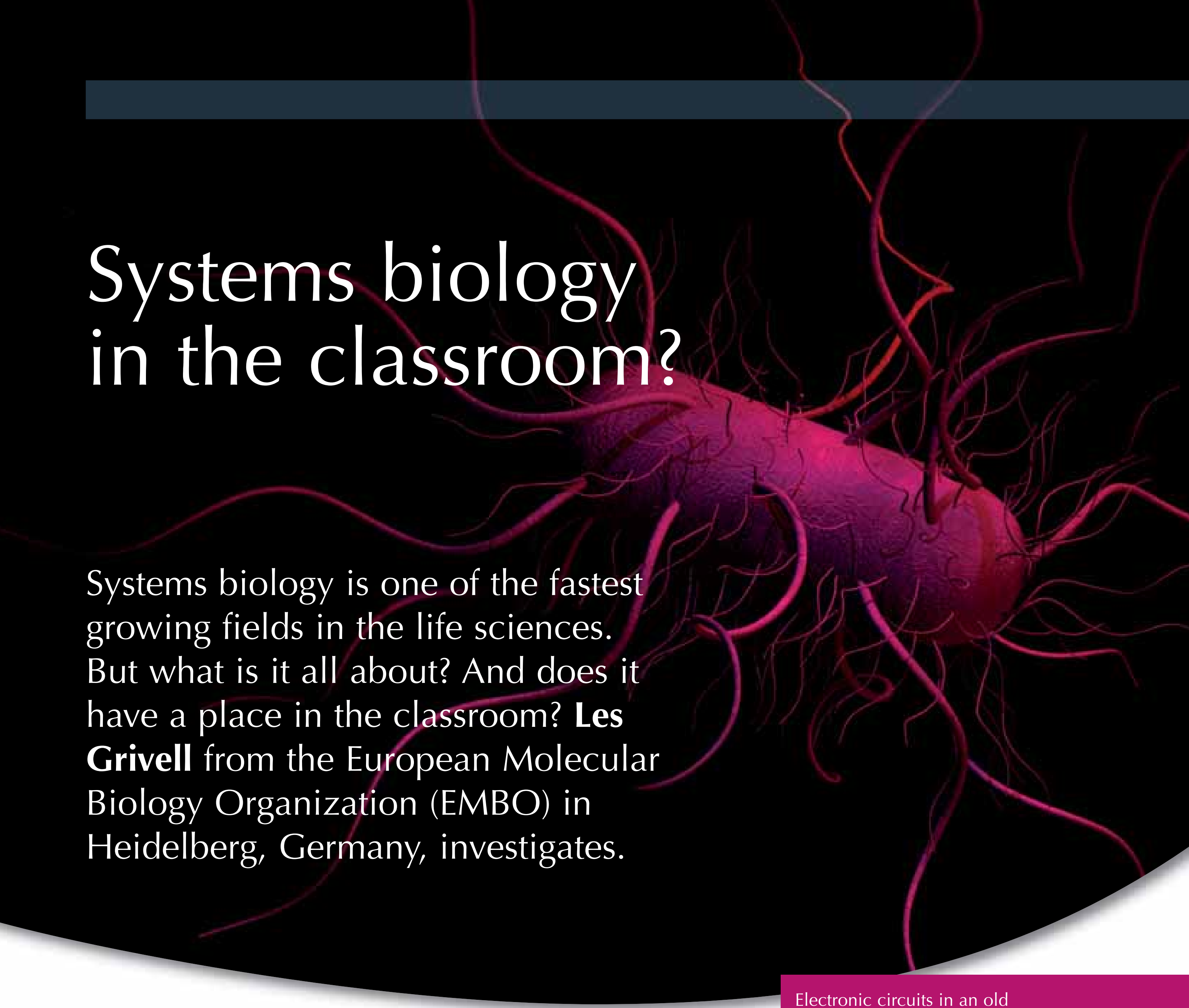
REVIEW

Experts in the field of science education emphasise that energy is a tricky topic. In addition, it is not easy for students to comprehend the significance of energy in life. Their interest may pick up when they come to realise that without electricity or fuels, they would not have MP3 players, PCs, TVs, Internet – nor would they have the basic comforts usually taken for granted, such as lighting, heating or cars. Moreover, it is important for the citizens of tomorrow to understand the vital role of energy, the environmental problems that the increased consumption of fossil fuels creates, and the urgent need for sustainable forms of energy.

In this article, Gieljan de Vries talks about the importance of energy, providing interesting and motivating information and numbers on the current and future needs for huge amounts of energy. This article combines environmental, science and economic issues: energy as a topic lends itself to a large variety of interdisciplinary and cross-curricular teaching opportunities.

Vangelis Koltsakis, Greece

Image courtesy of gilleslougassi / iStockphoto



Systems biology in the classroom?

Systems biology is one of the fastest growing fields in the life sciences. But what is it all about? And does it have a place in the classroom? **Les Grivell** from the European Molecular Biology Organization (EMBO) in Heidelberg, Germany, investigates.

If you type the phrase 'systems biology' into the search box of the main biomedical literature database PubMed[w1] and restrict the output to any year before 2000, your query will return only a handful of hits. Do the same for 2008, and the outcome will be links to several hundred publications dealing with this rapidly growing area of biological research. Do the same kind of search in Google and compare the outcome (around 36.9 million hits) with those for areas like high-energy physics (about 11.4 millions hits), or aerospace engineering (around 2.5 million hits). Assuming that in each case the number of hits is a reflection of the ongoing activity in the respective area, systems biology is really quite an active new kid on the block.

But what is it?

Cynics might reply that 'systems biology' is just another buzzword – one more way for researchers to tap into new sources of funding. Physiologists might say that it is nothing new; just a high-tech way of doing what they have always done or have attempted to do. Systems biologists themselves will tell you that it is a radically new way of thinking about biology. Instead of exploring the characteristics of isolated parts of a cell or organism, as biochemists and molecular biologists have done for many years, systems biologists focus on the whole system.

Let's look at a radio as an analogy: a radio transforms electric waves into

Electronic circuits in an old vacuum tube radio

Image courtesy of Ermin Gutenberger/iStockphoto

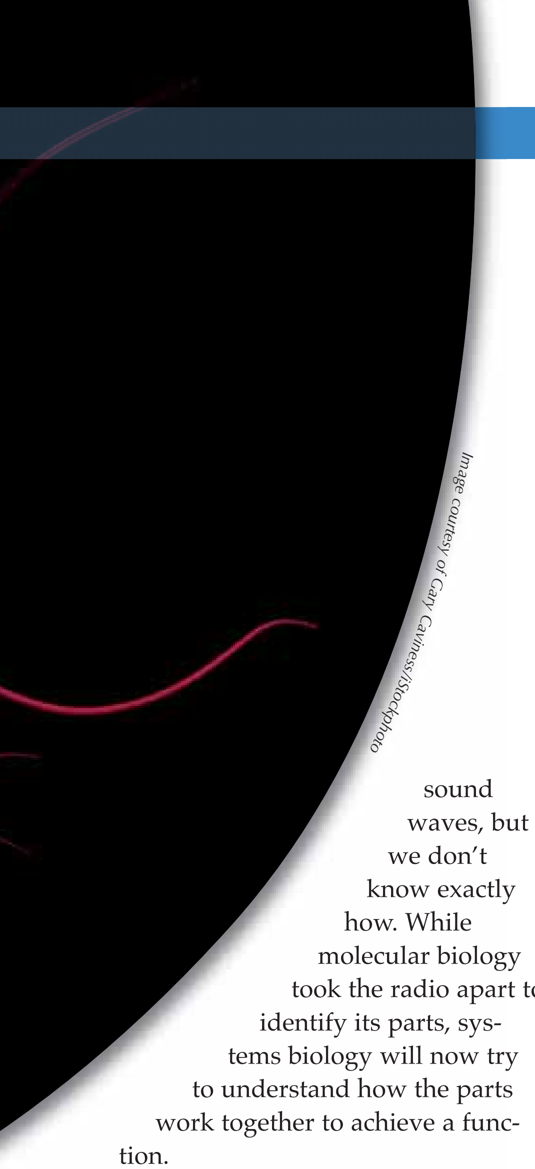


Image courtesy of Gary Caviness/iStockphoto

sound waves, but we don't know exactly how. While molecular biology took the radio apart to identify its parts, systems biology will now try to understand how the parts work together to achieve a function.

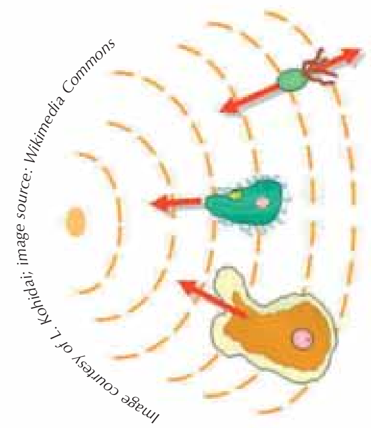


Image courtesy of L. Kohidai; image source: Wikimedia Commons

Chemotactic movements of bacteria and eukaryotic cells towards a source of nutrients

Consider, for example, the ability of bacteria to detect and swim in the direction of a source of nutrients (chemotaxis). The molecular biologist will try to characterise the individual components of the chemotaxis machinery and how each of them works – by purifying them and the genes that encode them, and by studying the effects of mutations on each component. In contrast, the systems biologist wants to understand how the highly complex swimming and tumbling pattern of the cells[w2] is controlled – by looking at the impact and interactions of as many components in the system as possible. The systems biologists, therefore, may study everything from the first contact between nutrients and the relevant receptors in the bacterium, through the entire signal transduction pathway, to the mechanism that controls the rotation of the bacterial propulsion motor – its flagellum.

According to Leroy Hood, the founder of the world's first dedicated Institute for Systems Biology[w3] in Seattle, USA, systems biology can be defined through six essential features:

1. Global measurements: scientists measure dynamic changes in all genes, mRNAs and proteins, rather than in individual genes or mRNAS or proteins.
2. An integration of data types: information about DNA, RNA, proteins and their interactions are computationally and mathematically integrated.
3. Dynamic measurements rather than static ones: across different developmental, physiological, disease and environmental areas.
4. The research is discovery-driven and hypothesis-driven, rather than only one or the other
5. The measurements made are quantitative, rather than just qualitative (you want to know how much more of a protein is produced under certain circumstances, rather than just that there is more)
6. An interactive cycle of data: data → model → prediction → verification → modification → data.

