Spring 2007 Issue 4

# SCIENCE in SCHOOL

## In this issue:

### Ethics in research

Nadia Rosenthal discusses the use of embryonic stem cells and live animals in research

**Also:**

The Faulkes Telescopes:
real-time, remote-control astronomy for schools

**Highlighting the best in science teaching and research**

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## Cover Images

Escher mice
Image courtesy of Nadia Rosenthal

The Faulkes Telescope
Image courtesy of the Faulkes Telescope Project

# Contents

# Welcome to the fourth issue of *Science in School*

Once again, we are happy to offer you a wide range of articles written by teachers, scientists and others from nine different countries.

In our feature article, Nadia Rosenthal, one of two stem-cell researchers to deliver the 2006 Howard Hughes Holiday Lectures on Science for high-school students, discusses the ethics of using stem cells and live animals in research. She is not only a leading scientist, but also a talented artist – as you can see from our front cover. Ethical issues are also the focus of Democs, a card game to investigate and discuss controversial issues such as nanotechnology, genetically modified food or vaccination policies.

In the second part of our 'Fusion in the Universe' series, Henri Boffin and Douglas Pierce-Price investigate our celestial ancestry. Rachel Dodds also looks to the heavens, with a project allowing school classes to control telescopes via a computer link and to take their own astronomical pictures. Or, if you are feeling more Earth-bound, why not follow Mark Tiele Westra's simple instructions for building your own spectrometer, and start investigating the hidden beauty and complexity of white light?

The natural world can also provide inspiration for future scientific developments. Giovanna Cicognani and Montserrat Capellas describe recent research into spider silk, man-made versions of which could be used to repair ligaments or construct light-weight armour. Taking a larger-scale look at biomimetics, Julian Vincent explains how imitating biological systems may provide a sustainable answer to many of our engineering challenges.

Looking back in history, Angelika Börsch-Haubold investigates how our modern understanding of hallucinogenic plants casts light on the persecution of 'witches'. And Isabella Marini demonstrates how students can follow in the footsteps of $19^{th}$-century scientists and discover for themselves what makes enzymes so special.

Of course, many of our articles present different ways to enthuse school students in science. In this issue, ideas include Canadian school science fairs, the Belgian

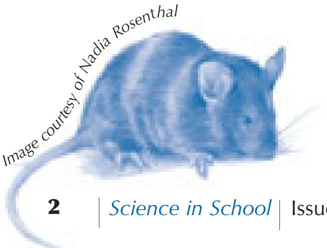

Image courtesy of Nadia Rosenthal

scientists@work school project, French multimedia science workshops, the European CISCI project to use movie clips in lessons, and the schools outreach work of French toothpaste-researcher, Linda Sellou.

We hope you enjoy these and other articles in this issue and we would be interested to hear how you use them. If you adapt articles from *Science in School* to use as teaching materials, perhaps you would like to share your work with other teachers by submitting those materials for publication. If you would like to discuss the adaptation with us, we would be delighted to hear from you.

As you will see from our events list, there are many opportunities for teachers to share their knowledge and learn from each other. If you organise events that you would like listed in *Science in School*, just send us brief details (date, location, title, abstract, website and contact email address). If you are able to distribute flyers and copies of *Science in School* to participants, please let us know.

We also welcome suggestions for future content. Perhaps you know (or are) a particularly inspiring science teacher, suitable for our 'teacher profile' section? You might like to suggest a high-profile scientist to be interviewed for a feature article, or you may know a young, enthusiastic scientist whom we should interview for the 'scientist profile' section. Please email us your suggestions.

Finally, do leave your comments about our articles online; there is a comments link at the end of each article. You can use this feature to tell us and other readers what you enjoy about the articles or how you would adapt them, perhaps to make them more applicable in your country.

**Eleanor Hayes**
Editor, *Science in School*
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# Forthcoming events

*29 January - 12 December 2007*
**Many UK venues**
**Lectures: Institute of Physics Schools Lecture Series 2007**
The science of light and colour is fantastically important in an enormous number of areas: from observing and understanding the Universe in astronomy; to diagnosis and treatment processes in medicine; to efficient communications and signal processing in industries.
The Institute of Physics 2007 schools lecture will be presented by Dr Pete Vukusic, a researcher and lecturer at the University of Exeter's School of Physics. He is one of the leading scientists in the world involved in broadening our understanding of how nature uses and controls the flow of light and colour.
Light Fantastic: the Science of Colour will open pupils' eyes to the basic concepts of the science of light and colour and show how technology is making the most of light's astonishing properties. This presentation will include demonstrations, hands-on activities and movie clips to help shed light on the science of colour. The lecture lasts an hour and is suitable for 14-16-year-olds.
*More information: www.iop.org*

*26-27 February 2007*
**European Molecular Biology Laboratory, Monterotondo, Italy**
**Lectures: Stem Cells – from Basic Research to Clinical Applications**
Organised by Cusmibio in collaboration with the European Molecular Biology Laboratory in Monterotondo, this course is intended for high-school science teachers and PhD students in the biological sciences. Given by prominent scientists in the field of stem cells, from basic research to clinical applications and bioethics, the lectures (in Italian) will cover:
- Stem cells: biology and clinical applications
- Neuronal stem cells
- Stem cells and neuronal diversity
- Epithelial stem cells in regenerative medicine
- Cancer biology and epigenomics
- Bioethical and legal aspects of embryonal stem-cell research.

*More information: www.cusmibio.unimi.it*

*Until 2 March 2007*
**Worldwide**
**Competition: Catch a Star!**
This competition, organised by the European Organisation for Astronomical Research in the Southern Hemisphere (ESO) and the European Association for Astronomy Education, aims to encourage students to work together, learn about astronomy and discover things for themselves by researching information.
Student teams can write a project about a chosen topic in astronomy, selecting an astronomical object such as a nebula, star, planet or moon, or a more general theme such as 'black holes' or 'star formation'. Younger students may take part in a drawing and painting competition. Prizes include a trip to visit ESO's Very Large Telescope facility on the Paranal mountain-top in Chile.
Deadline for entries: 2 March 2007.
*More information: www.eso.org/catchastar/*
*Contact: eduinfo@eso.org*

*9 March - 30 April 2007*
**UK**
**Competition: SciNews Writing Competition**
Are you a budding science reporter, aged 14-16? Why not enter our science writing competition and win a day with the Cancer Research UK press team? To take part, write a news story about something related to health or medicine that has recently been in the headlines.
Entries should be no more than 300 words and the competition is open to all schools in the UK. Deadline for entries: 30 April 2007.
*More information: http://info.cancerresearchuk.org*

*15-16 March 2007*
**Riga, Latvia**
**Conference: Didactics of Science Today and Tomorrow**
This conference will consider the development of science didactics in Latvia, current problems in science education, as well as its place in pedagogy and natural sciences. Discussions will take place in plenary sessions and workshops. University teachers, scientists, school teachers, doctoral and masters students and others interested in the issue are invited to participate.
The conference is organised by the Riga Teacher Training and Educational Management Academy, the Association of Biology Teachers of Latvia and the Natural History Museum of Latvia. Conference fee: €10 (5-7 LVL for participants from Latvia). Deadline for submission of abstracts: 1 February 2007.
*More information: www.rpiva.lv*
*Contact: Janis Gedrovics (janis.gedrovics@rpiva.lv)*

*25 March - 1 April 2007*
**Potsdam, Germany**
**Competition: European Union Science Olympiad**
The European Union Science Olympiad (EUSO) is a team competition for EU secondary-school science students (aged 16 or under). The intention is:
- To challenge and stimulate gifted science students to develop their talents and to promote their careers as scientists
- To provide invaluable experience for students who may take part in the International Science Olympiads
- To offer the opportunity to compare the syllabi and educational trends in science education within the EU member states, which could help improve science education at national levels.

The deadline for applications is 1 March 2007.
*More information: www.euso2007.de*
*Contact: Michale Cotter, ESO President (michael.cotter@dcu.ie)*

*14 March 2007*
**Keele, UK**
**Training course: Motivating the Disaffected in Science**
This new course views learning from the pupil's perspective and seeks engaging solutions to motivate and inspire adolescents to succeed in science. Pop culture, movies and games can all be applied in new teaching and learning approaches. This course will share outcomes from classroom-trialled activities and recent research findings to provide participants with immediate ideas for the classroom.
*More information: www.slcs.ac.uk/wm/*
*Contact: enquiries@slcwm.keele.ac.uk*

*19 March 2007*
**Warwickshire, UK**
**Training course: Learning Skills in Science**
This training course aims to:
- Enhance learning skills for science among secondary-school students
- Provide teachers with resources that can be easily integrated into a variety of scientific subjects
- Design flexible teaching and learning tasks suitable for different levels of students and a variety of learning styles.

*More information: www.slcs.ac.uk/wm/*
*Contact: enquiries@slcwm.keele.ac.uk*

*20 March 2007*
**Worcestershire, UK**
**Training course: Learning Skills in Science**
This training course aims to:
- Enhance learning skills for science among secondary-school students
- Provide teachers with resources that can be easily integrated into a variety of scientific subjects
- Design flexible teaching and learning tasks suitable for different levels of students and a variety of learning styles.

*More information: www.slcs.ac.uk/wm/*
*Contact: enquiries@slcwm.keele.ac.uk*

*Until 30 March 2007*
**Europe-wide**
**Competition: Marine Biodiversity**
To celebrate Biodiversity Day, MarBEF (Marine Biodiversity and Ecosystem Functioning) are launching a competition for European children and adults to capture marine biodiversity by:
- Drawing a picture
- Designing a mascot
- Taking a photograph.

Winners will receive prizes of up to €100, and their entries may be published online and in the MarBEF newsletter, which is delivered to almost 1000 scientists across Europe.
*More information: www.marbef.org/outreach/kids/competition.php*
*Contact: Chris Emblow (cemblow@ecoserve.ie)*

*2-6 April 2007*
**European Synchrotron Radiation Facility, Grenoble, France**
**Science teaching festival: Science on Stage 2**
Science on Stage offers European science teachers the chance to exchange successful and innovative teaching methods and materials. In 2006, national competitions, workshops and events in 30 participating European countries raised awareness of best practices in science teaching and identified exceptional teaching projects and outstanding educators in each country.
At the European science teaching festival at the European Synchrotron Radiation Facility in Grenoble, France, 500 teachers selected from the 30 countries will take part. The event will showcase the very best of today's science education and serve as a discussion forum for relevant topics.
*More information: www.scienceonstage.net*
*Contact: Physics.on.Stage@esa.int*

*10-12 May 2007*
**Pavilion of the Future, Seville, Spain**
**Science fair**
During the three-day science fair, students from primary and secondary schools as well as universities will present science projects that they have prepared with their teachers. The projects will be communicated and exhibited to visitors in an interactive, engaging and entertaining way. National private and public institutions will also present their current research.
Organised by the Andalusian Society for the Popularisation of Science (Sociedad Andaluza para la Divulgación de la Ciencia), the science fair aims to help teachers, students and scientific communities share scientific experiences, as well as to promote science in our society. Most participants will be from Andalucia, but everyone interested in presenting and developing this kind of educational science project is welcome to attend. The working language will be Spanish.
*More information: www.cienciaviva.org*
*Contact: Maria Jose Garcia Belmonte (mariajosegarciabelmonte@hotmail.com)*

*11 May 2007*
**Museum of Industry, Oberhausen, Germany**
**Conference: Innovative Technologies Move Europe II**
Eleven teams from four different countries participated in the European school project, Innovative Technologies Move Europe. The teams of teachers and students developed creative and innovative projects in their schools, addressing one of the following topics:
- Movement – constructing a means of locomotion
- Energy requirement – one litre of water
- Energy – constructing a model of a system that converts regenerable energy into electric power
- Chaos – representation of chaotic movement using elementary means.