At the molecular level, systems biology often makes use of high-throughput technologies, such as massive DNA sequencing, and cell- or tissue-wide RNA, protein and

Image courtesy of Nicolle Rager Fuller, National Science Foundation; image source: Wikimedia Commons

Escherichia coli cells use long, thin structures called flagella to propel themselves. These flagella form bundles that rotate counter-clockwise, creating a torque that causes the bacterium to rotate clockwise

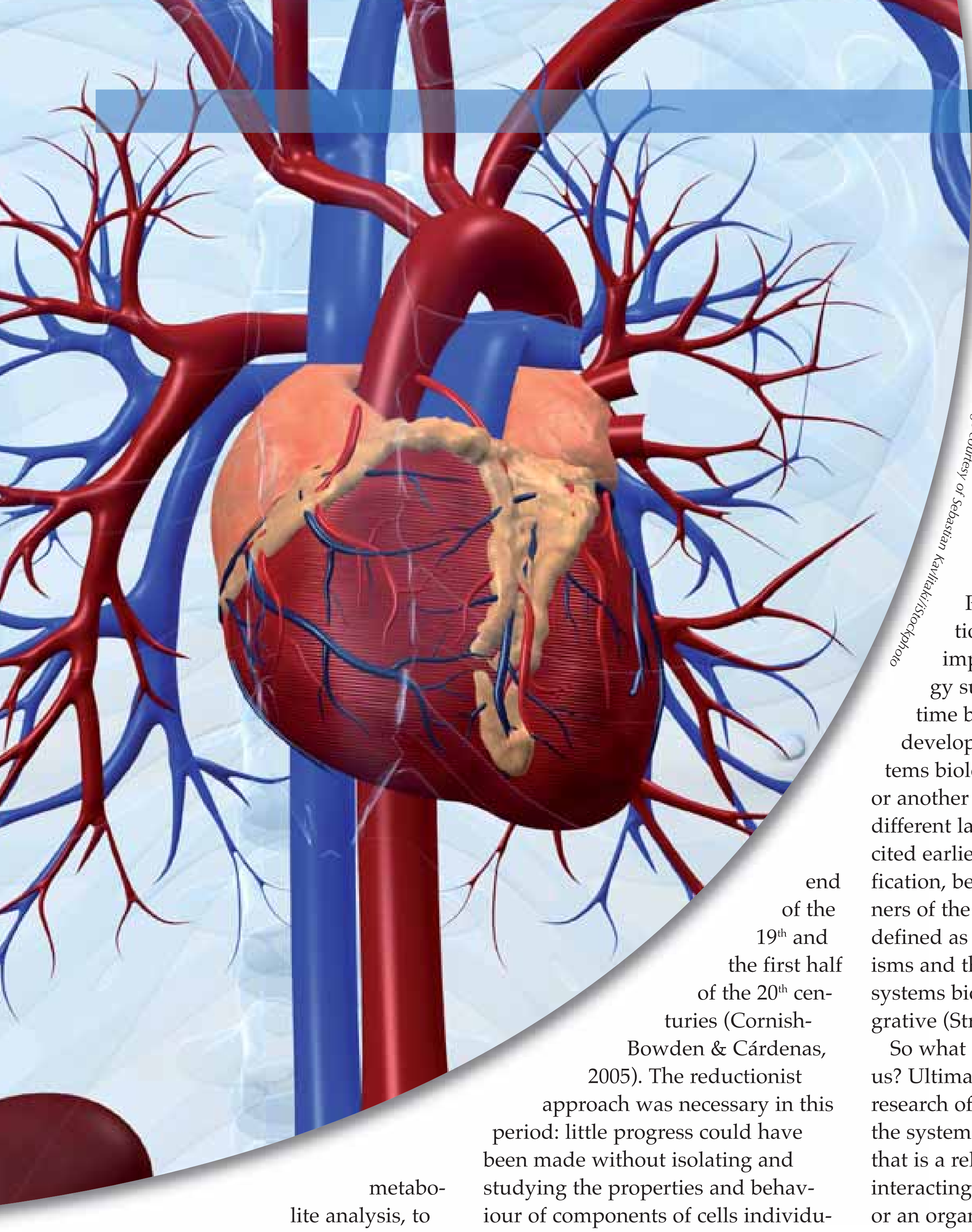


Image courtesy of Sebastian Kaulitzki/iStockphoto

metabolite analysis, to assemble comprehensive data sets that characterise the system being studied. The ways in which gene expression or metabolites change with time, or in response to genetic mutations and/or stimuli from the environment, are then used to construct computational models that are able to predict behaviour and thereby to better understand the molecular principles and strategies that underlie such changes.

This emphasis on a system as a whole is a significant one, since it marks the reversal of a strongly reductionist approach to research that started with the earliest biochemical studies on isolated enzymes at the end of the 19th and the first half of the 20th centuries (Cornish-Bowden & Cárdenas, 2005). The reductionist approach was necessary in this period: little progress could have been made without isolating and studying the properties and behaviour of components of cells individually. However, it is becoming increasingly clear that the behaviour of a single cell, or of populations of cells, is the result of a complex mix of interactions that feeds both upwards to higher levels of organisation and back downwards to individual molecules or their complexes in such cells.

A good example of this kind of complexity is the systems biology studies that have led to the first models of a human organ – the virtual heart[w4] (Noble, 2007). Here, biophysical and biochemical studies on specific ion channels in heart cells led first to models of the behaviour of single cells, then to linked models of two- and three-dimensional blocks of tissue in the heart's atrium and ventricle, and eventually to the simulation of the electrical and mechanical behaviour of the beating heart as an entire organ, in which every cell plays its specific role in concert with its neighbours.

The results of the PubMed searches mentioned earlier may give the impression that systems biology suddenly appeared sometime between 1999 and 2000 and developed rapidly. In reality, systems biology has existed in one form or another for much longer and under different labels. The physiologists cited earlier on could, with good justification, be regarded as the forerunners of the field, since physiology is defined as 'the study of living organisms and their parts' and thus is, like systems biology itself, inherently integrative (Strange, 2005).

So what can systems biology tell us? Ultimately, of course, this kind of research offers an understanding of the system being studied, whether that is a relatively simple network of interacting molecules, a cell, a tissue, or an organ.

Image courtesy of Jacopo Werther and Michael Pereckas; image source: Wikimedia Commons

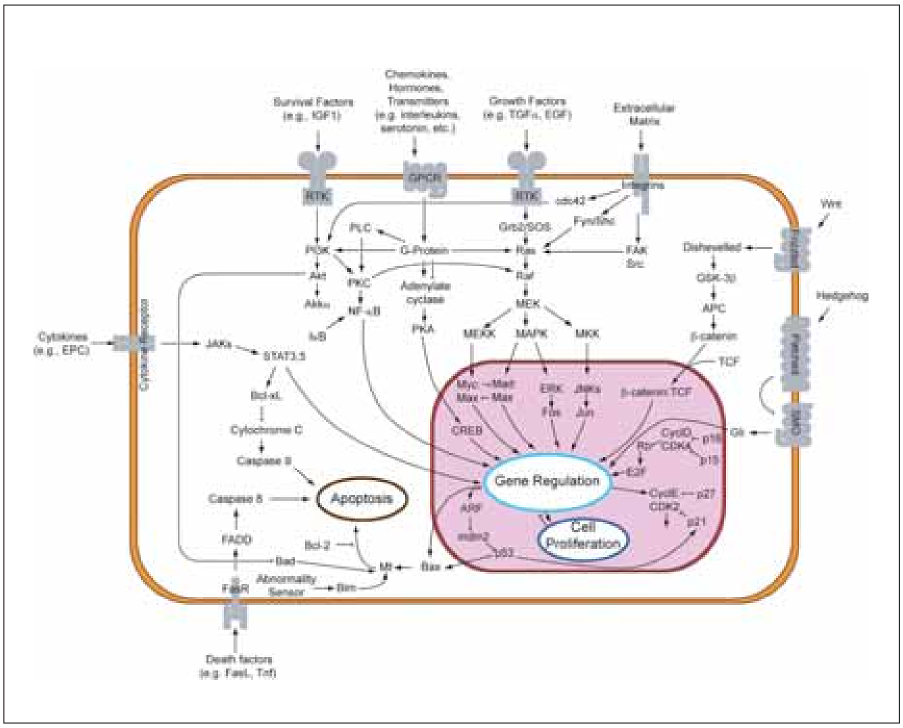
A DNA sequencer

At the level of the individual cell, Cheong and Levchenko (2008) analyse the recent data compiled on the NF-kappaB pathway. This molecular signalling cascade is widely used by cells in the inflammatory response to infection. A wealth of data had been collected on the individual components of the system over the past few decades, but now systems biologists are integrating them into quantitative computer models of the entire pathway within a cell, and then testing experimentally if the predictions made by the model are correct. The results have led to remarkable insight into the underlying, highly complex molecular circuitry that cells use to detect and combat infection. This knowledge will eventually help us understand why individuals differ in their inflammatory responses and thereby should lead to more effective treatment.

At the level of a whole human, Nicholson (2006) proposes a systems approach to metabolism including gut flora. Cellular metabolism is very much a game of chance in which metabolites or drug molecules interact with enzymes and other molecules in a chance fashion. These interactions can result in many outcomes, some of which may cause cellular damage. And this is only for one cell – imagine how complex it is to predict the metabolic state of an entire human being! It is only by study and mathematical modelling of the system as a whole that we can hope to understand the complexity of such responses and develop therapies that are exactly tailored to the system state of any particular individual.

Should systems biology be included in the school curriculum? In my opinion – yes. By this I do not imply that students need to have access to high-throughput microarray or proteomics facilities. Rather, I think it important that they are exposed to some of the basic principles of systems biology, and that above all, they are taught to

Public domain image; image source: Wikimedia Commons



Signal transduction pathways in a cell

realise the limitations of the reductionist approaches that have dominated biological research for so long.

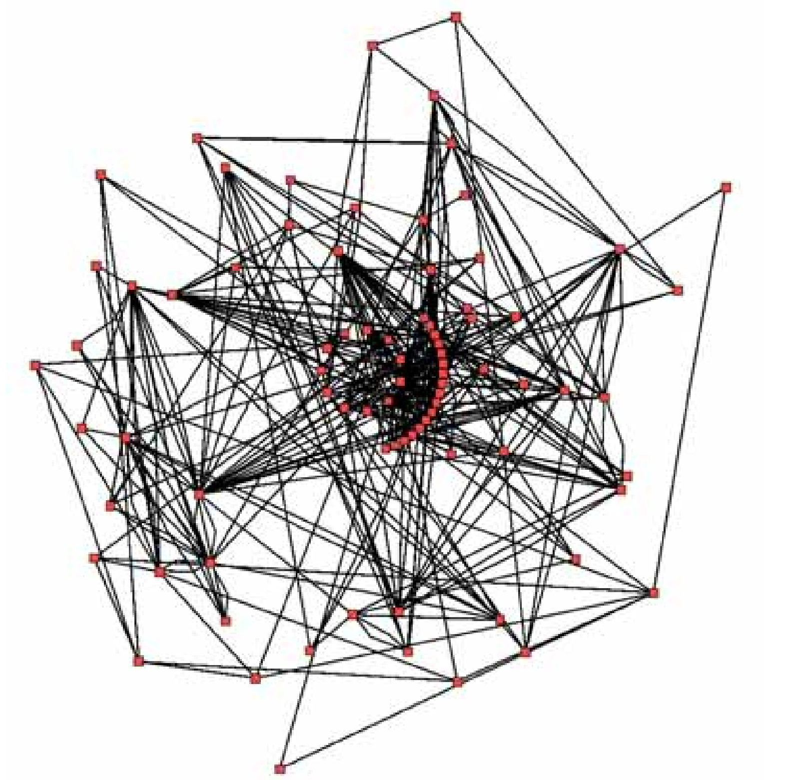
Starting with questions like "What is a gene?", "How many genes do you need to make a minimal self-maintaining organism?" and "How can I make a biological clock?", it is possible to introduce typical systems concepts. These include, for example, non-linearity of biological systems, a broad, but important concept: many metabolic and signalling pathways are organised in a cyclic, non-linear fashion. There are negative and positive feedback loops within a cell, and more often than not they will interact with each other at several levels. Besides, the relationships between an input into a biological process and its outcome are often non-linear. So it is quite difficult to predict off the top of your head what will happen if you tweak one component of a pathway to be slightly more or slightly less active, and how this will influence all the other components.