Teachers are invited to join this final meeting, where the students will present the results in English.
*More information: www.science-on-stage.de*
*Contact: info@science-on-stage.de*

*7 June 2007*
**Rugby School, Rugby, UK**
**Conference: 19th Annual Meeting for Teachers of Physics in Schools and Colleges**
Organised by the Institute of Physics, this is a one-day meeting for teachers of physics in schools and colleges, and for teachers in training. The main purpose is to bring together physics teachers from both state and independent schools to learn about the latest developments in physics and physics education. Three lectures are given by leading research physicists and by physics education experts, together with a series of six hands-on workshops, discussion sessions and a teacher exchange of news and information. The meeting also provides an opportunity for equipment suppliers, publishers and awarding bodies to communicate their new products. Most participants come from England and Wales, but teachers from further afield are very welcome. Conference fee: £30 including lunch (concession for new and trainee UK teachers: £15).
*Contact: Chris A. Butlin, Chairman of the Institute of Physics School Physics Group (ChrisAButlin@aol.com or +44 (0)1904 607 169)*

*14 June 2007*
**Technopolis, Mechelen, Belgium**
**Conference: PENCIL Final Science Teachers' Conference**
The European PENCIL project aims to strengthen the operational relations between informal science education in science centres and museums, and in schools. Findings from the 14 pilot projects will be shared during this conference. Practical tools together with new approaches will be communicated, and there will be many workshops to make it easy to grasp and test new concepts and practices.
Science teachers and science-centre explainers are particularly welcome.
*Contact: info@ecsite.net or Karl Sarnow (karl.sarnow@eun.org)*

*26-31 August 2007*
**Opatija, Croatia**
**Conference: GIREP-EPEC: Frontiers of Physics Education**
For the first time, the GIREP (International Research Group on Physics Teaching) Seminar is organised as a joint event with the European Physics Education Conference (EPEC).
Whereas GIREP traditionally gathers experts and practitioners in educational physics, EPEC is a young conference organised by the European Physical Society, which attracts the top physicists in Europe.
The joint conference will bring together physics teachers from schools and universities across Europe, encouraging dialogue and the exchange of best practice in physics education.
Teachers are invited to join this conference. (Theme to be arranged, the working language will be English.)
*More information: www.ffri.hr/GE2/*
*Contact: ge2@ffri.hr*

*14 September 2007*
**Universität Kassel, Germany**
**Workshop: English-language biology and chemistry lessons in German schools**
Biology and chemistry teachers who teach in English are invited to a workshop organised by the Verband deutscher Biologen and the Vereinigung der Schulen mit deutsch-englisch bilingualem Zug in gymnasialen Bildungsgängen in Hessen. Participants who already have experience in bilingual teaching are requested to submit worksheets or teaching ideas for a joint collection of teaching materials. Teachers from outside Germany are warmly welcome.
Workshop fee: €10
*Contact: Matthias Bohn (mbohnde@aol.com)*

*Until 30 November 2007*
**Italy, Austria and Switzerland**
**Competition: Junge Forscher gesucht! – Giovani ricercatori cercansi! (Wanted: young researchers!)**
In this search for talented young researchers, young people are required to develop scientific projects on many topics, including art and music. Regional finalists, selected on the basis of a report they submit, present their project to an international jury and the public. Prizes of €1500-3000 are awarded.
The competition is open to people aged 16-20, living in South Tyrol (Italy), Trentino (Italy), Tyrol (Austria) or Grisons (Switzerland) and is held in the regional languages German and Italian.
To enter the next competition, register before 30 November 2007. The final event will take place in March 2008 at the University of Innsbruck, Austria.
*More information: www.explora-science.net/wettbewerb/*

*Throughout 2007*
**Schullabor Novartis, Basel, Switzerland**
**Workshop: 'Gentechnik Erleben' (Experience Genetic Engineering)**
These workshops focus on practical laboratory work, but background information is given for all experiments. Students isolate plasmid DNA from bacterial cultures and digest it with restriction enzymes. The resulting DNA fragments are separated and visualised by gel electrophoresis. Students should already have the necessary theoretical background and be over 17 years of age. The workshops are free, are in German or English (on request) and have a maximum of 20 participants.
*More information: www.schullabor.ch*
*Contact: gesche.standke@novartis.com*

*Throughout 2007*
**Schools and other venues in England**
**Roadshow: Cool Seas**
Run by the Marine Conservation Society, the Cool Seas Roadshow will visit 150 primary schools throughout England between September 2006 and March 2008. It entertains and educates primary/junior school children about England's spectacular marine wildlife, using life-size inflatable models of whales, dolphins, sharks, turtles, seals and porpoises in dynamic presentations given by a marine wildlife education specialist. The roadshow takes a full day at each school, and is free.
Each school that is visited receives printed materials and web-based resources, including an activity booklet and bookmark for every pupil, and a poster for every classroom. The web-based resources can be viewed here: www.mcsuk.org/coolseas/
The project also has funding for 37 visits to English venues other than schools, mostly in summer 2007. If you have a large and suitable audience who would like a visit from the Cool Seas Roadshow, please get in touch.
*More information: www.mcsuk.org/mcsaction/education/cool+seas+roadshow*
*Contact: Angus Bloomfield (angus.bloomfield@mcsuk.org)*

*Throughout 2007*
**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*

*Throughout 2007*
**Glasgow Science Centre, Glasgow, UK**
**Free teacher visits**
Teachers, classroom assistants, nursery teachers and technicians are invited to visit the Glasgow Science Centre free to explore and investigate what's on offer.
*More information: www.glasgowsciencecentre.org*
*Contact: +44 (0)871 540 1003*

*Throughout 2007*
**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 the lively travelling 'Science Circus'. Science Circus activities consist of amazing live science shows and interactive exhibits delivered at your venue.
*Contact: +44 (0)871 540 1004*

*Throughout 2007*
**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 (ages 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:*
*Pembrokeshire Darwin Science Festival*
*Contact: Marten Lewis*
*(M.B.Lewis@pembrokeshire.ac.uk)*

*Throughout 2007*
**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 (ages 8-11), costing £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 (ages 8-11)
- Climate change workshop for Key Stage 2 pupils (ages 8-11)
- Marine litter workshop for Key Stage 1 pupils (ages 4-7).

*More information: Pembrokeshire Darwin Science Festival*
*Contact: Marten Lewis*
*(M.B.Lewis@pembrokeshire.ac.uk)*

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**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, website and contact email address, to editor@scienceinschool.org**

# Launch event of Cinema and Science (CISCI)

Science and science fiction are the basis of many popular films. **Rafael Reyeros** from the CISCI project describes the launch of this Internet database to help teachers use film clips to illustrate, discuss and debate science in their lessons.

*Image courtesy of CISCI*

CISCI (Cinema and Science) is an educational project providing a new classroom resource for 10 to 18-year-old pupils. It combines the two most popular forms of media among youngsters, namely movies and the Internet, and aims to stimulate interest in science and innovative teaching methodologies. CISCI is setting up a free online database of video clips from documentaries and popular movies that serve to illustrate scientific and mathematical concepts. Students and their teachers will be able to analyse the scientific content of these clips, both by using films that accurately portray aspects of science and by engaging in discussion and debate over pseudo-scientific films. Each entry in the database provides teachers with all the information required for a classroom discussion of the scientific concepts. Depending on the copyright situation, entries include either the video clip itself or the relevant links to purchase the film.

The project was launched on 15 November 2006 at the Università degli Studi di Milano, Italy, in the presence of Stephen Parker from the European Commission, the rector and vice-rector of the Università degli Studi di Milano, members of the CISCI consortium, interested teachers and educational experts from Italy and all over Europe. The event consisted of an institutional welcome followed by presentations from educational experts. Heinz Oberhummer from the Vienna University of Technology and co-ordinator of CISCI then gave his presentation on the structure of the project, its objectives and examples of how to use the resource in classrooms. The excitement and interest after the presentations were reflected in a vivid and lengthy discussion, and many positive comments were received from attending teachers. After the presentations, attendees were offered the chance to test the CISCI website[w1], as well as engage in some more discussions over a light buffet meal.

CISCI is part of the NUCLEUS cluster[w2], funded under the European Commission's Sixth Framework Programme in 'Science and Society'. CISCI was online in seven European languages (English, German, Italian, Czech, Slovenian, Estonian and Latvian) with more than 130 content units in each language by the end of 2006. The number of content units in CISCI is expected to grow on a weekly basis.

If you are interested in contributing content units to CISCI, please contact the co-ordinator of the CISCI project, Heinz Oberhummer (heinz@oberhummer.at). For further details and to view content, please visit the CISCI website[w1].

## Web references

w1 - CISCI website: www.cisci.net

A sample content unit from CISCI is available in this issue of *Science in School*: see *Erin Brockovich* on page 67.

w2 - The NUCLEUS cluster of projects includes not only CISCI, *Science in School* and Science on Stage, but also the PENCIL project (see *Explor@mobile: using new technologies to teach science to teenagers* on page 35), the Volvox network for bioscience education, and Scienceduc, a project to improve primary-school science teaching. For further information, see:

Science on Stage website: www.scienceonstage.net

PENCIL website: www.xplora.org/ww/en/pub/xplora/nucleus_home/pencil.htm

Volvox website: www.eurovolvox.org

Scienceduc website: http://scienceduc.cienciaviva.pt

## Resources

The launch event can be viewed online here: www.brera.unimi.it/eng/iniziative/cisci/Workshop06.html

# Ethics in research

Is it acceptable to use human embryonic stem cells in research? What about live animals? Professor Nadia Rosenthal, head of the European Molecular Biology Laboratory in Monterotondo, Italy, talks to **Russ Hodge** about the ethics of her research.

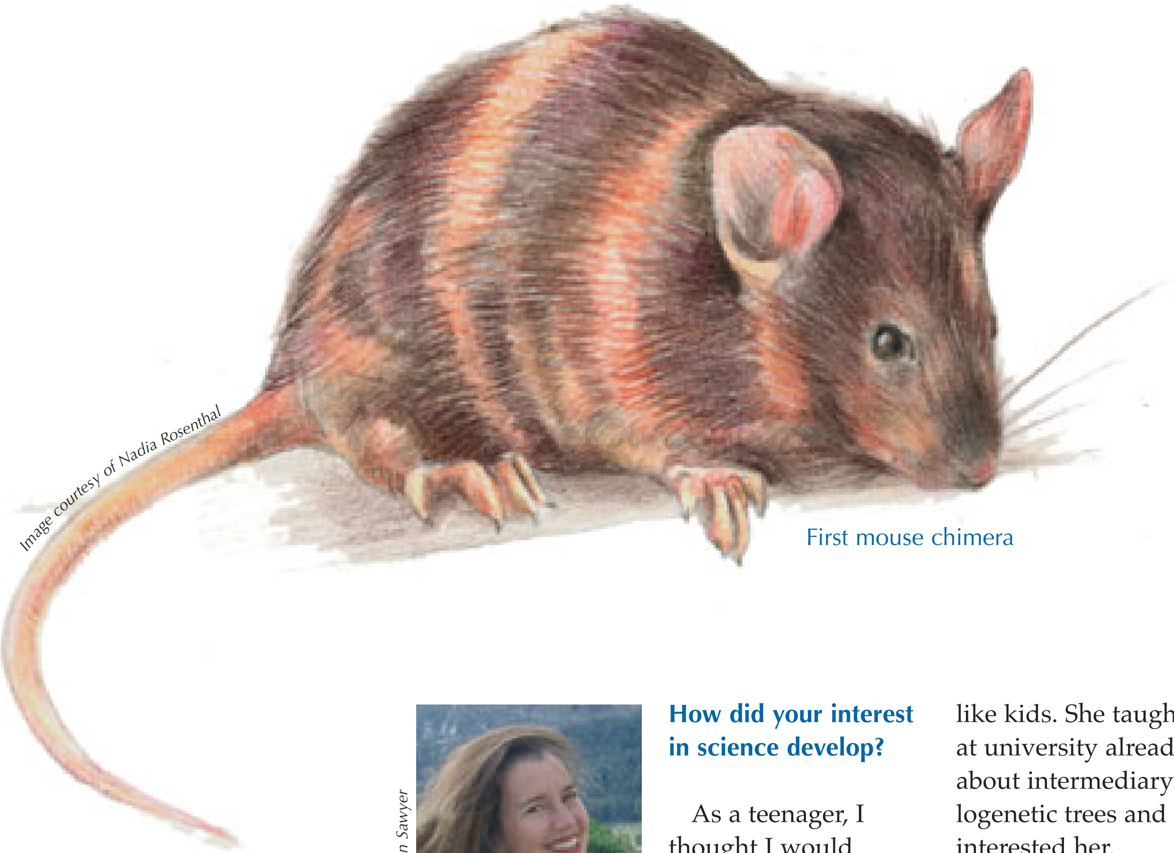

Image courtesy of Nadia Rosenthal

First mouse chimera

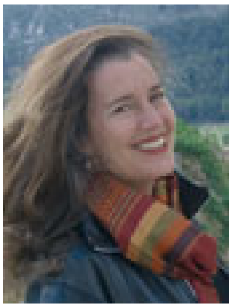

Image courtesy of Alan Sawyer

Nadia Rosenthal

## How did your interest in science develop?

As a teenager, I thought I would become an artist. My parents worked in the theatre and were musicians, and it seemed natural. Nonetheless, I was drawn to the life sciences, especially after an excellent course in advanced biology. Our teacher had a very uncompromising attitude towards her students: she didn't think that we should be treated like kids. She taught us as if we were at university already, so we learnt about intermediary metabolism, phylogenetic trees and other topics that interested her.

I was fascinated by the crystalline quality of knowledge in biochemistry. My particular interesting was in pattern formation – in developing organisms and across phyla – and I figured that it would have a similarly crystalline explanation, if only I could find the right textbooks. So I arrived at university convinced that within a few years, I would have the whole explanation of pattern formation. Little did I realise that it would take another 25 years – and in fact we are still working on it.

By the time I realised that the explanation would take much longer to find, I was hooked by science and couldn't imagine any other profession. I had become particularly interested in developmental biology, after reading an article about how limbs are formed. It seemed that there was very little known about limb formation, but I was fascinated by the problem, which seemed to encapsulate my interest in pattern formation.

**Some animals are able to regenerate limbs, but mammals aren't good at that, at least as adults. Why is that?**

We don't really know. Lower vertebrates can regenerate whole limbs, fins and tails – even jaws and parts of their hearts if they are injured. In contrast, we can't regenerate much more than a fingernail. The current explanation is that all organisms have some fundamental capacity to regenerate, but that in higher vertebrates, regeneration is prevented by scar formation. If your finger is cut off, you have to close the wound very rapidly. Our immune system launches a massive inflammatory response to keep out infections; this only produces a very useful scar, which stops the bleeding and prevents the wound from getting infected, but also physically blocks the regeneration of the missing limb.

In contrast, a salamander forms a large group of cells called a blastema, capable of developing into just about any part of the limb. The amazing thing is that the cells in the limb appear to know where they are: if the salamander's limb is cut off close to the body, the blastema regenerates the entire limb. Instead, if the salamander loses its limb at the wrist, the blastema makes just the hand and the fingers. There are theories that gradients of certain molecules are higher at the proximal end of a limb (close to the body) and lower at the distal end, and that these gradients tell the cells which part of the limb they are in. More and more of these molecules are now being investigated in animals such as newts and fish; with the advent of high-throughput sequencing, we may be able to learn what is different about these organisms at the genomic level and maybe even why we can't regenerate our limbs.

Of course, it's not only limbs that regenerate. Studying fish, scientists are also learning more about the molecules that guide their heart regeneration and have recently identified factors that are also present in mammalian hearts. When some these factors are introduced into injured mouse heart, they appear to improve wound healing, which is very exciting, but it's early days. I say that with great disappointment, because I am approximately 30 years older than I was when I first answered this question. And the answers I'm giving you now are only sophisticated versions of the answers I read in the article that got me involved in this topic in the first place. It's a mystery.

**To understand tissue regeneration in mammals, you have worked with stem cells. Could you explain the connection?**

The kind of stem cells involved in regeneration are, of course, adult stem cells: stem cells used to replenish the tissues in the adult body when we are injured or diseased, or as we age. In particular, we look at stem cells in mouse skeletal muscle, as these cells have a high capacity to regenerate muscle tissue, even if they cannot regenerate an entire limb.

In contrast, the blastemal cells in the salamander and other lower vertebrates are pluripotent: they have the capacity to make all sorts of tissues. Paradoxically, those blastemal cells appear to come, at least in part, from the de-differentiation of skeletal muscle itself. This involves a much more dramatic reprogramming than we see in the stem-cell pool of mouse muscle.

BACKGROUND

## Send us your suggestions

We welcome your suggestions for future feature articles for *Science in School*. Which scientists in your home countries do you find particularly interesting? Why? What is their area of research? If possible, please include their contact details. Send your suggestions to editor@scienceinschool.org

**Adult stem cells don't seem to cause an ethical debate. But the topic of stem cells generally has raised a lot of ethical concerns.**

One area of ethical concern that does overlap with our studies on adult stem cells is reprogramming, which allows embryonic stem cells to generate virtually all the tissues in the body. We try to reprogramme adult mammalian stem cells to behave more like youthful pluripotent cells – in their ability to regenerate a wider range of tissues. Some of that programming has been moderately successful, but in general, adult stem cells do not have as efficient a reprogramming capacity as embryonic stem cells – at least in mammals.

The ultimate embryonic stem cell is of course the fertilised egg, which turns into a whole organism and is thus the source of every single tissue type and every cell type in the body. Scientists have shown that the environment of the egg can reprogramme even a fully differentiated adult nucleus to be pluripotent. This is the basis of therapeutic cloning, if the adult nucleus introduced into the egg comes from a patient. The resulting embryonic stem cells can participate in the generation of virtually any tissue type as the new 'personalised' reprogrammed egg divides. To better understand this process, we use mouse embryonic stem cells, harvesting embryos and destroying them to make stem cells. Translating this into a human scenario – harvesting human embryos and destroying them in the process of making what might be therapeutically very valuable stem cells – would cause a great deal of concern.

However, human embryonic stem cells are not identical to mouse embryonic stem cells in their function, gene expression patterns or capacity to be reprogrammed. This means that without studying human embryonic stem cells, we will never be able to reprogramme adult stem cells in humans – which would enable us to use them more extensively in research and thus avoid the prickly issue of human embryonic research. We have got to bite the bullet and decide how best to monitor research on embryonic cells from humans. We certainly don't seem to have an ethical problem with *in vitro* fertilisation (IVF), which requires the sacrifice of many human embryos, since only a few of the embryos harvested from a woman having IVF are actually ever implanted. The rest of these embryos are often discarded. Why, then, is there such resistance to the idea of using those otherwise unused cells for research that could benefit humans?


Image courtesy of Nadia Rosenthal

Daemon

### You have worked for a long time with animals, which also raises ethical issues. How do you feel about that?

I have chosen to study animals, which means that I have to work with animals. We have chosen the mouse for a number of reasons. It's got a very rapid gestation period and comes to sexual maturity very rapidly, so that we can work on many generations of mice within a short time. Also, we have learnt over the years to manipulate the mouse genome to recapitulate some of the genetic disorders we see in humans; this helps us learn how best to treat mice and thus develop therapeutic strategies for that same disease in humans. But I have to admit to the fact that I'm very deeply tied to my organism of study: I am a mouse fancier. I believe that the more you understand your organism, the better you can understand what happens when you perturb or manipulate it.

Much of my work has actually made mouse life better: we tended to focus on making mice even better than normal mice. Mice that live longer, mice that are stronger, mice

Image courtesy of Nadia Rosenthal

Escher Mice

that can have heart attacks and regenerate their hearts. In general, it's a little bit easier from an ethical point of view to make a mouse healthier rather than to make it ill. Nevertheless, I can't hide the fact that many of the changes we make render them less healthy than a normal mouse. We also have to sacrifice mice, so that we can study their tissues and organs. Of course, we keep and sacrifice our animals in a very humane fashion: they certainly suffer less than any animal in an abattoir suffers when it is killed for food.

Nonetheless, there is a definite ethical issue, which is whether we can justify using and then sacrificing animals for research, when we are aware that without this research these animals would never exist and would never be manipulated in these ways. It's a very complicated issue. I find it to be, if anything, more complicated than the embryonic stem-cell issue because embryonic stem cells are not human beings, they are cells. An embryonic mouse stem cell doesn't elicit the same ethical concerns in me as killing a live animal, a mouse, does.

This is one of the reasons that I have become involved in many large European-based mouse research projects: so that we can use animals as efficiently as possible. We do this by making sure that all European mouse research conforms to single health and handling standards, and that we make only one version of a particular mutation, then all use it and share our information. This enables us to get more data from fewer animals, limiting the number of animals we need to raise, observe and then kill. Minimising the number of animals used and minimising their suffering is probably the most ethical thing we can do.

## Resources

Nadia Rosenthal was one of two stem-cell researchers to deliver the 2006 Howard Hughes Holiday Lectures on Science for high-school students. The lectures are available online and the DVD can be ordered on the website of the Howard Hughes Medical Institute: www.hhmi.org/lectures

# Silken, stretchy and stronger than steel!

Could spider silk be the answer to medical and military challenges? **Giovanna Cicognani** from the Institut Laue-Langevin and **Montserrat Capellas** from the European Synchrotron Radiation Facility, France, investigate Christian Riekel and Tilo Seydel's research into this remarkable material.

Image courtesy of Richard Davies

Female golden orb spider (*Nephila edulis*)

Biomimetics is a hot topic in modern science, but the idea that humans can exploit evolutionary designs is nothing new. More than 400 years ago, Leonardo da Vinci was studying birds to inspire his flying machines. Now scientists in France are using cutting-edge techniques to unravel the secrets of a material that has been around for more than 150 million years.

For centuries, we have envied spiders for their ability to create elegant webs. Although fragile in appearance, these webs can stop insects in mid-flight and are robust enough to restrain prey without the silken threads breaking. The threads which make up these remarkable structures are biopolymers. However, unlike man-made polymer fibres such as Kevlar®, which is made by forcing a hot and acidic polymer solution under pressure through small orifices (spinnerets) into a coagulation bath followed by washing, drawing and drying steps, silk is produced at ambient temperature and spun from aqueous solution. A spider-web's ability to catch insects is due to the silk's unique combination of mechanical properties: strength, extensibility (up to 30%) and, most importantly, toughness, or resistance to breakage. Spider silk may be six times stronger than steel by weight, but it is its toughness that makes it so special, as it allows it to absorb a large amount of energy without breaking. Man-made materials such as Kevlar are strong, but lack this specificity. Moreover, unlike Kevlar, spider silk is biodegradable and recyclable: when repairing their webs, spiders frequently eat damaged parts of the web and absorb the nutrients.

These special characteristics make spider silk of interest to many different research fields. A polymer based on spider silk could be used in medicine, as a high-strength, non-toxic suture, or in ligament repair, because the fibre not only does not tire when frequently flexed, but also can withstand regular impact and great pressure. The military sector is also investigating this material because its ability to dissipate energy could make it ideal for lightweight armour.

But before we can produce and use artificial spider silk, we need to understand what confers its unique mechanical properties. Recent experiments at the Institut Laue-Langevin (ILL) and the European Synchrotron Radiation Facility (ESRF) in Grenoble, France, have used neutron scattering and synchrotron radiation to investigate the microscopic characteristics of spider silk. This has provided researchers with a new insight into the silk's structure, which in turn confers its mechanical properties. The two techniques, neutron scattering and synchrotron radiation, complement each other. Whereas synchrotron radiation, a type of very high-energy X-ray irradiation[w1], enables a single silk fibre to be studied as it is extruded from a living spider, neutron scattering allows us to identify differences in the organisation of proteins and their accessibility to water, which has a strong influence on its mechanical properties. Neutrons, unlike synchrotron radiation, are scattered differently by normal water containing hydrogen and heavy water containing deuterium. By exposing a silk fibre to heavy water, we can determine from the way in which it scatters the neutrons fired at it which hydrogen atoms have been replaced with deuterium atoms. This in turn gives information about the chemical context in which the atoms are found.

The results, obtained by a joint ESRF and ILL team, in collaboration with the Department of Zoology at the University of Oxford, UK, showed that spider silk is a hierarchically organised material. Its composite biopolymer structure is made of proteins which are composed almost entirely of repetitive motifs formed by amino acids such as alanine and glycine. The alanine motifs form crystalline domains, which are separated by non-crystalline, glycine-rich domains. These crystalline and non-crystalline domains are organised in nanofibrils, which are embedded in an amorphous protein matrix. Scientists are still debating how this structure results in the amazing mechanical properties of spider silk: is it due to 'molecular springs' in the amorphous protein matrix or to the properties of an amorphous network, reinforced by crystalline domains (see diagram)?

Scientists have been able to artificially produce the spider silk proteins themselves for some time, and we now understand in greater, although incomplete, detail how the proteins are organised to confer the impressive toughness of spider silk. Nonetheless, further work is necessary to understand – and replicate – the mechanism of protein aggregation and fibre formation. In the spider, the silk proteins are synthesised and secreted in a gland as a kind of a viscous liquid crystal. This liquid is then pushed through a long duct to a spigot at the end of the spider's spinneret. On its way out, a thickening process and pH change alter the viscous liquid, resulting in the aggregation of the silk proteins. The spider is even capable of resorbing and recycling water during the thickening process. Other factors, such as the movement of the spider's body, also play an important role in the spinning process.

Exactly how these factors interact, and how they could be mimicked to produce artificial spider silk in laboratories, is a question that continues to occupy scientists. At ESRF, ILL and other institutes around the world, biomimetic research continues into a man-made alternative to one of the most remarkable natural materials – and with it, a new generation of cheaper and more ecological materials.