Modularity is another important concept: that is, biological systems are complex, but they can be regarded as networks of smaller and simpler units (modules) that perform defined functions. Other central themes of a system are robustness (continued function despite genetic or environmental perturbations) and evolvability (the potential for change).

The international Genetically Engineered Machine competition (iGEM)[w5] challenges university students to put a number of these systems biology principles into practice through the design and use of standardised, biological components. The register of these components[w6] is a fascinating web resource that also shows that systems and synthetic biology is fun! Alongside an intriguing BacteriO'Clock[w7] – a simple test tube containing modified bacteria that change colour according to the time of day (Paris team) – current iGEM team projects include the engineering of *Lactobacillus* to produce yoghurt that cleans your teeth[w8] (MIT team), a bacterial biosensor that can be directly integrated into an electrical circuit[w9] (Harvard team) and an *E. coli* cell that glows when it detects pathogenic bacteria in drinking water (Sheffield team).

Finally, upcoming generations need to be made aware that there are tremendous opportunities for tackling a wide range of intriguing problems about the living world that will be of utmost importance to society. Systems biology requires systems biologists and there is a real need for scientists in the disciplines of physics, computer science and biology to work together to develop the field to a stage at which it can begin to return benefits to society as a whole.

Image courtesy of TimVickers; imagesource: Wikimedia Commons



Metabolic network showing the links between enzymes and metabolites in a specific metabolic pathway of the plant *Arabidopsis thaliana*. Enzymes and metabolites are the nodes (red), interactions are the lines. In total, 43 enzymes and 40 metabolites are shown

Acknowledgement

I am very much indebted to Dr Thomas Lemberger (EMBO), both for his comments on this article and for a variety of other discussions about systems biology.

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w1 – To access PubMed, visit: www.ncbi.nlm.nih.gov/pubmed

w2 – You can find movies on bacterial motility here: www.microbiologybytes.com/video/motility.html

w3 – For more information on the Institute for Systems Biology, see: www.systemsbiology.org

w4 – To watch a video of Denis Noble illustrating the principle of systems biology using the virtual heart, see: http://videolectures.net/eccs07_noble_psb
Find out more about the virtual heart in Noble D (2008) *The Music of Life: Biology Beyond Genes.* Oxford, UK: Oxford University Press. ISBN: 9780199228362
Take a look at the virtual heart website from Cornell University (not Denis Noble’s version, which is not online, but a very good one nevertheless): http://thevirtualheart.org

w5 – To learn more about the iGEM competition, see: http://2008.igem.org/Main_Page

w6 – The website of the BioBricks register of components to be used in the iGEM competition can be found here; http://partsregistry.org/Main_Page

w7 – For an explanation and video of the BacteriO’Clock, see: http://2008.igem.org/Team:Paris

w8 – For more information about the iGEM MIT team’s ‘biogurt’ that cleans your teeth, see: http://2008.igem.org/Team:MIT

w9 – To find out more about the Harvard team’s ‘bactricity’ project for iGEM, see: http://2008.igem.org/Team:Harvard

Resources

In an insightful historical overview of the evolution of systems biology, Westerhoff and Palsson (2004) show how ideas on molecular and cellular self-organisation were subsequently extended to modelling and quantitative analysis of metabolic networks. These small-scale approaches constitute important preludes to the development of present-day systems biology.

Westerhoff HV, Palsson BO (2004) The evolution of molecular biology into systems biology. *Nature Biotechnology* **22**: 1249-1252.

See the blog 'What is systems biology?' at http://blog-msb.embo.org/blog/2007/07/what_is_systems_biology_3.html

For a review of a more reductionist but nonetheless cutting-edge approach to biology – protein crystallography – see:

Cornuéjols D (2009) Biological crystals: at the interface between physics, chemistry and biology. *Science in School* **11**: 70-76. www.scienceinschool.org/2009/issue11/crystallography

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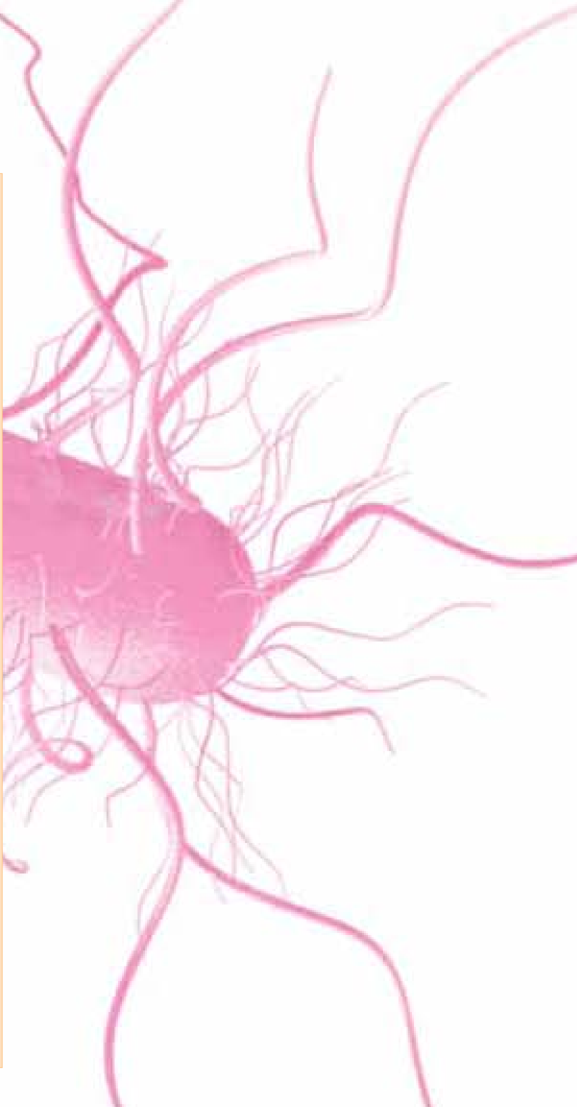
Les Grivell is a molecular biologist. Before joining EMBO, the European Molecular Biology Organization, he headed a research laboratory at the University of Amsterdam, the Netherlands, with interests in yeast genetics, genomics and bioenergetics. At EMBO he coordinated a European research network that focused on text-mining, semantic tagging, and integrating information in the scientific literature better with the many different types of bioinformatics data generated by molecular biology research. He is currently manager of the EMBO publications, and is also associate editor of the journal *Molecular Systems Biology*.



REVIEW

Physiology considers how biological systems work. This article describes how the molecular approach to biology demonstrates how cells and even systems work together to perform systems functions. The virtual heart model on the cited website is worth watching, as it illustrates how the cells perform as a system. The iGEM competition website can be accessed to investigate novel applications of genetic engineering and systems biology. This could provoke some interesting discussion and may motivate some students to come up with their own ideas.

The article could be used to discuss the following topics:

- Heart structure and function
- Genetic engineering: social, ethical, and commercial applications (of products such as tooth cleaning yogurt!)
- Physiology: integration of systems.

Possible comprehension questions to ask the students include:

- What is the purpose of systems biology?
- State what is meant by a molecular signalling cascade.
- Do individuals exhibit the same inflammatory responses?
- Explain how systems biology could be useful in predicting an individual's response to drug therapies.

Shelley Goodman, UK

Biological crystals: at the interface between physics, chemistry and biology

Dominique Cornuéjols from the European Synchrotron Radiation Facility introduces us to the world of crystallography. It's not all shiny diamonds…

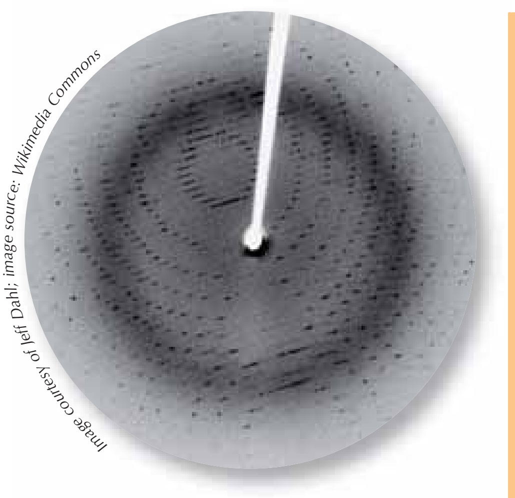
'Crystal' is not a word that immediately comes to mind when thinking about biology. Crystals are better known as magnificent representatives of the mineral world. Gemstones, the shining stars of the underground world, have fascinated us since time immemorial, and the most famous of them, the diamond, has become the symbol of both hardness and eternity. On the contrary, most biological tissues are soft, and everyone knows that life is not eternal. However, it is possible to isolate the molecules of life, such as proteins, and grow biological crystals from them in the lab. The study of such artificially grown biocrystals has driven – and is still driving – an entire discipline known as macromolecular crystallography.

Crystals and structure

The scientific study of mineral crystals (crystallography) started at the end of the 17th century. At first, it meant describing and measuring the faces and angles of different crystalline structures and classifying them according to their geometric characteristics. Soon, crystallographers proposed that the definite geometry observed at the macroscopic scale be explained by the regular arrangement of very small particles (in fact atoms, molecules or ions), invisible to the naked eye and even under a microscope. With the atomistic theory still in its infancy, this model was extensively debated in the 18th and 19th centuries, without a definitive conclusion.

A series of crucial breakthroughs in physics revolutionised the way we look at matter today:

- In 1895, W.C. Röntgen discovered X-rays. These rays have the extraordinary ability to penetrate objects and bodies, thus revealing their internal features. X-rays found an immediate application in medical imaging, but their nature (as electromagnetic waves) remained an enigma for the next 17 years.



X-ray diffraction pattern of crystallised 3Clpro SARS protease

- In 1912, Laue discovered X-ray diffraction, when he had the bright idea to put a crystal in an X-ray beam. In a crystal, atoms or molecules are arranged in an orderly, repeating pattern at distinct positions: it is a regular array of atoms. Since atoms act as X-ray scatterers, the regular arrangement of atoms in a crystal produces constructive interference of the scattered rays, which are therefore emitted in specific directions. These emitted rays are recorded on a detector as spots, and the resulting image is called the diffraction pattern. Laue's experiment proved two things: that crystals consist of a very regular arrangement of atoms, and that X-rays have a short wavelength, in the order of a few tenths of a nanometre – the typical distance between atoms.
- In 1913, the Braggs (father and son) established a relationship – known as Bragg's law (see Hughes, 2007, for a further explanation of Bragg's law) – between the wavelength (λ) of the X-rays, the distance (d) between two atomic planes in a crystal, and the angle of incidence (θ) of the X-rays: $2 d \sin \theta = n \lambda$ where n is an integer. This important discovery marked the beginning of X-ray crystallography, i.e. the possibility of deciphering the

BACKGROUND

The ESRF: one of the most intense X-ray sources in the world

The ESRF 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 piece of material, a protein crystal, a fossil, or a catalytic reaction, for instance). Most users travel to Grenoble a couple of times a year to collect data at the ESRF.

Image courtesy of P. Ginter/ESRF

The European Synchrotron Radiation Facility

As a third-generation source, ESRF produces extremely intense X-rays, called synchrotron radiation. These X-ray beams are emitted by high-energy electrons (6 GeV) which circulate in a large 'storage ring' measuring 844 metres in circumference. The synchrotron X-rays are very collimated, somewhat like laser beams (the rays of collimated light are nearly parallel).

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 10 of them, this speciality is protein crystals. The beamlines at the ESRF are becoming ever more automated, making them easier to use and, recently, granting scientists remote access. This allows users to drive their synchrotron experiments without physically leaving their home laboratory. The crystals are shipped rather than personally taken to the ESRF, even if the scientists go there themselves, because current security restrictions make it difficult to travel with sensitive biological samples.