Nanofibril structure

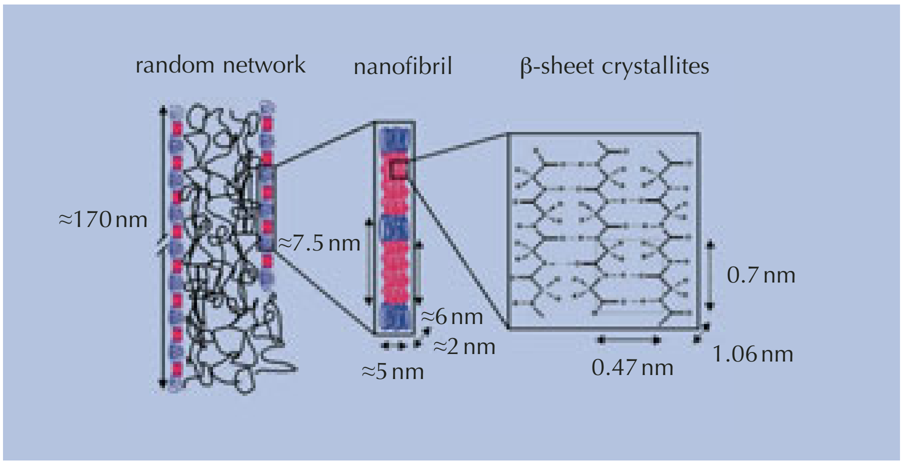


*Image courtesy of Daniel Sapede*

Image courtesy of Richard Davies

Female golden orb spider (*Nephila edulis*)

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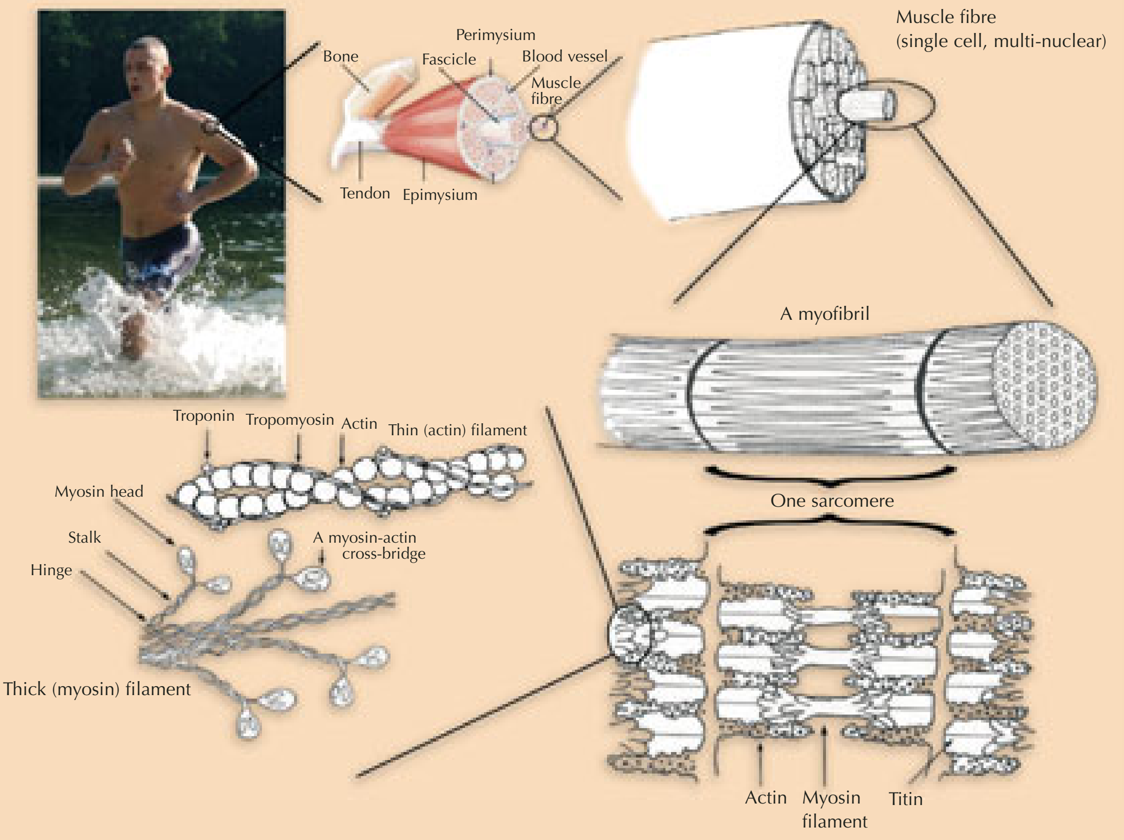
REVIEW

This article could be used in chemistry, biology and physics lessons, for children aged 11-17. In particular, it is applicable to considerations of crystallography, lattice structures and the role of pH in protein aggregation.

*Eric Demoncheaux, UK*

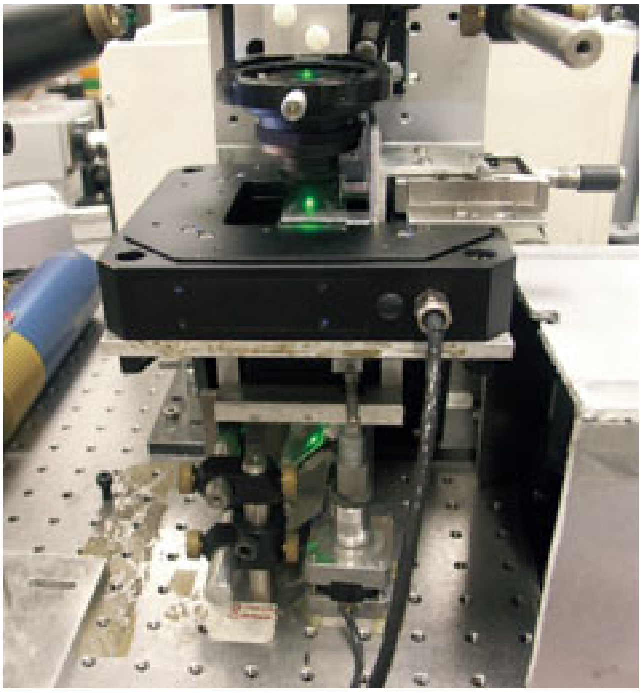
# How do muscles produce work? Using optical tweezers to study molecular machines

**Alexandre Lewalle** from King's College, London, UK, pushes back the frontiers of our knowledge of motors – at the molecular level.




Myosin motor molecules and actin filaments are the most basic constituents of muscle tissue. They form overlapping filaments in the cells that slide past one another to make the muscle contract

*Image courtesy of Raul654; image source: Wikimedia Commons*



The optical tweezers apparatus

Image courtesy of Alexandre Lewalle

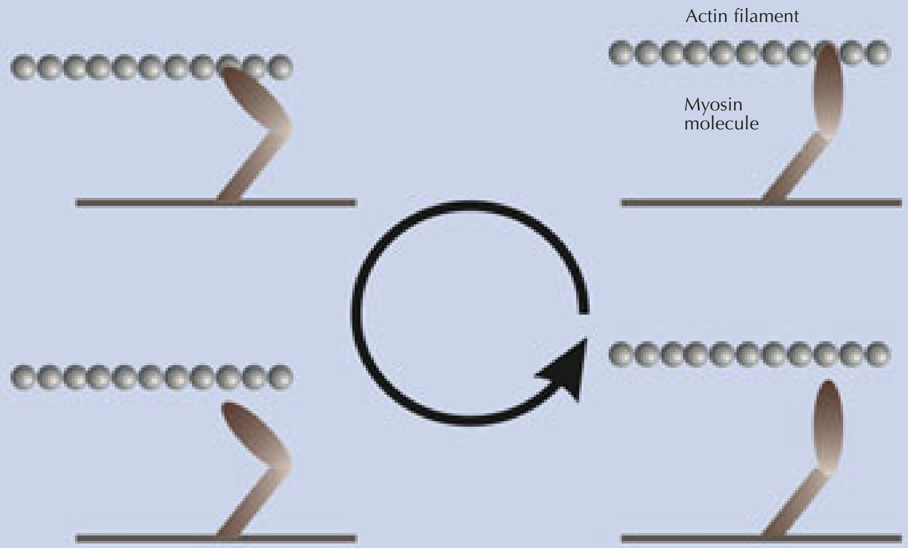
There is little mystery in how we lift a shopping bag: we bend, grasp and pull. As we know, our body transforms chemical energy into mechanical work, like a motor powered by fuel. But surely our body isn't an engine made of gears and pistons – or is it? As it turns out, at the microscopic level, every cell in our muscles is made up of millions of proteins that indeed are tiny motors comprising only one type of molecule, no bigger than a few nanometres. These proteins, called myosin, are arranged in a regular pattern and work in unison to produce forces and movement many times greater than those they achieve individually. There is currently much enthusiasm for nanotechnology, the field that explores and seeks to control the microscopic world. In my lab at King's College, London, we use an apparatus called 'optical tweezers' to manipulate and study these motors individually. Microscopic man-made machines may still be the stuff of science fiction, but through experiments of this kind, nature may well teach us our first lesson.

By understanding how these molecules work in detail, we can gain insight into the ways that nature, through evolution, has engineered many different forms of life from remarkably few templates. Many kinds of single-molecule 'machines' exist in nature, and the tasks they perform are as varied as they are vital. They enable living cells to function, move and reproduce. For example, some of them transport nutrients across the cell by 'walking' along an intracellular railroad network. Molecular-sized motors probably play a crucial role in cell division by separating chromosomes after they have replicated. Other types of motors rotate the flagellum that propels sperm cells and some bacteria. Many of these motors are structurally very similar, and yet they perform distinct tasks.

Muscle contraction is achieved by sliding two kinds of filaments past one another. One of these filaments is made of myosin (the motor), the other of a substance called actin (see figure). The two kinds of filaments overlap in the muscle cells to maximise their interactions. Just like a more familiar engine, myosin operates in a cyclical manner, as shown in the figure on the next page, to ensure energy is used efficiently. During each cycle, the myosin molecules first bind to the actin filament, bridging the gap between the two filaments. Then, they 'burn' fuel by reacting with one ATP molecule (the fuel of most biological processes). This reaction releases energy and makes the myosin molecules undergo a transformation that causes them to swing their 'lever arm' structure and pull on the actin filament. They then release the actin filament and swing the lever arm back to its original position, ready for the next cycle. During each cycle, the two filaments slide past each other by a short distance – this is the basis of muscle contraction. The forces and movements produced by a single cycle are minute, but the combination of millions of myosin molecules acting simultaneously amplifies the effect by many orders of magnitude.

Biologists have been studying muscle and myosin for many decades, but for all our present knowledge, there still remains a vast region of mystery: how strongly do the individual myosin molecules pull and over what distance? How is the duration of one cycle affected by the chemical environment? We know that the total work done by the myosin molecule is strongly affected by the external force against which the motor has to pull, but the relationship between them is still poorly understood. Because of their small size, motor molecules like myosin react to their environment very differently than would larger molecules. For example, in contrast to a car engine, the effects of viscosity in the environment and of the continual

Image courtesy of Alexandre Lewalle




The myosin motor produces mechanical work by pulling on the actin filament in a cyclical manner: (1) binding to the filament, (2) pulling on the filament, (3) releasing the filament, and (4) refuelling (one molecule of ATP)

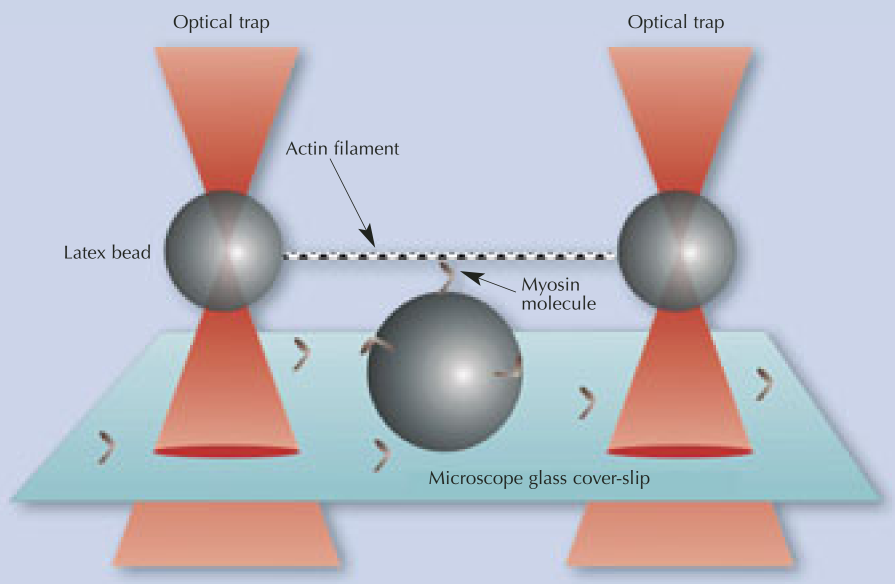
bombardment of water molecules (the phenomenon known as Brownian motion) are considerable. At the molecular scale, moving through water actually feels more like what we would experience when swimming in turbulent honey!

Scientists are insatiably curious. Theorists devise models to suggest how muscles work, but at the end of the day, only experiments will really push our understanding further. However, a detailed understanding of myosin cannot be gained by looking at whole muscles because what we see is only the overall effect of many myosin motors acting independently. What is needed instead is a way to control and examine the myosin molecules *in isolation*. But this is a monstrous challenge in itself. These are obviously not objects you can simply hold with a steady hand!

It is only in recent years that scientists have developed tools that allow them to manipulate single molecules, opening up new avenues of research and blurring the boundaries of traditional disciplines like physics and biology. The 'optical tweezers', or 'optical trap', use the effect by which a laser beam, when focused by the strong objective lens of a microscope, traps microscopic objects. This trapping effect works by exploiting the fact that photons carry momentum and therefore exert minute forces on particles. A small displacement of a particle away from the focus causes a deflection of the beam, and hence, by Newton's Third Law, the particle experiences a restoring force back towards the trap centre. This sensitive technique provides a direct handle on the individual molecules. The appeal of applying it to study myosin is that the forces exerted by the laser are of similar magnitude to those exerted by myosin itself.

Our experiment at King's College is designed to recreate, under the microscope, the basic unit of a contractible muscle. The aim is to investigate how a single myosin molecule responds to an external force applied to an actin filament via the optical tweezers. First we produce two traps by shining two laser beams into our microscope objective (see figure on opposite page). Each trap is then made to catch one micron-sized plastic bead that is specially coated to bind actin filaments. A single filament is caught and stretched between the beads, producing a kind of dumbbell. We now steer this dumbbell towards another bead that is stuck to the surface of our microscope cover slip and coated with myosin molecules. When the conditions are just right, we manage to make just one myosin molecule, located near the top of the central bead, interact with the actin filament in the dumbbell, just as it would do in a whole muscle fibre.

Interactions between myosin and actin can be detected by monitoring the positions of the two beads in the dumbbell. When myosin binds and pulls on the myosin (as illustrated in the figure above), the beads are displaced from the trap centres by a small but measurable distance. This displacement tells us not only how far the myosin motor has pulled the actin, but also how much force it has exerted against the strength of the two traps. Our measurements suggest that the average displacement from a single myosin molecule is about 10




The 'dumbbell' experiment. A single filament of actin is stretched between two plastic beads held in optical tweezers. The myosin molecule can then bind to the filament, and its working stroke is detectable from the positions of the two trapped beads

*Image courtesy of Alexandre Lewalle*

nanometres (a millionth of a centimetre), with typical forces of only a few piconewtons ($10^{-12}$ newtons). These values are important parameters in any theoretical model that tries to explain the physiology of muscles from the bottom upwards.

It goes without saying that these experiments require a good dose of patience. They also require the collaboration of scientists with very different domains of expertise. Biologists are crucial to connect the results of the experiments to the known physiological behaviour of muscles, and to ensure that the project remains on the right track. Physicists are equally important in properly setting up the optical and electronic components of the apparatus and in analysing the results quantitatively. As in any area of research, the frontiers of our knowledge are only extended by trying out new things and by being endlessly curious and inquisitive. So the next time you think there is nothing simpler than throwing a basketball, think again.

REVIEW

Nanotechnology is a fashionable subject in science fiction as well as in cutting-edge research and, in this interesting article, Alexandre Lewalle tells us about nanomotors in muscle cells (the tiny actin and myosin filaments) and about the ways in which they are investigated by means of nanotools (the optical *tweezers*).

The article, written in an enjoyable style with clear examples and vivid metaphors, is suitable for biology teachers willing to update their knowledge and for upper secondary school students interested in the forefront of research.

While the addressed topic is not part of the usual biology curricula, it is related to physiology and biochemistry, and it is a good example of current research in the biomedical field. It can be used to foster interest in science and encourage young people to continue their scientific studies.

*Giulia Realdon, Italy*

# Two hydrolytic enzymes and an epistemological-historical approach

Why are enzymes so special? How do they differ from inorganic catalysts? **Isabella Marini** from the University of Pisa, Italy, describes a classroom protocol to enable students to answer these questions for themselves.

## Can history and epistemology help us to teach science?

When students begin to learn about chemical reactions, they reason as alchemists, not as chemists: when they see a chemical reaction, they think in terms of transmutation (as alchemists did) and not of transformation (as the modern chemist does). As they learn, students re-run the development of human knowledge; this is a critical process that cannot be underestimated.

Although teachers need not necessarily teach specific lessons on the history of science, they must be aware of its importance. Science history and epistemology (the philosophy of knowledge) are fundamental because they, together with psychology, help us to understand what is required at each phase of the educational process. Recognising that humans have observed particular phenomena and have misinterpreted them for hundreds of years, and that the solution to these complex problems forms the basis of science, helps us to realise that many arguments are incomprehensible to our students without a gradual approach to new concepts.

When introducing the idea of enzymes to younger secondary school students, I wanted the students to discover for themselves what makes enzymes so special and so important. I chose amylase and invertase, two accessible enzymes whose catalytic activity can be easily detected without any instruments except the eyes.

## Some historical hints

In 1812, Kirchoff succeeded in hydrolysing starch by heating it with sulphuric acid. Surprisingly, the pH did not vary, suggesting that the acid did not take part in the reaction; however, its presence was indispensable.

Two decades later, Payen and Persoz performed an ethanol precipitation and isolated a white, water-soluble substance from germinating barley (Payen & Persoz, 1833). This substance, capable of hydrolysing starch, was named diastase. Diastase was later renamed amylase, but the suffix '-ase' has remained to indicate almost all the enzymes we know.

In 1835, Berzelius demonstrated that the germinating barley extract catalysed starch hydrolysis more efficiently than did sulphuric acid. He coined the term 'catalysis'; very small amounts of a catalyst increased the rate of a particular reaction without being used up. The rates of biochemical reactions could thus be explained; special catalysts in cells were able to operate in mild conditions. The same idea underlies these experiments.

## Amylases

To use the carbon and energy stored in starch, the human digestive system must first break the polymer down into smaller sugars. Salivary α-amylase (1,4-α-D-glucan glucanohydrolase; Enzyme Commission (EC) number 3.2.1.1) begins the digestion of polysaccharides in the mouth (the process is completed in the small intestine by the pancreatic amylase). It is a monomeric calcium-binding glycoprotein which randomly hydrolyses the α(1,4) glucosidic bonds in starch (see diagram).

β-amylase (1,4-α-D-glucan maltohydrolase, EC 3.2.1.2) catalyses the hydrolysis of the α(1,4) glucosidic bonds in starch, removing successive maltose units from the non-reducing ends of the chains. It is one of the major proteins found in the starchy endosperm of barley (*Hordeum vulgare*) grain and it is a key enzyme in the degradation of starch during brewing.

### Invertase

Invertase or sucrase (sucrose-α-D-glucohydrolase; EC 3.2.1.48) catalyses the hydrolysis of sucrose and maltose. Sucrose, commonly known as cane sugar, is a disaccharide composed of an α-D-glucose molecule and a β-D-fructose molecule linked by an α1-β2 glycosidic bond. When this bond is hydrolysed, an equimolar mixture of glucose and fructose is generated (see diagram). In yeast (*Saccharomyces cerevisiae*), invertase exists in intracellular and extracellular forms.

## Classroom protocol

### Materials

- Phosphate buffer, 50 mM, pH 7 (Buffer A). This is prepared by dissolving 3.55 g dibasic phosphate ($Na_2HPO_4$) in distilled water and titrating to pH 7.0 (with a pH meter) with hydrochloric acid (HCl) before adding distilled water to make the final volume up to 500 mL.
- Solutions in Buffer A: starch 10 g/L, sucrose 0.1 M, glucose 0.1 M and fructose 0.1 M.
- Iodine solution N/50. Distilled water is added to 20 g KI and 12.7 g iodine, to make the volume up to 1 L. This solution is diluted 1:5 with distilled water.
- Fehling solutions A (7 g $CuSO_4$ in 100 mL distilled water) and B (34 g potassium sodium tartrate and 12 g NaOH in 100 mL distilled water).
- 5 M sodium hydroxide (NaOH)
- 5 M hydrochloric acid (HCl)
- Saliva. In saliva, α-amylase is already in solution and does not require homogenisation. It can simply be diluted 1:10 with Buffer A.
- Barley seeds. Homogenise germinated barley seeds (three to five days after sowing) by grinding them in a mortar and pestle with Buffer A (about 1 g seeds/mL buffer). Centrifuge the extract at 15,000 g for 5 min; the liquid is used as the β-amylase sample. If you do not have access to a centrifuge, filter the mixture and use the filtrate.
- Yeast solution 0.4 g/L in Buffer A (baker's yeast, which can be bought from the supermarket).

### Methods

**Iodine method**

Iodine in aqueous solution with starch forms a blue-violet complex of high sensitivity and specificity. Maltose and glucose are colourless in the presence of iodine.

**Fehling method**

When heated in the presence of reducing sugars (such as glucose or fructose, but not sucrose or starch), an alkaline solution of cupric ions ($Cu^{2+}$) is reduced to cuprous ions ($Cu^{+}$), forming a yellow-red precipitate of cuprous oxide ($Cu_2O$).

### Procedures

To demonstrate the test methods, test all four carbohydrate solutions (starch, sucrose, glucose and fructose) with both the Fehling and iodine methods. Starch is the substrate of amylase; sucrose is the substrate of invertase, whereas glucose and fructose are the products of the reaction it catalyses.

**Amylases**

Starch hydrolysis is shown either by the disappearance of the blue colour in the presence of the iodine solution or by a yellow-red precipitate with the Fehling test.

For both α-amylase (saliva) and β-amylase (barley extract), prepare seven test tubes, mixing 2 mL Buffer A with 400 μL starch solution. Then treat each tube as described in Table 1.

| Tube | HCl | Saliva or barley extract | Heat on the Bunsen burner for: | Leave at room temperature for: |
|---|---|---|---|---|
| 1* | 2 drops | | 5 min | |
| 2* | 2 drops | | | 5 min |
| 3 | | | 5 min | |
| 4 | | | | 5 min |
| 5 | | 0.5 mL | | 5 min |
| 6* | 2 drops | 0.5 mL | | 5 min |
| 7 | | 0.5 mL** | | 5 min |

Table 1: Treatments for α-amylase (saliva) and β-amylase (barley extract)

* Add one drop of NaOH before Fehling test.
** Heat this saliva/barley solution with a Bunsen burner for 3 min before adding it to the test tube.

Divide the contents of each test tube into two parts: test one part with 2 drops of iodine, the other with 500 $\mu$L Fehling A and 500 $\mu$L Fehling B solution. Enter the results of the tests in Table 3.

To test amylase specificity, repeat the procedure for tube 5, replacing saliva with 300 $\mu$L yeast solution (yeast does not contain amylases) in tube 5.

**Invertase**

Prepare seven test tubes, mixing 1 mL Buffer A and 0.5 mL sucrose solution. Then treat each tube as indicated in Table 2.

Test each tube with 500 $\mu$L Fehling A and 500 $\mu$L Fehling B. Enter the results of the tests in Table 3.

To test invertase specificity, repeat the procedure for tube 5, replacing the yeast solution with 500 $\mu$L 1:10 diluted saliva.

| Tube | HCl | Yeast extract | Heat on the Bunsen burner for: | Leave at room temperature for: |
|---|---|---|---|---|
| 1* | 1 drop | | 5 min | |
| 2* | 1 drop | | | 5 min |
| 3 | | | 5 min | |
| 4 | | | | 5 min |
| 5 | | 0.5 mL | | 5 min |
| 6* | 1 drop | 0.5 mL | | 5 min |
| 7 | | 0.5 mL** | | 5 min |

* Add one drop of NaOH before Fehling test.
** Heat this yeast solution with a Bunsen burner for 3 min before addition.

Table 2: Treatments for invertase

| | α-amylase (saliva) | | β-amylase (barley extract) | | Invertase |
|---|---|---|---|---|---|
| **Tube** | **Iodine test** | **Fehling test** | **Iodine test** | **Fehling test** | **Fehling test** |
| 1 | | | | | |
| 2 | | | | | |
| 3 | | | | | |
| 4 | | | | | |
| 5 | | | | | |
| 6 | | | | | |
| 7 | | | | | |

Table 3: Test results

## Safety

These experiments do not use or generate any hazardous reagent, except for HCl or NaOH. These reagents and saliva should only be handled while wearing safety gloves.

Iodine must be weighed carefully and a safety mask should be worn, as iodine is easily sublimated. Care must be taken when heating tubes with the Bunsen burner and while dissolving starch in the warm buffer.