Synchrotron radiation accounts for about 80% of the macromolecular crystal structures currently deposited in the Protein Data Bank[w7] (in 1995, only 17% of these came from synchrotron data, see image on page 73). ESRF produces some 20% of this total.

structure of a crystal by exposing it to X-rays. The first atomic-resolution structure to be 'solved' (in 1914) was that of table salt, followed very closely by that of diamond. Boosted by these early successes, the very powerful technique of X-ray diffraction has provided scientists with the key to the understanding and clarification of the atomic and molecular structures of all sorts of crystals. "It was like discovering an alluvial gold field with nuggets lying around waiting to be picked up," as the Braggs themselves acknowledged.

At the same time, the first biological crystals were grown, making it possible to study biological molecules using X-rays. The first diffractive image of a protein, obtained as early as 1930, was of an enzyme called pepsin. Soon after that, scientists were able to isolate a virus, crystallise it and show that it did not lose its biological vigour as a result: the tobacco mosaic virus was still infectious for tobacco plants after crystallisation. Macromolecular crystallography was set to go!

Interestingly, not a single biologist was involved in all this early research on complex molecular structures. It was entirely conducted by chemists, physicists and crystallographers, reflecting the fact that during the first half of the 20th century, many scientists from other disciplines took an interest in biology. This is best represented by the book *What is Life?*, written in 1944 by Erwin Schrödinger, a well-known physicist in the field of quantum mechanics. Molecular biology, which appeared in the 1940s as a merging of biochemistry and genetics, has been – from the very beginning – an interdisciplinary field. Obviously, this nascent discipline has had tremendous help from innovative tools invented by physicists. On a more conceptual level, the idea that life can be explained by simple chemico-physical mechanisms has been very controversial, and many thought that the complexity of the living world could not be reduced to the interactions between biomolecules. Today, structural molecular biology is recognised as a main branch of biology, and is still developing at a very fast pace.

It relies heavily on macromolecular crystallography, taking advantage of the fact that each protein molecule has its own cloud of electrons, which diffracts the X-ray beam used in crystallography. The shape and size of the electron cloud determines the pattern in which the X-rays are diffracted[w2] – that molecule's signal. The many tiny signals obtained from the large number of protein molecules in a crystal add up to a measurable signal.

The resulting diffraction image, taken from several angles of a rotating crystal, is transformed mathematically (this operation is called a Fourier transform) into an electron density map of the protein, which represents the electron cloud of the protein. With the help of computer modelling and refinement techniques, the sequence of amino acids of the protein can be fitted into this electron cloud to determine the three-dimensional arrange-

DNA double helix

Image courtesy of geopaul / iStockphoto

ment of atoms in the protein, which is the final structure.

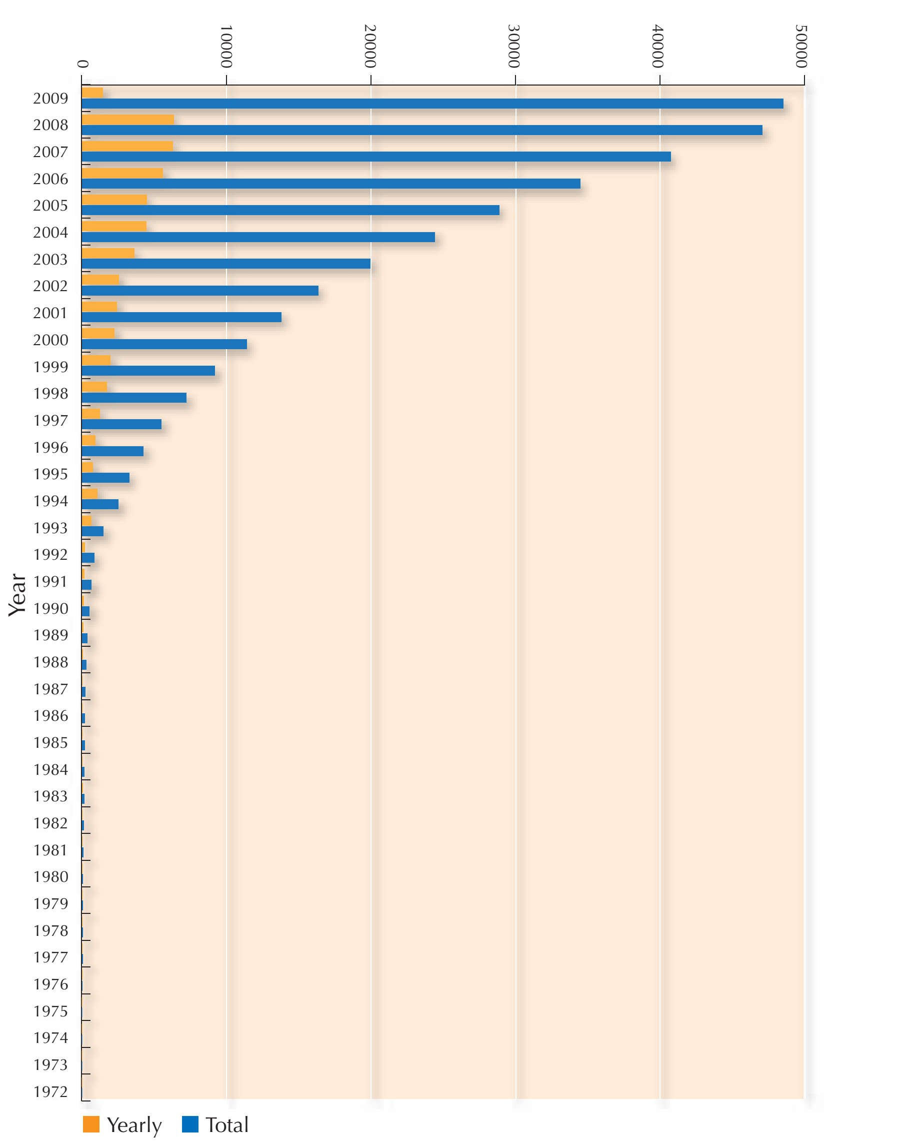
But why is their three-dimensional structure so important for the study of proteins and other biological molecules?

Structure and function

Our hands and eyes, like other anatomical features of the plant and animal kingdoms, have been shaped through evolution to meet the needs of life. In a similar way, the microscopic structure of each subcellular organelle and biological macromolecule is intimately linked to its function. Molecules with the right shapes are responsible for turning genes on and off, catalysing the complex chemistry of life, defending against cellular invaders, and flipping the switches that initiate cell division and control development.

The importance of molecular structure for an understanding of function is best exemplified, of course, by DNA. The simple and beautiful double-helical, base-paired structure of DNA immediately made genetics intelligible in chemical terms. Genes, the previously mysterious factors that controlled the inheritance of particular traits, were segments of the DNA molecules that could be spooled out of solution at the end of a rotating glass rod, like cotton candy on a stick (see Madden, 2006, for a simple DNA purification classroom protocol), thus producing a fibre that could be studied by X-ray diffraction. The determination of the remarkable but simple structure of DNA marked a milestone in structural biology.

By contrast, the study of the structures of proteins has not yielded a simple and all-encompassing explanation of protein structure and hence function. To this day, and despite knowing the structures of about 45 000 different proteins, we are still unable to establish a set of general rules that would allow us to predict a protein's three-dimensional structure



Increasing number of protein structures solved by X-rays.
Note: searchable structures vary over time as some become obsolete and are removed from the database.

from the amino-acid sequence of its polypeptide chain. Proteins fulfil a much wider range of biological functions than DNA does, and functional diversity has dictated structural diversity.

A bottleneck in structural genomics: protein crystallisation

In comparison with molecular genetics, progress in research on protein structure has been painfully slow, partly because of the simple technical problem of obtaining protein crystals which are large enough to use for crystallographic analyses and which diffract X-rays well enough to allow the structure to be determined with a high (atomic) resolution. Furthermore, although they look like crystals of small molecules, such as cooking salt crystals, protein crystals are much smaller and generally very fragile.

Protein crystallisation has therefore always been a hit-and-miss business with no predictive theory. Some proteins crystallise readily, others stub-

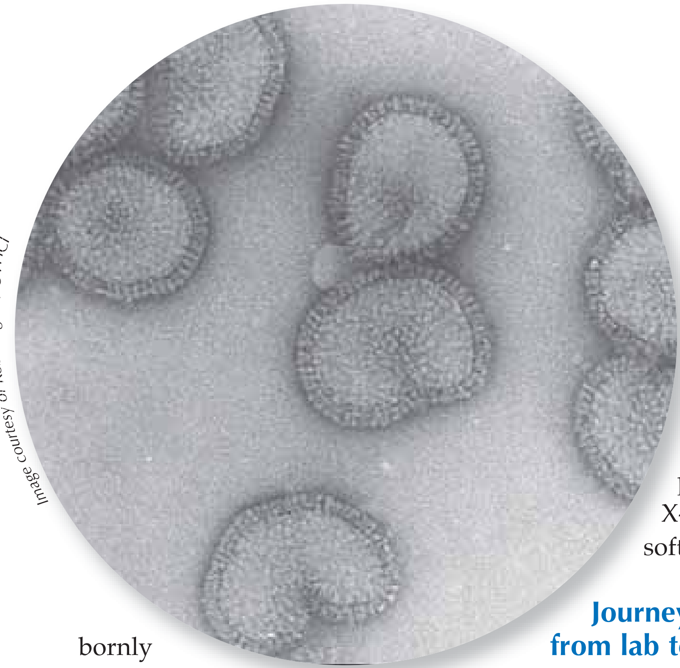


Image courtesy of Rob Ruigrok/ UVHCI

Influenza virus seen under the electron microscope

bornly refuse to produce suitable crystals; some investigators seem to have 'green fingers', like good gardeners, and can grow crystals where others fail. As a result, protein crystallisation has sometimes been felt to be more of an art than a science.

For each new protein, scientists must screen a large number of conditions to find the particular circumstances under which it will crystallise. Variables that can be changed in the conditions are, for example, protein concentration, temperature, pH, and the concentration of a wide range of precipitation agents that may be used in combination with various salts. To try out the best conditions for crystallising a protein in a classroom experiment, and have your results analysed by X-ray diffraction in a real crystallography lab, see Blattmann & Sticher (2009) in this issue. Because protein crystallisation has posed so many difficulties, until recently the most studied proteins have been those that crystallise easily, and which can be produced in large quantities, rather than the most interesting ones. However, much progress has been made in the last decade as can be seen in the figure showing the growth in protein structures solved by X-ray crystallography since 1983. This spectacular progress is due to improved techniques in three areas: crystal preparation, synchrotron X-ray crystallography and software development.

Journey of a protein from lab to lab

To illustrate how a protein's structure is solved using today's state-of-the-art instruments, we will look at how scientists identified the structure of one of the influenza virus' proteins, the polymerase. A group of scientists from the European Molecular Biology Laboratory (EMBL Grenoble outstation[w3], France) and from the Unit of Virus Host-Cell Interaction[w4] (UVHCI, Grenoble) have been studying this protein, which is involved in the mechanism that the virus uses to take over key processes in the human cells it infects (see Ainsworth, 2009, in this issue, for details of the study and its findings). For this project, the scientists made use of the Partnership for Structural Biology[w5] (PSB), a collaboration to decipher structures of biological molecules with high medical interest.