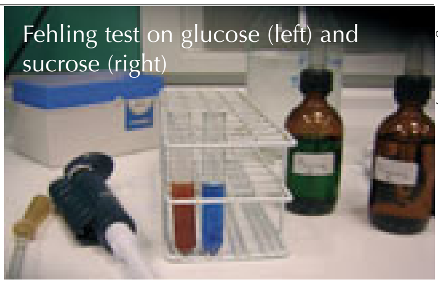
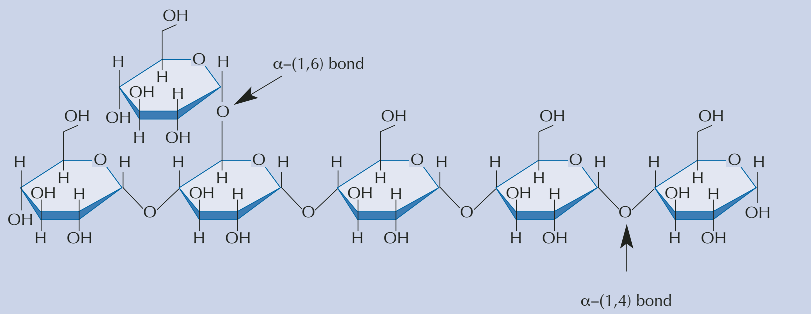
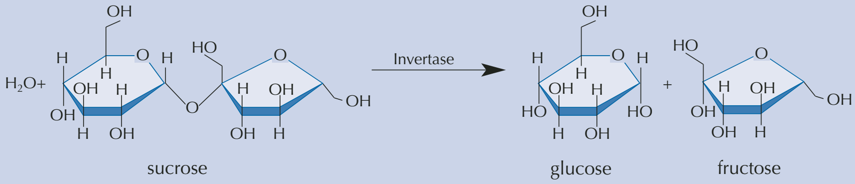

Fehling test on glucose (left) and sucrose (right)

*Image courtesy of Isabella Marini*

Image courtesy of Isabella Marini




A schematic representation of starch. Amylase catalyses the endohydrolysis of α(1-4) glucosidic bonds




Substrate and products of the reaction catalysed by invertase

## Expected results

Together, the extreme conditions resulting from heating and the addition of hydrochloric acid enable starch and sucrose to be hydrolysed. However, neither heating nor hydrochloric acid addition alone is effective.

Under mild conditions (no heating and no addition of acid), saliva, barley and yeast extracts hydrolyse their substrates. Both heating and the addition of hydrochloric acid prevent the hydrolysis: the extracts are thermolabile and sensitive to pH.

## Discussion

Comparing the extreme conditions required for chemical catalysis (elevated temperature and extreme pH) with the mild conditions required by biological extracts introduces students to the idea of a 'special and powerful substance' present in living organisms, which is thermolabile, specific (unlike inorganic catalysts) and able to catalyse reactions. In this way, high-school students can re-run the development of historical knowledge about enzymes; the term enzyme will no longer seem obscure because "words can detach and preserve a meaning only when the meaning has been first involved in our own direct intercourse with things" (Dewey, 1910).

## Acknowledgments

I wish to thank Professor Umberto Mura, Department of Physiology and Biochemistry, University of Pisa, for his constant encouragement. Special thanks are due to Professor Rosanna Striccoli for the English revision of the manuscript and also to my students for their precious observations and doubts.

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Image courtesy of Isabella Marini

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*Image courtesy of Isabella Marini*

Germinated barley seeds for β-amylase isolation

The author, Isabella Marini, and her students at the Liceo Scientifico Ulisse Dini, Pisa

*Image courtesy of Isabella Marini*

# Democs: a conversation card activity for teaching science and citizenship

Image courtesy of NEF

**Karen Smith** from NEF, the New Economics Foundation, London, UK, describes an approach to creating a safe space where students can discuss sensitive topics, like stem-cell research or genetically modified food. How can students be encouraged to explore their values in relation to science topics, and to debate the ethics of science itself?

Democs (**DE**liberative **M**eetings **O**f **C**itizen**S**) is a conversation card activity developed by NEF[w1], with funding from the Wellcome Trust[w2] and the UK Department of Trade and Industry[w3], to promote discussion of controversial topics in science. Each Democs kit is written on a specific topic and since there are no right or wrong answers, players are free to express their own opinions without having any prior knowledge of the topic. Players learn new information (written and checked by experts in the field), discuss the topic with other players, and can vote on the policy options they would recommend to decision-makers.

Democs has been adapted for schools with the help of the Centre for Science Education at Sheffield Hallam University, UK[w4]. From evaluation, it was clear that Democs could be a useful tool for learning in schools. It has the appeal of its game-like format and the informal way in which students learn about a topic, which motivates them to find out more once they have played.

However, there were a number of challenges. How would Democs fit best into the school timetable? What age range would it suit most? How could we avoid overloading students with information? And how could preparation be made as simple as possible for teachers?

NEF, along with the Centre for Science Education and trained facilitators, worked hard to address these issues. A number of trials were run in UK schools, and at the British Association for the Advancement of Science's Festival of Science in 2005[w5]. Further revisions were made to kits before a final version was released in 2006. Democs is a resource that can be a useful tool in cross-curricular activi-

BACKGROUND

## Try Democs for yourself

For general information about Democs and Democs in schools, see: www.neweconomics.org/gen/democs.aspx

Democs resources are free to download from the NEF website: www.neweconomics.org/gen/democsdownload.aspx. In addition to the school kits, there are also kits on the topics of xenotransplantation, pre-implantation genetic diagnosis and over-the-counter genetic testing, suitable for older students/adults.

A Democs kit on nanotechnology for students aged 16 and above is available to download from the Wellcome Trust website: www.wellcome.ac.uk/knowledgecentre/education.

A CD-ROM with a short video on Democs, and interactive process charts for each school topic is available for £15. Boxed kits are also available to purchase. For more information please visit: www.neweconomics.org/gen/howtogetholdofdemocs.aspx

A variation of Democs called Decide has been translated into different languages, but has not been adapted for schools use. See: www.decide.org for more information.

Karen Smith has moved on from NEF since writing this article. To find out more about Democs, contact Perry Walker at the NEF on +44 (0)20 7820 6339 or email perry.walker@neweconomics.org

ties too, such as citizenship, English, geography and religious studies (for ages 13-16), and in general studies, philosophy, and personal, social and health education (PHSE) lessons (for ages 16 and above). Topics already available include vaccinations, climate change, animal experimentation, stem-cell research, genetically modified food and neuroscience.

Democs helps students reflect on controversial science topics and their impacts on society. They can develop their own opinions, share their views and appreciate others' standpoints. It also encourages students to influence decision-making. The votes from each Democs game are returned to NEF, collated and displayed on the NEF website. Soon teachers will be able to input their results online, and results can also be used to influence local or national decision-making.

Teachers have been quick to praise Democs:

*"It makes students more comfortable sharing ideas. Sensitive issues can be made more comfortable. It feels safer."*

*"Fantastic approach to introducing discussion and information on ethical issues."*

*Teachers' comments after playing Democs at the East of England Science Learning Centre*

*"Democs clearly has a role in schools. It was a valuable experience in helping pupils develop conversational skills."*

*Head of Citizenship, secondary school, Oxfordshire, UK*

And it's not just teachers who think Democs is a great way to encourage students to discuss such sensitive subjects:

*"Everyone got to talk. Usually if I'm in something like this I won't normally say much – I'm a listener – but everyone got a chance to talk this time."*

*"It gave the information so anyone can take part in the conversation to a competent level, whereas if you were to bring it up outside of the game the conversation wouldn't have gone so well."*

*Young people in Peckham, London, UK, aged 15-19*

### Web references

w1 - NEF (the New Economics Foundation) is an independent organisation that aims to improve quality of life by promoting innovative solutions that challenge mainstream thinking on economic, environment and social issues, putting people and the planet first: www.neweconomics.org

w2 - The Wellcome Trust is the world's largest medical research charity funding research into human and animal health: www.wellcome.ac.uk

w3 - UK Department of Trade and Industry: www.dti.gov.uk

w4 - The Centre for Science Education at Sheffield Hallam University: http://extra.shu.ac.uk/cse

w5 - The British Association for the Advancement of Science: www.the-ba

# Biology teacher Shelley Goodman from Chelmsford College, UK, tested Democs for *Science in School*.

REVIEW

Finding teaching and learning methods that engage students is a challenge that all teachers face. Controversial issues are particularly difficult to teach, as the teacher must present all the information with a balanced view in a sensitive manner. The students must understand all the principles behind any issues before they can make their own informed opinions, rather than expressing beliefs based on sketchy knowledge or hearsay. An essential part of learning science involves learning how to evaluate information, question its validity and relate it to everyday life. Democs encourages the exploration of scientific ideas and considers the role of science in society, helping students to develop scientific literacy with a critical approach to reading scientific evidence and methods. Participants in Democs develop their communication and collaborative skills through group discussion and presentation.

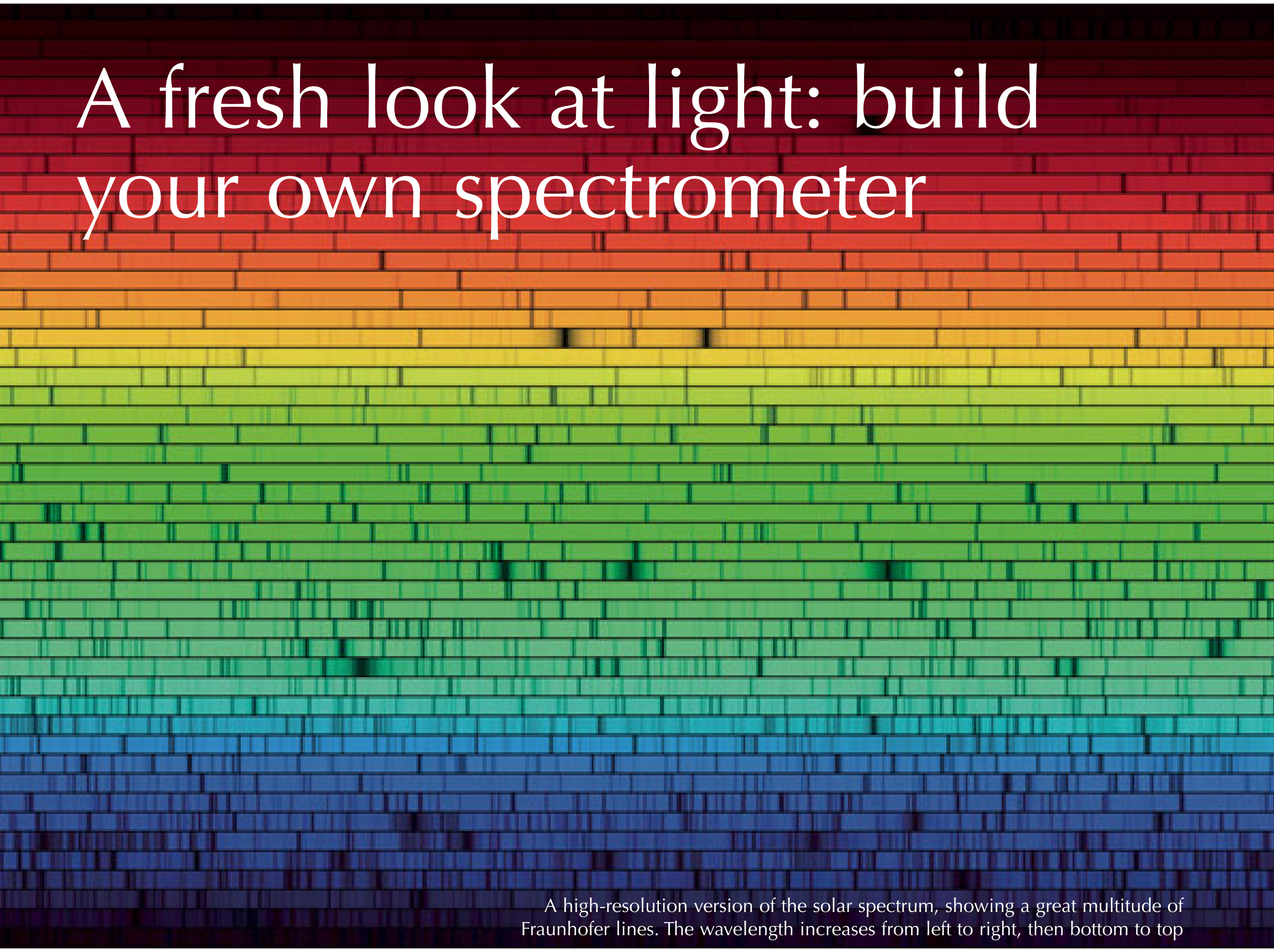
Each pack includes a teachers' guide, topic cards, topic activity and follow-up activity. The pack provides the necessary background knowledge, a series of story cards that investigate the effect of the subject in question on different people, and a set of cards that outline the major issues with key questions to provoke discussion. Students are encouraged to vote at both the start and the end of the session, to compare how their views change once they are fully informed of the facts.