Cloning and expression (at the UVHCI, EMBL and PSB)

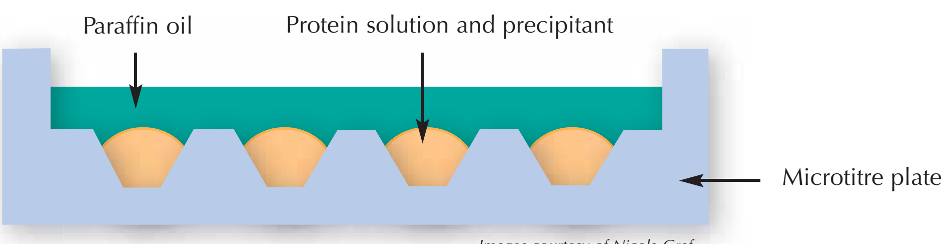
Once the protein had been selected for study, its corresponding gene was amplified, i.e. cloned into a special expression system. This allows large quantities of protein to be produced using a host system, usually bacteria.

Purification (at the PSB) and quality assessment (at the IBS)

The bacterial cells were then 'harvested' by centrifugation, and

Image courtesy of ESRF

The building hosting the PSB



Images courtesy of Nicola Graf

Microbatch method


Image courtesy of ESRF

Protein crystal being put into place on an ESRF beamline

cell debris and possible contaminants such as nucleic acids were removed. The protein was then subjected to a lengthy but crucial multistep purification process, since at least 95% purity is desirable for crystallisation. Protein quality was assessed at the Institut de Biologie Structurale Jean-Pierre Ebel[w6] (IBS) by mass spectrometry (for a short introduction to mass spectrometry, see Wilson & Haslam, 2009, page 24 in this issue), and a sequencer was used to check that the purified protein was the one that was wanted: the influenza virus' polymerase.

Crystallisation (at the PSB)

Scientists started attempting to crystallise the protein by using multifactorial screens. In other words, they exposed different concentrations of the protein to different crystallisation agents, buffers, temperatures, and so forth. Known as the microbatch method (see image above), this is designed to obtain maximum information on the protein one wishes to crystallise while using a minimal amount of sample.

X-ray diffraction on a synchrotron beamline and data collection (at the ESRF)

Once they had obtained crystals of the polymerase, the scientists cryogenically preserved them in liquid nitrogen and transported them to a beamline at the European Synchrotron Radiation Facility (ESRF)[w1]. There, the crystal was fixed on a goniometer head – this is usually done by a robot – and exposed to synchrotron X-rays, which are extremely intense. A goniometer is an instrument that allows an object, such as a crystal, to be rotated to a precise angular position. The goniometer head is rotated in the X-ray beam, in order to produce a maximum number of reflections, or diffracted beams. This produced enormous quantities of data, as is typical of data collection at

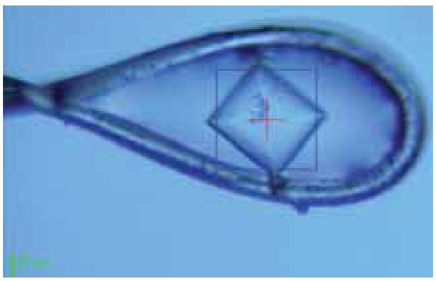


Image courtesy of EMBL-UVHCI

Crystal ready to be illuminated by X-rays

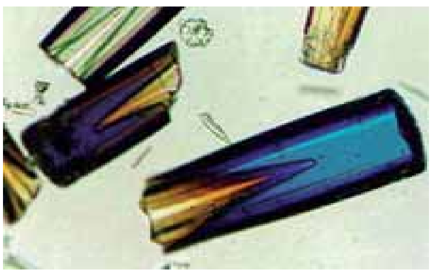


Image courtesy of ESRF

Protein crystals

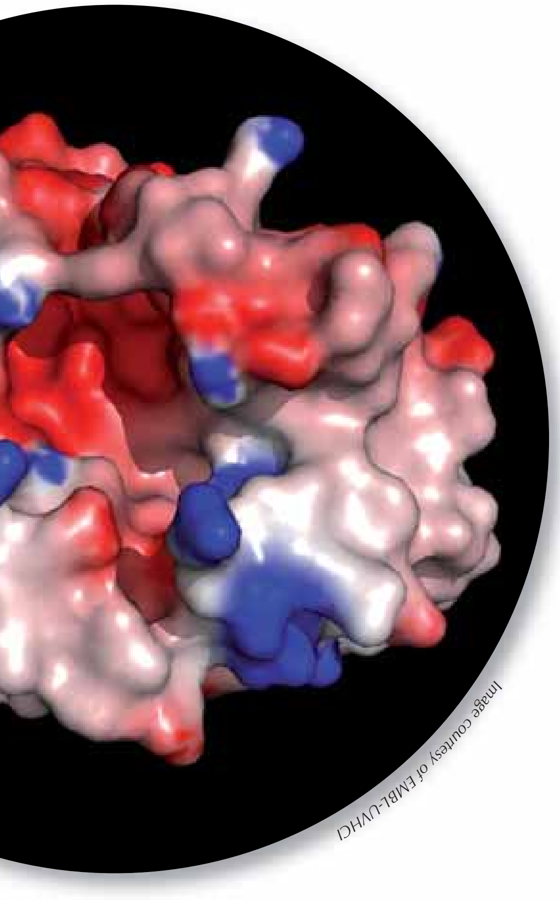

Image courtesy of ESRF

Experimental set-up on an ESRF beamline

synchrotron sources, so the actual structure of the protein was then determined automatically, using a set of software packages specifically developed for the purpose.

Model building, map fitting, refinement and validation (at the UVHCI and EMBL)

Based on the collected and processed data, an atomic model of the polymerase was built and compared with the electron density map. The model was then iteratively refined to best fit the observed data, thanks to powerful software and interactive molecular graphics. After model validation, the structure was finally published and deposited in the publicly accessible Protein Data Bank[w7].



3-D image of the PA protein domain of the influenza virus

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w1 – For more information on the ESRF, see: www.esrf.eu

w2 – More information on the theory of protein crystallisation and X-ray diffraction can be found here: www-structmed.cimr.cam.ac.uk/Course

w3 – To find out more about the EMBL outstation in Grenoble, see: www.embl.fr

w4 – To learn more about the Unit for Virus Host Cell Interaction, see: www.uvhci.fr

w5 – The Partnership for Structural Biology (PSB) is a collaboration between EMBL, the Institut de Biologie Structurale, ESRF and the Institut Laue-Langevin – the world's leading neutron source. The PSB provides an integrated structural biology environment with a portfolio of state-of-the-art techniques on one site: cloning and expression, crystal production, physico-chemical-biochemical characterisation, X-ray and neutron crystallography, nuclear magnetic resonance (NMR), electron microscopy and tomography, small angle X-ray and neutron scattering, mass spectroscopy and advanced light microscopy. See: www.psb-grenoble.eu

w6 – To find out more about the IBS, see: www.ibs.fr

w7 – For the website of the Protein Data Bank, see: www.rcsb.org/pdb

Resources

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For a website with crystal growing experiments, see: www.sciencecompany.com/sci-exper

For the website of the International Union of Crystallography, see: www.iucr.org

Serendipity in life (and) science: Christian Mellwig

Life has a funny habit of turning out quite differently from what you expect. Take Christian Mellwig, for example. He explains to **Vienna Leigh** that he was determined that, whatever path he took in life, it wouldn't be teaching.

"My father was a teacher," explains Christian, who for the past six years has taught chemistry, mathematics and bioinformatics to 14- to 23-year-olds at the Marie Baum Schule[w1] in Heidelberg, Germany, a vocational college with an integrated biotechnology high school. "When I was a kid, he'd come home all the time with terrible stories about what had happened in his classes. I'd think, how can he enjoy his job?

"It's not that I didn't have a good time at school myself; I did like the chemistry and maths classes very much, because the lessons were interesting. The teachers I had at that time were very motivated, and at the same time funny and human. But nevertheless, throughout my childhood and teenage years I swore I would *never* become a teacher."

So Christian embarked on a scientific career. He studied chemistry and mathematics at the University of Freiburg[w2] and then started a PhD there, which he completed at the European Molecular Biology Laboratory (EMBL)[w3] in Heidelberg in cooperation with Freiburg's Physical Chemistry Institute[w4]. At this institute, researchers use physics methods to investigate biological systems. One focus is the molecules involved in photosynthesis, such as the ATP-synthase enzyme, a membrane protein. During his PhD, Christian analysed and modelled the structure of this protein using electron microscopy

Christian Mellwig in front of the Marie Baum Schule

Image courtesy of Christian Mellwig

Image courtesy of Christian Mellwig

Christian's bioinformatics class at the Marie Baum Schule

Image courtesy of Christian Mellwig

Christian's chemistry class at the Marie Baum Schule

Images courtesy of EMBL Photolab

EMBL Heidelberg

and three-dimensional reconstruction. So far, so good. But during his PhD, he worked at the university as a Hilfswissenschaftler, someone who helps organise and supervise the practical work of students – in this case chemistry classes for first-semester chemistry students, as well as for biology and geology students.

"I found that I really enjoyed explaining things and helping people," he says. "I'd never had a problem talking in front of people, but I started to discover that I really actually enjoyed teaching!

"At the same time, I realised that a major part of being a scientific group leader consists of writing grant applications, papers and doing a lot of administrational work, and I could not imagine myself enjoying that kind of job. Additionally, it was very difficult for a chemist to find a position: many friends from university had finished their PhDs and did not find jobs although they were very good scientists. So I decided teaching could really be an alternative, and went through the necessary procedures. I did a Staatsexamensarbeit [a dissertation for teachers] and completed a Referendariat [a two-year vocational training that is generally required in Germany to become a teacher] at the Marie Baum Schule, and became a science teacher instead."

It was absolutely the right decision for Christian, although, of course, not without hurdles. "One of the biggest challenges as a teacher is to motivate the students in scientific subjects, especially chemistry and mathematics," he says. "Very often the students tell me that their parents don't mind if they have problems in these subjects, because the parents had the same problems themselves.

"Chemistry and mathematics are two subjects that require a lot of hard work, and I think that if a student is interested enough and willing to work hard, they can reap great rewards in these fields."

Christian's at a slight advantage, though, when it comes to motivating his pupils. "The students at our school are already interested in science from the beginning. In most schools, and especially in science classes, the students are clearly divided into two groups: one group which loves science, so it's very easy for them to understand even complicated scientific ideas, and the other, which has trouble following concepts, and therefore comes to hate scientific subjects. We only really see the first group."

In Germany, the school system differs slightly from one federal state to another. In Baden-Württemberg, students at the age of 16 who decide to pursue the three-year qualification for university have four school types with different profiles to choose from: the economics high school (Wirtschaftsgymnasium), the nutritional science high school (ernährungswissenschaftliches Gymnasium), the technical high school (technisches Gymnasium) and the biotechnology high school (biotechnologisches Gymnasium). Biotechnology high schools also exist in the federal states of Bavaria and Saxonia. In Baden-Württemberg, they cover a wide range of science subjects: biotechnology (six lessons a week, one of them in the form of practical work in professionally equipped laboratories), bioinformatics (two lessons a week), physics and more chemistry lessons than in other school types. In addition, there are special subjects within life sciences ('Sondergebiete der Biowissenschaften') covering topics like nutritional studies, nanochemistry or bionics, in which labwork is very important.

Christian and his colleagues also motivate their students to take part in the International Biology and Chemistry Olympiads[w5], and one of their students even won a silver medal for Germany at the International Biology Olympiad in Argentina in 2006. This is why the Marie Baum Schule has a sterling success rate for turning out scientists. "Roughly half of our students choose a science career, mainly in biology, medicine, chemistry or molecular biology," says Christian. "Due to their education they have a fantastic starting point for university and are interesting candidates for a range of companies.

"To try to keep in contact with as many of them as possible, I've established a web platform on our school homepage where the alumni can register. From time to time we meet at the school, and some of them tell me that the notes they made during my lessons are very useful and they still use them at university. They also send me emails asking for advice when they have problems in chemistry!" And sometimes, they make Christian proud: "Recently, I got an email from an overjoyed student who had received one of only 23 positions at the Heidelberg German Cancer Research Centre (DKFZ)[w6] – out of 2000 applicants!"

Despite the success rate, though, Christian has several ideas about how science teaching in schools can be developed and improved on a general basis. "I think it's very important for children to meet 'real' scientists and talk to them to get ideas of what kind of options there are with a science background," he says. "Some of my students visited EMBL, where I did my PhD, and they were very surprised, because they didn't expect scientists to be like everyday people, with hobbies and other interests!

"I didn't have the chance to meet a scientist when I was at school; the first time I met one was when I started at university. For me, for a long time, all scientists just looked like Albert Einstein!"

In the classroom, though, Christian can't emphasise enough the importance of practical sessions. "Practical work is the only way to get children and students excited about science," he says. "It takes up a lot of time, and so many teachers have doubts about whether all their efforts are worth it. But the practical work is a major part of my lessons because I believe every theoretical concept should be backed up with experiments."

Christian gets his ideas from various sources, and recently picked up some useful inspiration at a teacher-training course. "The chemistry retraining was about automatic data recording during chemical experiments. We were able to learn

Heidelberg

Image courtesy of Frumpy; image source: Wikimedia Commons

EMBL Heidelberg

Image courtesy of EMBL Photolab

Heidelberg main street

Public domain image; image source: Wikimedia Commons how to handle the machines by ourselves and try out some experiments. I feel I learn more if I have 'hands-on' training rather than listening to someone explain how these machines work, and it's the same for my students: information stays with them longer than if they're just listening to me standing in front of them talking.

"When I was at school, 'chalk and talk' was the most usual teaching method, but nowadays schools are also more keen for children to work on projects in teams and learn new topics by self-organisation, so every student is able to learn at his or her own speed. This makes it easier for me, the teacher, because I can help the students individually – and it gives me a break from being the centre of attention!"

Image courtesy of Michael Schmalenstroer; image source: Wikimedia Commons

Freiburg cathedral

Despite his own decision to leave research, Christian always encourages those students who choose to follow a scientific path. "It's a fascinating thing. For me, science was always like a puzzle, where you try to find out which pieces belong together. Of course, you normally only work on one little piece, but to find some new information about the whole puzzle is hugely exciting.

"One day from my scientific career that will stay with me forever was a day when I did something absolutely wrong – or so I thought – and the result I got was one I had been waiting a whole year for. I was trying to get a three-dimensional structure of ATP synthase using electron microscopy, but my samples never contained the enzyme. The problem was obvious to me, but not the solution: I always used detergent to embed the samples, since I thought that membrane proteins – such as ATP synthase – needed this to stay soluble. On the other hand, every student knows that detergent destroys the surface tension of water. But this surface tension would have been required to get a thin layer of vitrified water, a form of ice in which the water molecules are arranged exactly as in liquid water, rather than forming crystal structures as in normal ice. The formation of ice crystals can destroy the structure of the proteins you are trying to analyse, so vitrification is essential. Then one day I accidentally forgot to add the detergent – and the enzymes were embedded nicely. I think I never would have made it as far as I did without that accidental discovery, and that's the fantastic thing about science."

REVIEW

This article can be used in teacher-training classes to prompt discussion about scientists becoming teachers. It could also start teachers thinking about how students perceive scientists; they could ask students to draw or describe scientists.

The article could also be given to students in a science class when looking at different career options. It helps to show that there are many diverse paths a scientist can follow, and that teaching may be one of those paths.

Shaista Shirazi, UK

Web references

w1 – The website of Marie Baum Schule can be found here: www.mbs-hd.de

w2 – For more information on Freiburg University, see: www.uni-freiburg.de/index_en.php

w3 – For more information on the European Molecular Biology Laboratory, see: www.embl.org

w4 – To find out more about the Physical Chemistry Institute at Freiburg University, see: www.physchem.uni-freiburg.de

w5 – For more information on the International Biology Olympiad, see: www.ibo-info.org

For more information on the International Chemistry Olympiad, see the websites of the 2008 edition: http://icho.hu/pages/Home.aspx or the 2009 edition: www.icho2009.co.uk

w6 – The website of the German Cancer Research Centre Heidelberg (DKFZ) can be found here: www.dkfz.de

Resources

Christian's PhD work on the structure of ATP synthase (in German) can be found here: www.freidok.uni-freiburg.de/volltexte/560

His work is published in English here:

Mellwig C, Böttcher B (2003) A unique resting position of the ATP-synthase from chloroplasts. *Journal of Biological Chemistry* **278(20)**: 18544-18549. www.jbc.org/cgi/content/full/278/20/18544

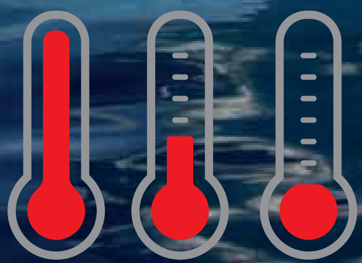
"Admitting to being a physicist isn't really the best chat-up line"

Alison McLure tells **Marlene Rau** about her adventurous life as a physicist – from being a TV presenter and forecasting the weather in the Antarctic to taking gap-year students on an expedition to an island in the South Atlantic.

Image courtesy of Alexander Hafemann/iStockphoto

Image courtesy of the British Schools Exploring Society's expedition to South Georgia

Alison on a yacht off South Georgia



Alison McLure was born in Thurso, at the northernmost tip of Scotland, and grew up in Glasgow with physics as an integral part of everyday life: her parents – both enthusiastic physics teachers – would constantly talk about physics and ask their three children questions such as "Why do we all lean one way when the car is going around a roundabout?". In school, Alison was especially impressed by the experiments her father conducted with the class (he was her teacher then). She was also taken by chemistry, with its flash-bang-smoke experiments, but her ties with physics were stronger, so she went on to study physics at Aberdeen University, as did her brother.

To Alison, real-life problems have always been the most appealing ones in science, particularly if finding a solution to them will make a difference. When she was young, Alison learned about the applicability of science first-hand: she used to sail a lot, and physics helped her to understand how the sails and the weather worked. This understanding of the intricacies of the weather also led Alison to her first job as a meteorologist with the Met Office[w1]. At that time, the Met Office liked to train its own people, so you didn't need a degree in meteorology. Alison joined straight after graduating, hoping to do something practical, rather than conducting research. Ironically, she was posted to a research lab to start with: "Luckily, the research was to do with measuring the weather in extreme environments, so I got to put experimental automatic weather stations on top of mountains and on ocean buoys."

As if this was too boring, Alison was selected to become a TV presenter for the weather on 'Reporting Scotland'. She had been forecasting the weather at Aberdeen and London Weather Centres and a couple of Royal Air Force stations, so she was a reasonably experienced forecaster by that time. Besides, she had done a fair bit of local radio, so she had experience as a presenter: "My short spell on TV was with BBC Scotland to cover between one presenter leaving and the famous Heather the Weather arriving in 1994. My boss didn't really give me a lot of choice. I was very nervous and wasn't really cut out to be a glamour girl – I scraped off the makeup as soon as I finished my piece. Once I was recognised cycling home in a deluge. They probably thought that I had got the forecast wrong, but I just like cycling in the rain! It didn't make the news, but I didn't expect or want anyone to recognise me at all. That's when I realised I wanted to give up."

Those were exciting times: besides ending up on screen, Alison was offered the chance of a six-month secondment to the British Antarctic Survey[w2]. She was lucky enough to pass the interview and after a month's preparation, spent five fantastic months working at Rothera Research Station on the Antarctic Peninsula. Forecasting the weather in such an extreme environment was incredibly challenging, but Alison still managed to make time to climb, ski and watch the amazing wildlife. "Rothera is next to the sea on the Antarctic Peninsula, so it is not on the ice cap, which is all ice and snow and no wildlife. I went during the Antarctic summer, our winter, so I had three summers in a row. The base was pretty basic, but everything you needed was there. They had professional cooks, a library and a bar, and social evenings were arranged. During the day, all of us had our own jobs to do, and I was impressed by everyone's professionalism. There were around 50 people on the base at the time – it's busy in their summer and minimal staff in winter. I was the only woman there for most of the time, and living with so many men had its moments.

"My room was right next to the bar, so through the wall I could hear the shenanigans late into the night. I had to be first up in the morning to get the forecast sorted out, so eventually I moved out of that room and into a container outside… pretty chilly, but at least it was quiet. Tourist ships occasionally came to the base, which gave us a welcome change of conversation, although we had to laugh when one tourist stepped off the ship and asked what height we were at. I suppose they couldn't get their head round the snow and ice at sea level."

After ten years of the weather, Alison decided it was time for a change – in fact, quite a number of changes over the years. First, she worked as joint manager of a marina in the west of Scotland: "The marina had just been taken over by a new owner, and they were looking for new staff. Although I had no experience in working for a business, I persuaded them that I would learn quickly. Also, the yachties loved the fact that I would give them personal forecasts and knew a fair bit about boats. The job involved all sorts of things, from fixing and launching boats, and maintaining the infrastructure of the marina, to doing the books and accounting forecasts and making strategic decisions on the direction of the business."

Three years later, Alison became a policy officer with the Scottish Government[w3] in the Environment and Rural Affairs Department, a position she held for another three years. "I was meant to find out as much as I

Impressions of South Georgia


Image courtesy of Alexander Hafermann/iStockphoto


Image courtesy of Richard Lindle/iStockphoto


Image courtesy of Alexander Hafermann/iStockphoto

Image courtesy of João Freitas/iStockphoto

could about beef and sheep in Scotland, so that I could advise the minister on any developments or potential issues. It also involved liaising with landowners, crofters and farmers to find out their concerns."

Having now developed a taste for change, Alison moved jobs again, and spent another three years with the Scottish Leadership Foundation[w4] before taking on her current job with the Institute of Physics[w5], where she has been since 2005. It was the mixture of experiences that Alison had gained over the years, within and outside science, which earned her this latest job – and she advises everyone to keep an open mind when applying for a position: "It is amazing how many transferrable skills you have as a scientist," she says.

However, working as the National Officer for the Institute of Physics in Scotland doesn't leave time for boredom. "One day I might be talking to a member of the Scottish Parliament, and the next I could be making solar cookers with a class of students," enthuses Alison. Her job involves organising events for members of the Institute of Physics in Scotland and promoting physics to anyone who will listen. "It would be great if I could show people what a great and fascinating time you can have if you take physics, at any level," Alison says.

The main challenge that scientists face, according to Alison, is one of image: "People either think you are too clever by half, or that you must be like a cartoon scientist. Admitting to being a physicist isn't really the best chat-up line, unfortunately. I think people struggle to understand what scientists do in their day-to-day job. Perhaps it is up to us to make ourselves more visible to the public. I certainly receive great feedback when I give talks about my time working in the Antarctic and the science that goes on there. When people see the pictures and meet a real person, science becomes more tangible to them. If everyone had some grounding in science and how science works, perhaps that would help them to understand some of the issues which we face as a society."