The teachers' guide for the vaccinations policy is very detailed, although it took awhile to understand all the steps involved. An outline lesson plan is included, suggesting that vaccinations policy should be explored over four lessons, taking from one to two-and-a-half hours in total. The suggested timings are useful and very clear, but I feel that it would be hard to start the topic in a single lesson and would suggest a double lesson to begin with. Students are first introduced to the idea of a policy stance and policy-making and are given clear conversation guidelines, so that all students in a group of four to eight can contribute equally, followed by an initial vote on their policy stance. It is suggested that lesson two uses pair work to explore the background knowledge and then lesson three is used to unravel the issues and challenges involved. The students then take an informed vote and compare it with their initial vote. A final lesson is advised to consolidate learning and communication.

These kits could easily be used at GCSE (ages 14-16) and A-level (ages 16-18) to cover syllabus material, but they could also be used as extension work. Students could be encouraged to research further information using the Internet, press releases and journals such as *New Scientist* and *Nature*. This would improve their ability to find and evaluate relevant information and to express opinions and ideas. Students could present a short seminar to each other and then write up the topic, giving them valuable experience in both written and verbal communication skills. Overall, I believe that these packs give the teacher and student an unbiased view of a topic that may be difficult to teach, in a convenient and simple format.

Image courtesy of National Optical Astronomy Observatory/Association of Universities for Research in Astronomy/National Science Foundation

# A fresh look at light: build your own spectrometer



A high-resolution version of the solar spectrum, showing a great multitude of Fraunhofer lines. The wavelength increases from left to right, then bottom to top

Take a CD and a cereal box, and what do you have? With a little help from **Mark Tiele Westra**, your very own spectrometer! Time to explore the delights of colour, hidden in the most prosaic of objects.

White light is not actually white – it consists of many different colours. The composition of light – its *spectrum* – is studied by a device called a *spectrometer*. In this article, we describe how one can build a fully functioning spectrometer with little more than a cereal box and a compact disc. We will use the do-it-yourself instrument to marvel at the wonderful world of hidden colours behind everyday household objects such as light bulbs, fluorescent lights, computer monitors and candle flames. Let's explore!

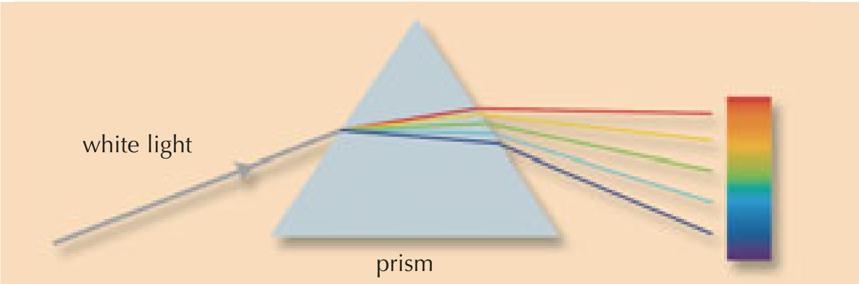
## How to separate light

There are different ways to split white light into its different colours. One way is to use a prism, like Newton did. Due to variations in refractive index, different colours follow distinct paths through the prism, causing the colours to separate.

Another way is to use a so-called *diffraction grating*, which consists of a large number of tiny grooves, placed parallel to each other on a surface, as shown below.

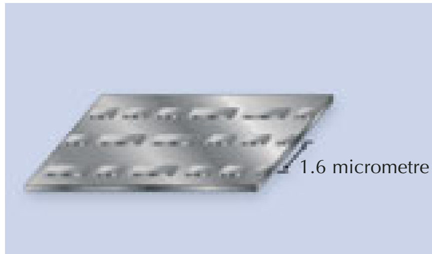
The interaction of the tiny grooves with the light waves leads to the different colours being reflected in different directions.

It is very fortunate that everybody has high-quality diffraction gratings at home: compact discs (CDs). The beautiful colours that can be seen when light reflects off the surface of a CD are a clear indication that it acts like a diffraction grating. But why? The illustration above shows what a strong magnification of the surface of a CD would look like. The music is encoded in short and long pits, which are placed in a long spiral groove on the surface of the CD. The grooves, which are spaced just 1.6 µm (1600 nm) apart, act as a grating.



A prism separates white light into its constituent colours

*Image courtesy of Mark Tiele Westra*



A 6250-fold magnification of the surface of a compact disc

*Image courtesy of Mark Tiele Westra*

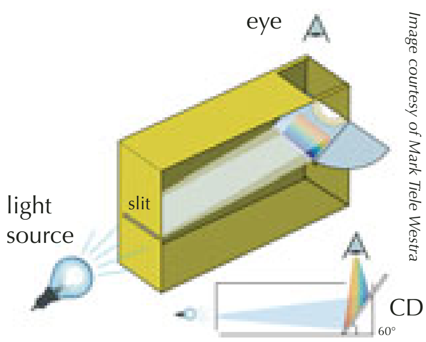
## Constructing a cereal-box spectrograph

We can make good use of these household diffraction gratings for constructing our own spectrometer. It consists of two important elements: a CD, which separates the light into its different colours, and a narrow slit on the opposite side of the box which produces a narrow beam of light.

The slit is constructed on one side of the box using some thick paper and duct tape. A slightly fancier model can be made using the two small blades from a disposable razor, which are taped down with the sharp edges facing each other, as shown in the picture. If the slit is too broad, the spectrum will be blurred, and if it is too narrow, the spectrum will be too dim. A width of 0.2 mm seems to work well, but one can experiment. The quality of the spectra obtained is dependent on the quality of the slit, so it should be constructed with care.

On the other side of the box, a CD (the author used an empty rewritable CD) is mounted at a 60° angle to the bottom of the box. On top, a hole is cut, through which the CD can be observed. Stray light is excluded from the box by covering any holes around the CD, as well as the edges of the CD, with dark tape.

To observe a spectrum, the slit is pointed towards a source of light (the closer the better), and the investigator looks down through the hole on top. Move the box around a little to get a feel for what to look at. Photos of the observed spectra can be made using a simple digital camera, with 'macro' capability for close-up focus, attached to the box by tape or rubber bands. The camera should preferably have manual focus, as it can be difficult to get sharp spectra with auto-focus.



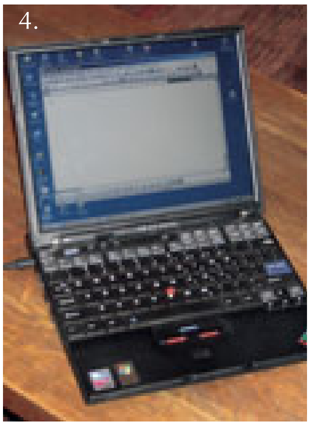
Construction of the cereal-box spectrometer. The CD is placed at a 60° angle to the bottom of the box

*Image courtesy of Mark Tiele Westra*

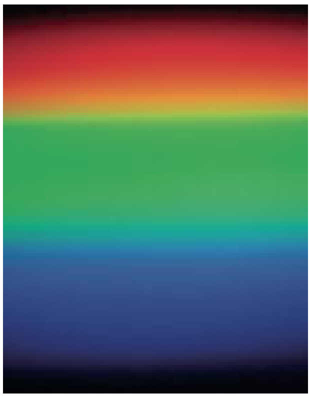
The spectrometer constructed by the author. The bottom-right picture shows the slit constructed from razor blades

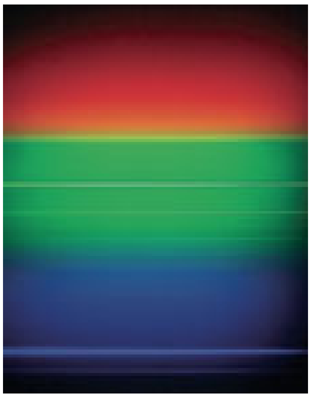
*Images courtesy of Mark Tiele Westra*

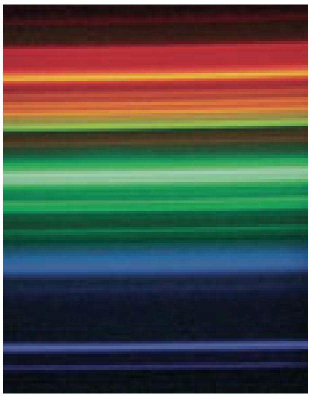


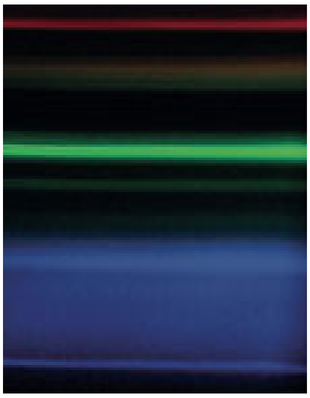




Images courtesy of Mark Tiele Westra









## Measurements

Time to experiment! Our first attempt is to look at the spectrum of an ordinary incandescent light bulb. The result is shown above. We see a nice, continuous spectrum, with all the colours of the rainbow. In a light bulb, light is produced by a very hot filament of metal.

Secondly, we look at two different fluorescent lights, which both emit white light.

The first, which is an ordinary fluorescent light, shows a number of sharp lines against the background of a continuous spectrum. These *emission lines* (see text below) are produced by low-density mercury vapour in the tube. The mercury also produces ultraviolet light, which is turned into a continuous spectrum of visible light by a thin layer of phosphor on the inside of the tube.

The second fluorescent light shows a very different spectrum. The reason is that manufacturers can vary the colour of the light by using different combinations of phosphors. The lamp illustrated uses a phosphor that emits a continuous spectrum, but this type uses so-called tri-colour phosphors: a combination of three phosphors which each has its own set of emission lines. We perceive the resulting mix of colours as white.

A small section of the screen of a laptop showing a white Word document produces the spectrum shown above. The three pixel colours that make up the image – red, green and blue – are very distinct.

1. Spectrum of an incandescent light bulb
2. Spectrum of an ordinary fluorescent light
3. Spectrum of a fluorescent light using tri-colour phosphors. Due to overexposure by the camera, some of the lines appear to have a slightly different colour to that which they really have. The bright yellow line in the red part of the spectrum should be red as well
4. The spectrum of a laptop screen

## How spectra are formed

Some of the spectra that can be seen with the cereal-box spectrometer have a continuous background, with the colours varying smoothly from dark red to dark blue. Others consist of sharp lines on a continuous background, sharp lines without background, or even dark lines on a continuous background, like in the solar spectrum (see right). Why all this diversity? How are spectra formed?

It is all due to the atoms. An individual atom can find itself in different energy states, depending on whether its electrons occupy their usual orbits or have been excited to higher orbits. An atom cannot have just any energy: the energy levels are sharply defined, dictated by the detailed atomic structure. When an electron jumps from one orbit to another, the change corresponds to a precise amount of energy which is emitted in the form of a single photon. The energy of the emitted photon determines its colour.

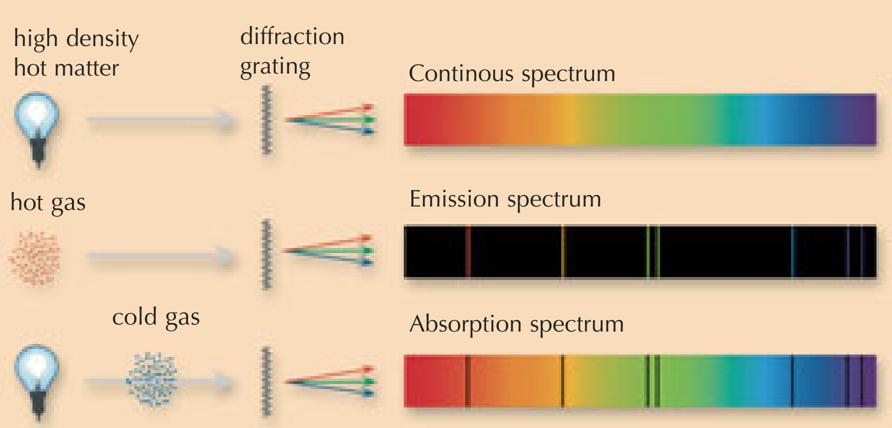
Because many different jumps are possible, each atom can emit a range of distinct colours of light. If this light is separated by a prism or a diffraction grating, each colour is visible as an *emission line* in the spectrum, which is itself called a *line spectrum*.

To demonstrate the formation of an emission line, we look at what happens when some ordinary table salt (sodium chloride, NaCl) is put in a candle flame. The upper pictures show the continuous spectrum of the flame itself, just like that of an incandescent light bulb. When a little table salt is put on a knife and held in the flame, a distinct orange line appears in the spectrum, which corresponds to the emission line of sodium (Na, at 589 nm).