Alison doesn't stop at hopes and words – she also takes action. In 2007, she was Chief Scientist on a British Schools Exploring Society (BSES)[w6] expedition to the small island of South Georgia in the South Atlantic. "We surveyed penguin colonies, monitored glaciers, did plant surveys and meteorological readings, as well as general exploring and climbing

REVIEW

The importance of educating students about career possibilities for science graduates is rather underestimated in science education. Yet, providing students with an overview of possible career choices, other than working in a laboratory, will positively adjust their conceptions about science.

This narrative gives a rich, illustrative and realistic description of the life of a scientist, in which not only appealing career possibilities are explained, but also a variety of the transferable skills that scientists develop during their studies and careers are described. Furthermore, this interview explicitly portrays several research dispositions, such as being curious, or enjoying the uncertainty when doing research. Although these dispositions are highly valued by scientists, they too often stay hidden to students. This interview can positively influence students' aspirations to engage in further study of science subjects. I would encourage all science teachers to present to their students this article and many other good examples of what scientists actually do. These kinds of authentic accounts will positively change students' conceptions of science.

Roeland van der Rijst, Netherlands

mountains. BSES wanted to set up a project for gap-year students along with *HMS Endurance*[w7], the UK Royal Navy's ice patrol ship, and they agreed to support the project for five years, so that we could gather some meaningful data, rather than a snapshot of one year, which has limited value. There were 18 young explorers between 18 and 22 years old, and six leaders. Each year, there will be different young explorers and mostly new leaders, but the expeditions will follow a similar programme and run similar experiments. I had applied to BSES to go on a Greenland expedition, but when they noticed that I had been to the Antarctic before, they asked if I would go on this project instead." Alison would like to go back there in 2012, at the end of the five-year programme, to find out if the experiments she set up with the youngsters have yielded useful results.

Alison likes a life of change and a challenge – and this is also her attitude to science: "I enjoy the uncertainty of the journey – whatever piece of research you do, it turns up more questions than answers." And this is the thrill, really.

Web references

w1 – The website of the Met Office can be found here: www.metoffice.gov.uk

w2 – The website of the British Antarctic Survey can be found here: www.bas.ac.uk

w3 – To find out more about the Scottish Government, see: www.scotland.gov.uk

w4 – For more information about the Scottish Leadership Foundation, see: www.lums.lancs.ac.uk/leadership/scotdip/slf

w5 – To find out more about the Institute of Physics in Scotland, see: www.iopscotland.org

w6 – You can find out more about the British Schools Exploring Society and the possibilities for participation here: www.bses.org.uk

You can also read all about the BSES expedition to South Georgia in their blog: http://antarctica.physics.org

w7 – To learn more about *HMS Endurance*, the UK Royal Navy's ice patrol ship, see: www.royalnavy.mod.uk/server/show/nav.1843

Image courtesy of the British Schools Exploring Society's expedition to South Georgia

Young explorers on South Georgia with Alison on the right

How to write a good science story: writing competion

Image courtesy of Guillermo Lobo/iStockphoto

Rebecca Skloot tells **Sonia Furtado** and **Marlene Rau** how she became a science writer, where she finds inspiration for her stories – and invites you to enter the *Science in School* science writing competition.

Image courtesy of EMBL Photolab

Rebecca Skloot

Rebecca Skloot[w1] was going to be a veterinarian. As part of her degree in biomedical sciences, she had to study a foreign language in her third year. "The school that I went to weirdly considered 'writing' to be a foreign language," she says, "so I could take a writing class or I could take Spanish or French or German. I took writing because I thought that would be easier."

Rebecca enrolled in creative non-fiction writing, and one of her first assignments was to write about a place. She chose to write about the freezer in the vet school morgue. At the time, she was doing compulsory work at the morgue, and had been shocked to discover how many animals were needlessly killed at the school for teaching purposes. "A shift was just starting towards using computer simulation programs to help teach students and minimise the use of animals, but the school wasn't doing it yet," Rebecca says. "I was very upset about this, so I wrote about this freezer as a way to talk about the issue. It was an enormous warehouse sort of room, with cows and horses hanging from the ceilings on pulleys – just very shocking." After reading her text, her colleagues in the writing class were not only

Image courtesy of Rebecca Skloot

Rebecca Skloot with a monkey she recently wrote about for the New York Times Magazine

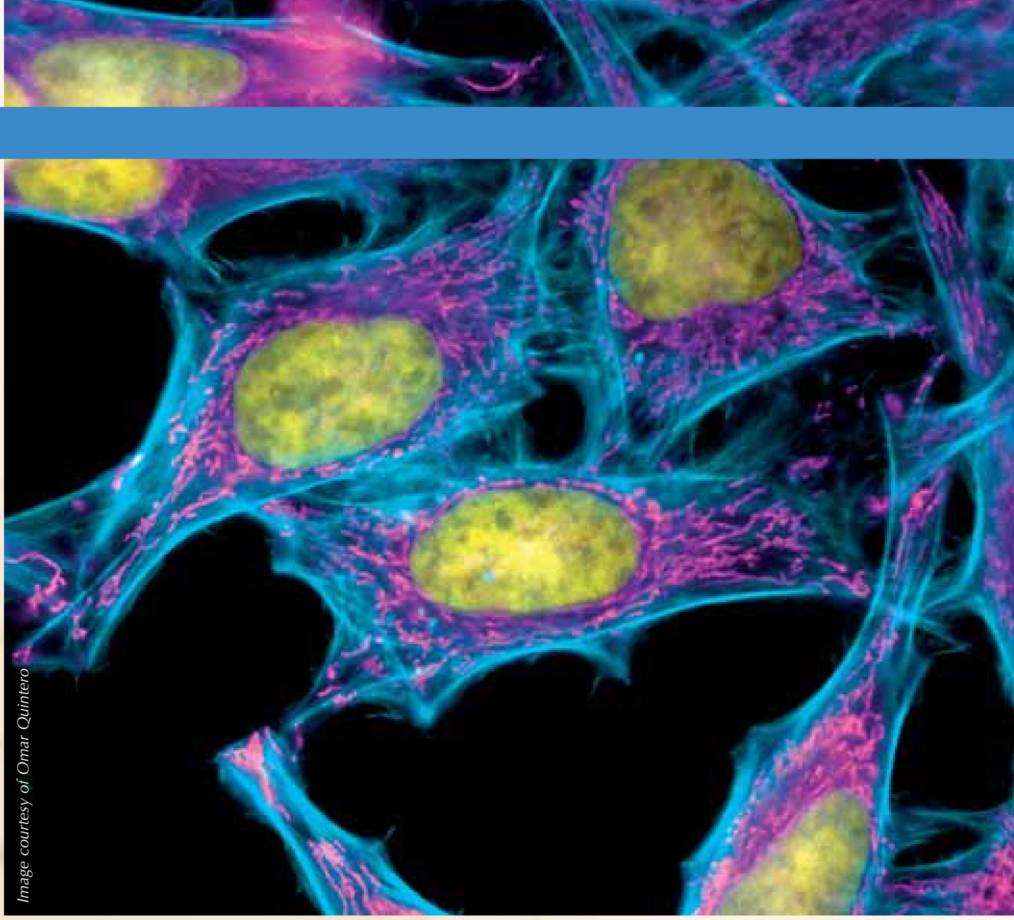


Image courtesy of Omar Quintero

HeLa cells

Image courtesy of the Lacks family; image source: Wikipedia

Henrietta Lacks (1920-1951) circa 1945-1950

shocked, but moved into action: "They got very riled. They wanted to go to the dean and protest, and they wanted to force the school to start using these simulation programs." That's when Rebecca first realised she could take a science-related topic she cared about, convey it to people who didn't know science, and make them care.

After that, she started taking more writing classes, until eventually the teacher suggested she was so good that she should consider a change of career. So instead of becoming a vet, Rebecca went to graduate school in writing and became a science writer.

She has now written more than 100 feature articles, personal essays, book reviews and news stories for newspapers and magazines, as well as working as an editor, teaching writing courses herself and judging writing competitions. Rebecca will soon publish a book, *HeLa: The Immortal Life of Henrietta Lacks*, on the immortal Hela cell line, which was derived from cervical cancer cells taken from a woman named Henrietta Lacks, who died from cancer on October 4, 1951. In her book, Rebecca pursues a life-long obsession with these cells that are commonly used in scientific research:

"I was 16 and I was in my first biology class. My teacher was lecturing, telling the class about HeLa cells used in cancer research and where they came from: 'There was this woman, Henrietta Lacks [HeLa], and she was black and that's all we know about her.' At that point, even though she had died in 1951, her cells had been alive for 30-something years. And I went 'What? What do you mean? Who is she and why her cells? Did she have kids?', and just got completely obsessed with her. But the teacher said 'Sorry, that's all we know.' Later, I would do extra-credit projects where I wrote papers about her cells, I worked in research labs where I would do research on her cells… they were just everywhere! Then, at university, in that same writing class where I got the assignment to write about a place, I got another assignment that was to write about something someone had forgotten: so I just started to write about Henrietta Lacks, and how the world forgot about her, and how nobody knows who she is. Then in graduate school, for my thesis I had to write a book-like thing, which I couldn't conceive of. So I thought I would write a collection of essays about forgotten women in science. I was going to have twelve of them, and I wrote down the numbers on a piece of paper: one was Henrietta Lacks, and I had no ideas for the rest of them… So I thought I'd just start with her and see what happens, thinking I was just going to write a small piece, and now, ten years later… it's a book!"

Not all Rebecca's stories are on such serious topics, though. While she likes to explore the political and ethical issues that arise at the interface between science and society, she loves science, and loves to write about quirky science, too.

And how does she find all these stories? Curiosity, she says. “If there’s one thing that all my stories have in common, it’s that at some point in them I went ‘What?’”. Like the time she was at the vet with her dog, and heard the vet tell the receptionist an operation had gone well: “Patient’s up, swimming around”. Rebecca thought “What?”, walked over, and promptly interviewed the vet on fish surgery for about an hour, taking notes on her bill!


Image courtesy of Gregory Lewbart, VMD

Radiography of a fish with a broken back that has been fixed with plates and screws

Of course, good science writing implies not only finding good stories but also writing them well. In Rebecca’s words: “To me, good science writing is really just good writing that happens to be about a scientific topic. At the basic story level there is no difference.” So, she says, you need the same basic ingredients in science writing as in any kind of storytelling: characters, scenes, actions and a plot. You need a narrative that people can follow, and some sort of tension to keep them interested. As Rebecca says, “We get interested when there is something at stake. Is the robber going to be caught? Is the person going to be killed? Is she going to find her long-lost mother? That’s why we keep watching. You know, there is always some tension there that keeps you going to find out what happens next.”

When it comes to describing the science, according to Rebecca the trick is to keep it simple. Not necessarily the science itself, but the language. “The complication comes with actually explaining the science and there it just takes clear language: really understanding what you’re writing about and saying it clearly. I think one of the problems people get into is that they try to get too fancy when they start talking about the actual science. Now just explain what happens, and you’ll be fine.” One tactic is to use comparisons and metaphors from everyday life, but these only work if they’re not too far-fetched. If you are able to contact scientists themselves, they can be very helpful too, especially if you ask them to explain things to you like they would to a ten-year-old. “You can get really interesting language out of them that way,” Rebecca remarks. Alternatively, writers can try this trick on themselves, and think: how would I explain this science story to a ten-year-old? If this sounds like a challenge you’d be tempted to give your students, check out our science writing competition on the next page!

Web references

w1 – To find out more about Rebecca Skloot and her book, see: www.rebeccaskloot.com

w2 – For more information on John McPhee, see: www.johnmcphee.com

Image courtesy of Rebecca Skloot

Image courtesy of Benjamin Brainard, VMD

Image courtesy of Benjamin Brainard, VMD

Image courtesy of Benjamin Brainard, VMD

Science writing competition

Is there a budding science writer in your classroom? Do any of your students enjoy regaling others with enthralling tales? Is there a hidden talent waiting to be discovered? Here's a chance to find out! Hand your students some pen and paper (or sit them at a computer), and get them to start scribbling… You never know, our science writing competition could be their first step towards becoming professional science writers like Rebecca Skloot!

Yes, we know the standard reply to this kind of competition is 'What do I write about?'. Rebecca's advice is to pick something you're interested in, and find the story within it. "Good stories are everywhere," she says. "Every bit of science has a great story in it, it's just a matter of being curious about it and giving yourself the freedom to ask the questions."

Just look at one of Rebecca's favourite science writers, Pulitzer Prize winner John McPhee[w2]: at the age of 70, he looked back and realised that about 90% of what he had written was about things he had been interested in since before he was 15.

So a student's interests can drive good storytelling for a lifetime, and are a great starting point for a competition like this. You can prompt your students to think about what makes a subject interesting by asking what first sparked their curiosity and made them want to find out more. It could be something a teacher said in class, as with Rebecca's interest in HeLa cells. They could have read something interesting in the papers or on the Internet. Or they could be itching to find out how that *CSI* guy discovered what the blue smudge was in last week's episode.

Alternatively, you can suggest particular topics yourself, encouraging your students to write about a place that has something to do with science, about a scientific mystery (solved or unsolved), about a local scientist or institution…. You can even use the competition to introduce or discuss a topic you're dealing with in class, or enlist the help of language teachers and make it an interdisciplinary project.

Whatever your tactic, the end result should be an interesting science article for a general audience. Be sure to check all the rules before submitting it!

So send us your students' best science stories, have them read by Rebecca Skloot and the rest of the jury, and the very best will be published in *Science in School*!

Rules

Entries are welcomed from students at secondary schools anywhere in Europe, and will be judged in two categories, according to the author's age on the date of submission: 11-15 year-olds, and 16 and over. Stories may be written individually or by groups of students (limited to one entry per individual or group), and must be:

- About science
- In English
- In a style appropriate for a magazine or newspaper
- No more than 900 words long
- Accompanied by the name(s) and age(s) of the author(s), the teacher's name, school and contact details (postal and email addresses).

Once you have a story that meets these criteria, send it to us by e-mail or post (no handwritten entries) to arrive by 30 September 2009.

Email: editor@scienceinschool.org

Postal address:

Dr Eleanor Hayes
Editor-in-Chief of *Science in School*
European Molecular Biology Laboratory
Meyerhofstrasse 1
69117 Heidelberg
Germany

Entries will be judged by a jury consisting of the editors of *Science in School*, Rebecca Skloot, and other science writers. Entries submitted by groups comprising students in both age categories will be judged in the 16+ category. The best story in each age group will be published in *Science in School*.

A Dictionary of Science and *Collins Internet-linked Dictionary of Science: Science Defined and Explained*

Reviewed by Friedlinde Krotscheck, Austria

As well as a good science encyclopaedia, all classrooms need a science dictionary, preferably with pictures and graphs as well as clear and correct explanations. Consulting a dictionary and following up cross-references encourages further reading, promotes independent research, and advances students' understanding of copyright issues and correct citation methods when using such information resources – as well as giving the teacher a break from endless questioning.

Two trusted reference publishers, Oxford University Press (OUP) and Harper Collins, have new editions of their science titles on the market, both of which might be worth owning, as their focuses are slightly different. The *Collins Internet-linked Dictionary of Science: Science Defined and Explained* concentrates more on biological and human-related topics in somewhat simplified terms, and, as the introduction claims, is written to "provide a guide to the vocabulary of modern science and (…) enhance the reader's understanding of science".

Cross-references are clearly marked with asterisks, and an advantage of this dictionary is that it contains a number of longer review entries including images in the style of an encyclopaedia. Easy to read, the Collins dictionary contains many illustrations and tables, mostly about biological and medical topics. The last four pages also list Internet links to worldwide scientific institutions and organisations. These could be a useful resource for students.

Though there's no thumb index, it's clearly laid out and easy to find your way around. While it would be an ideal dictionary for younger students, the Collins dictionary suffers in that explanations are often oversimplified, affecting accuracy, while at other times there's no explanation for complicated vocabulary used in the definitions.

On the other hand, Oxford University Press' experience in science dictionaries is clearly visible in the well-organised reference system and accuracy of *A Dictionary of Science*. It leans more towards physics and chemistry topics, and "aims to provide school and first year university students with accurate explanations of any unfamiliar words they might come across in the course of their studies", as the introduction claims.

As well as providing accurate explanations, the Oxford University Press dictionary provides in-depth cross-referencing tools such as 'compare', 'see also' and synonyms for each entry. There aren't many illustrations and tables, and those that are there explain mainly physics and chemical processes, but definition vocabulary is correctly cross-referenced, and the content is reliably accurate while still understandable and easy to read.

At just under UK£10 each, both these dictionaries would be a valuable addition to the classroom, although the OUP publication edges ahead thanks to its detailed accuracy and cross-referencing possibilities.

Details

A Dictionary of Science

Publisher: Oxford University Press

Publication year: 2005, 5th edition

ISBN: 9780192806413

Collins Internet-linked Dictionary of Science: Science Defined and Explained

Publisher: Harper Collins

Publication year: 2005, 2nd edition

ISBN: 9780007207336

Molecules with Silly or Unusual Names

By Paul May

Reviewed by Tim Harrison, Bristol, UK

Molecules with Silly or Unusual Names shows that chemists do have a sense of humour, even though it may be a little 'schoolboyish' at times. Based on a website of the same name (www.chm.bris.ac.uk/sillymolecules/sillymols.htm), the book – as its name suggests – is a collection of the strangest, silliest and even rudest names for real molecules, minerals, enzymes and genes.

Granted, the reader may need a good understanding of English to see the funny side of some of the names, and some of the amusement does rely on puns. Some names, such as windowpane, DAMN, gardenin, moronic acid and megaphone, can be enjoyed by all, but be warned – others can be downright naughty.

If you do decide that young minds can cope, there's plenty of slightly tamer stuff to make them snigger, such as SnOT, BARF, uranate and burpalite. They may also like the anthropomorphic Nanoputian molecules, named after the Lilliputians in *Gulliver's Travels*. With Nanokids as their basis, variants include Nanochef, Nanotoddler and NanoBalletDancer.

As an improvement on the website, the book is divided into chapters covering molecules, minerals, proteins, enzymes and genes, and there's also a game to play based on the silly names, which could double as a learning exercise. Though the website does allow the user to view the three-dimensional structures of the molecules provided that the appropriate software is installed, the book contains even more information than is available online.

While this book may be more appropriate in the science department coffee room than the lower school library, it's certainly a fun volume to dip into.

Details

Publisher: Imperial College Press
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A Dictionary of International Units: Metric-Matters: Names and Symbols

By Philip Bladon

Reviewed by Eleanor Hayes, Editor-in-Chief of *Science in School*

Have you ever wondered what a decasievert or a petahenry is? Why some symbols are written in capitals and others in lower case? What the difference is between ps and pS? How many ampere there are in a zettaampere? Or what Nikola Tesla's nationality was? These and many other questions can be answered in Philip Bladon's *A Dictionary of International Units*.

This book is a pleasure for those fascinated by scientific terminology and writing style – or indeed anyone with a critical copy editor. It also provides a perfect reference book for teachers faced with questions like "But why can't I write 'the car moved 10 ms'?" In fact, I wonder whether the book arose out of the author's own experience as a science teacher.

This slim paperback (87 pages) begins with a list of units ordered alphabetically by symbol, followed by the same information ordered by unit name. Then comes a list of all SI units named after scientists (yes, those are the symbols written with a capital letter), with the scientists' nationalities and dates.

The second part of the dictionary contains a selection of units for presenting data meaningfully. This selection is listed first by symbol (what does C/mm^2 symbolise?), then by quantity (which units should I use for heat or angular momentum?). Be careful not to lose the erratum notice, however, in which pA and pC are correctly listed as picoampere and picocoulomb, rather than petaampere and petacoulomb, as on page 61.

Next comes a table of SI prefixes and factors (did you know the prefix yotta has the symbol Y and the factor of 10^{24}?). The following section, on writing SI units and numerical values, includes rules such as avoiding capital letters (25 Ampere) or plurals (the car did not move 10 ms, but it might have moved *for* 10 ms), and how to express decimals (comma or dot?). The book concludes with a definition of the seven base units of the SI system.

A Dictionary of International Units is a delightful book that belongs on the shelf of any science teacher, editor or unashamed pedant. Whether you browse happily through it in a quiet moment or just consult it quickly, you won't regret owning it.

Details

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Potent Biology: Stem Cells, Cloning, and Regeneration

By Douglas A. Melton and Nadia Rosenthal

Reviewed by Michalis Hadjimarcou, Cyprus

Say 'stem cells' and you can guarantee some strong opinions and heated debate. The potential to regenerate tissues and organs by using stem cells and cloning is one of the hottest scientific topics of the moment, but how much about it does the average layperson really understand? What's the difference between regeneration and wound healing, for example, and which diseases could potentially be cured by the use of stem cells? What's the correlation between the aging process and stem cell function, and how does cloning by nuclear transfer work?

Potent biology: stem cells, cloning and regeneration – a DVD produced by The Howard Hughes Medical Institute as part of its Holiday Lectures on Science programme – addresses some of these issues with four one-hour presentations: Understanding Embryonic Stem Cells, Adult Stem Cells and Regeneration, Coaxing Embryonic Stem Cells, and Stem Cells and the End of Aging. Presented to a high-school audience by two experts in the field, Dr Douglas A. Melton and Dr Nadia Rosenthal, the lectures are understandable by anyone with a basic knowledge of biology. They start with very basic information on what development means in an organism, and cover such topics as the usefulness of stem cells derived from umbilical cord blood, regeneration in animals, and descriptions of some of the key experiments that drive stem cell research. During the lectures, the speakers interact with the audience and respond to their questions, making the presentations lively.

The two-disc set also contains a variety of features, animations, video clips and biographies of the lecturers and some of the younger scientists in their labs. In addition, specific topics are covered, such as how deer antlers can be shed and re-grown every year. There's even some inside information regarding the 'fountain of youth'. One highlight is the discussion session between the speakers, two ethics specialists and the students, on the politics and ethics of stem cell research. Finally, a short video gives the overall picture of the current worldwide status of stem cell research and policies restricting it.

The *Potent biology* DVD is easy to use, with a menu organised by scientific topic and with direct access to the various special features. Particularly useful to the teacher-viewer is the presentation with simple instructions and ideas on how to use the DVD in the classroom, suggesting potential discussion topics including the discovery of cures using embryonic stem cells versus respect for life, at which stage in development does a human become a human with all the legal rights and protection of a person, who has the right to create life and for what purpose, and the morality of experimentation on animals.

Details

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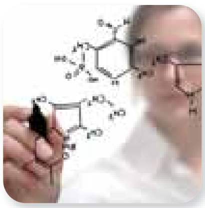

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