An atom not only emits light, but also *absorbs* photons of the same energy that it emits. If light passes through a cold, low-density gas of atoms, the atoms in the gas absorb specific frequencies causing dark lines in the spectrum, which are called *absorption lines*.

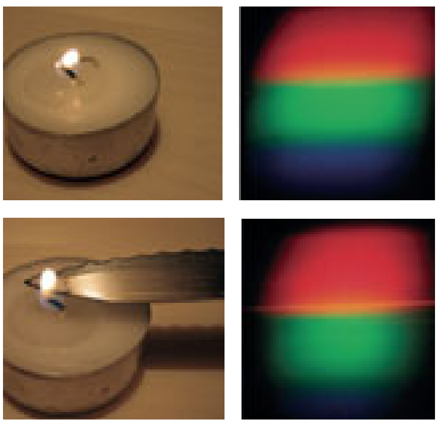
But if all spectra are formed by atoms emitting sharply defined colours, how are continuous spectra formed? For a single atom, unaffected by external influences, the lines are indeed sharp. This is the case in a low-density gas such as in a fluorescent tube. In a higher-pressure gas, such as the Sun, and also in fluids and solids, there are frequent collisions and many other mechanisms that cause the lines to lose their sharpness and become fuzzy, leading to a *continuous* spectrum. The three types of spectra are summarised in the illustration above.

Different atoms (and molecules) have different emission and absorption spectra. This difference can be exploited: just by looking at the light that comes from a distant object, for example the Sun or a star, we can tell which chemical elements are present. On Earth, this technique is used by shining light through a sample (often a gas) and measuring the absorption spectrum, from which the composition of the sample can be derived.




The three types of spectra and their origin. Solids, fluids and high-pressure gases emit a continuous spectrum (top). A low-density hot gas (middle) emits a line spectrum. Finally, when light with a continuous spectrum passes through a low-density cold gas, specific colours of light are absorbed, leaving dark lines in an absorption spectrum

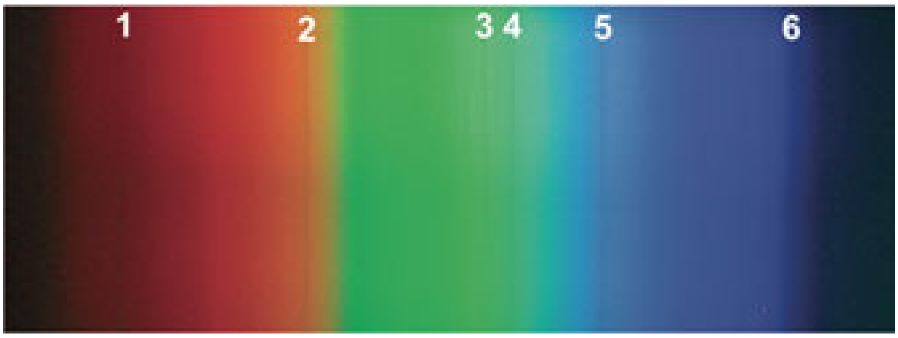
Image courtesy of Mark Tiele Westra



A little table salt held in a candle flame produces a sodium emission line

Image courtesy of Mark Tiele Westra

*Image courtesy of Mark Tiele Westra*




The spectrum of the Sun as seen with our cereal-box spectrometer. The lines correspond to: (1) hydrogen at 656 nm, (2) sodium at 589 nm, (3) iron at 527 nm, (4) magnesium at 518 nm, (5) hydrogen at 486 nm, and (6) iron and calcium at 431 nm

## The solar spectrum

Taking our spectrometer outdoors, we can look at the spectrum of sunlight. The spectrum, shown above, looks continuous at first glance. But if we take a closer look, several dark lines can be identified, which are caused by the absorption of specific frequencies of light by atoms in the outer layers of the Sun, and in Earth's atmosphere. The image above does not do justice to the full capabilities of the cereal-box spectrometer: with the naked eye the absorption lines can be seen in much greater detail.

The absorption lines that we observe in the solar spectrum have a name: *Fraunhofer* lines. Joseph von Fraunhofer (1787-1826) was the first to make a systematic study and careful measurements of these dark lines, although he was not the first to observe them. In all, he mapped over 570 lines, which he categorised and named.

Around 1860, Kirchoff and Bunsen discovered that each chemical element is associated with a set of spectral lines. They deduced that the Fraunhofer lines in the solar spectrum were caused by the absorption of specific colours of light in the outer layers of the Sun. Some of the lines are also caused by the absorption of light by atoms in the atmosphere of Earth, such as oxygen. The study of these lines eventually led to the discovery of the element helium in the Sun, which ultimately provided proof that the Sun is powered by nuclear fusion.

## Acknowledgements

I am indebted to Xiaojin Zhu of the University of Wisconsin-Madison, whose website (www.cs.cmu.edu/~zhuxj/astro/html/spectrometer.html) provided me with all the information I needed to construct my own spectrometer and to interpret the results. On his website more spectra are available. Also thanks to Bartjan van der Meer, who put me on the trail of this fantastic science project.

**REVIEW**

This article describes a very interesting hands-on experiment that can easily be replicated in class or at home. The spectrometer is constructed from common materials and is used to show the colour composition of white light and to compare the spectra of many light sources. Of particular interest is the historical background to the discovery of the light spectrum of the Sun and how it was used to identify the composition of its gases.

The article links physics and chemistry and would be interesting to both secondary school and university students.

*Gaetano Bugeja, Malta*

## Resources

Wikipedia article on the visible spectrum:
http://en.wikipedia.org/wiki/Visible_spectrum

### General info on spectra

Wikipedia article on the electromagnetic spectrum:
http://en.wikipedia.org/wiki/Electromagnetic_spectrum

Wikipedia article on spectroscopy:
http://en.wikipedia.org/wiki/Spectroscopy

Wikipedia article on the Fraunhofer lines:
http://en.wikipedia.org/wiki/Fraunhofer_lines

Wikipedia article on the emission lines:
http://en.wikipedia.org/wiki/Emission_lines

Mark Tiele Westra is the Public Information Officer at the FOM-Institute for Plasma Physics Rijnhuizen, the Netherlands.

# Explor@mobile: using new technologies to teach science to teenagers

**Claire Le Moine** from Explor@dome in Paris, France, explains the formula of the explor@mobile: two scientists, some computers and a gas-powered vehicle!

Image courtesy of Explor@dome

The Explor@dome[w1], a Paris science centre, is a popular place for science teachers to take a class of students eager to try things out for themselves – no 'please do not touch' signs, plenty of interactive activities, and staff willing to explain how to make a square wheel roll, demonstrate how to generate a tornado or assist in building an arched bridge. But for many schools, a trip to the Explor@dome is simply too complicated and too expensive to organise. So with the help of Apple, who provided laptops, and Gaz de France, who donated a natural-gas-powered car to transport the equipment, Explor@dome decided to extend its activities into the surrounding primary and secondary schools. Its science and multimedia vehicle, the explor@mobile, took to the road in September 2002 and has never looked back.

For many students, science lessons still mean equations and diagrams, which – particularly for students with learning difficulties – can be hard to understand. On the other hand, science lessons consisting purely of practical work and experiments would be difficult to provide and would not allow students the chance to assimilate what they have learned. In the explor@mobile, multimedia activities offer an innovative alternative.

Scientific concepts are introduced to students through two workshops, run by mediators from the Explor@dome. The first workshop focuses on practical scientific activities, such as building a 'magic box' to investigate symmetry (see box on page 37), experi-

Image courtesy of Explor@dome

*All images courtesy of Explor@dome*



ments on transformations of state in water, or pinhole photography. Phenomena such as forces or airflow are demonstrated using multimedia simulations.

BACKGROUND

## PENCIL

The explor@mobile is one of the activities in the PENCIL project[w2] (**P**ermanent **E**uropea**N** Resource **C**entre for **I**nformal **L**earning). PENCIL, co-ordinated by Ecsite[w3] and funded by the European Commission as part of the NUCLEUS cluster[w4], aims to strengthen the operational relations between schools and informal science education in science centres and museums. Fourteen science centres and museums have developed pilot activities in partnership with teachers and schools; material is already available online. Academic and school partners are now working to identify key ways to transform informal science activities into innovative, high-quality tools for science teaching.

The second workshop involves multimedia activities to reformulate and reinforce what was learned in the scientific workshop. Students may develop a slide-show presentation, or create a website, exhibition panels or a video film. The laptops brought in the explor@mobile allow the use of equipment and software (e.g. Photoshop or PowerPoint) not necessarily available in schools.

Examples of projects conducted in 2005-2006 with local secondary schools include:

- The production by 12-year-old pupils of a CD-ROM investigating the links between art and mathematics, covering optical illusions, paving and geometric constructions
- The creation of an illustrated novel and an exhibition on pinhole photography, by a class of 12-year-olds with learning difficulties. Photographs were taken using a pinhole camera made out of a tin can
- The design of exhibition posters about energy, by a class of 15-year-olds who intended to enter vocational training
- The production of a scientific documentary on a DVD by a class of 13-year-olds with learning difficulties.

For these projects, the explor@mobile visited the schools to provide students with six scientific and six multimedia workshops, each lasting one-and-a-half to two hours. Other projects involved up to 20 sessions with a group of students. The workshops are free to schools and students, thanks to financial support from the local government ('conseil general') in charge of secondary schools, the PENCIL project[w2] and other sources of funding.

The interdisciplinary nature of many of the projects, involving not only science, but also written communication, oral communication and information technology skills, draws in students who are not typically interested in science. And not only the students – many of the activities have involved collaborations between teachers from several disciplines.

The use of multimedia activities has many advantages. The students not only are interested initially by the activities, but also remain interested and committed to the project. Much of the information used in the workshops is taken from the Internet, demonstrating to students that – provided they are sufficiently selective – this can be an invaluable source of scientific information and relevant images.

As the students reformulate what they have learned to present it to others, whether as a website or an exhibition, they reinforce what they have learned and discovered, developing presentation skills in the process. Finally, the collaborative creation of a real and durable multimedia product demonstrates to the students the rewards and satisfaction of the project approach.

But the students are not the only ones to benefit. Teachers have also appreciated the originality of the pre-

BACKGROUND

## Symmetry activities

In the first, 'scientific' workshop, the students (ages 12-13) investigate bilateral symmetry by making geometric drawings, studying different geometric shapes and objects, and constructing a 'magic box' containing a mirror. They build half an object out of modelling clay and place it on a mirror, so that it appears whole and bilaterally symmetrical. Once the magic box is closed, the object appears to float and the mirror 'disappears'. Investigations continue with the construction of a camera obscura.

In the second, 'multimedia' workshop, students use software to investigate different symmetries in pictures and produce kaleidoscopic images. In a further scientific workshop, they build a kaleidoscope.

Symmetry is part of the school curriculum for students of this age, and these activities provide new ways to address mathematical concepts and to apply what they have learned to real objects (cameras, magic boxes and the kaleidoscope). For teachers, it provides a method to test if the students have understood their lessons on symmetry and whether they can apply their knowledge to new situations.

sentations and the quality of the material provided, whereas the Explor@dome mediators enjoy the challenge of designing projects for a new audience.

A laboratory of cognitive psychology at the University of Nanterre, France, investigated the impact of explor@mobile workshops linking mathematical concepts (symmetries and proportions) to a multimedia activity involving digitally editing photographs (see box above). The results suggested that the explor@mobile workshops helped the children to apply the mathematical concepts that they learned to new situations. Children who had not worked with the explor@mobile had greater difficulties. In particular, giving presentations and doing multimedia activities increased the children's ability to transfer their knowledge. Their degree of understanding of the topic was more closely linked to the context of the work. Further quantitative evaluation of explor@mobile is planned.

### Web references

w1 - The Explor@dome website: www.exploradome.com

w2 - Information about PENCIL is available on the Xplora website: www.xplora.org

w3 - The website of Ecsite, the European organisation representing science centres and museums: www.ecsite.net

w4 - Information about NUCLEUS is available on the Xplora website: www.xplora.org

# Fair enough? Balanced considerations for future science-fair organisers

**Eva Amsen** considers the pros and cons of science fairs, and offers tips for how teachers can get involved – or even organise their own science fair.

It was an unusually busy Saturday at the Scarborough campus of the University of Toronto, Canada. On 8 April 2006, hundreds of posters presented research from a wide range of fields. A display on the improvement of artificial limbs was set up just around the corner from a poster on RNA interference in the *Caenorhabditis elegans* worm. Other displays showed the effect of tobacco and marijuana on lung capacity, or the impact of blood spatters at a crime scene. As the broad theme suggests, this was not an academic conference. This was the annual Toronto Science and Technology Fair[w1], showcasing the best science projects from elementary, middle- and high-school students across Toronto.

I was a judge at this fair for the third year in a row, and every year I've been impressed with the work that students have put into their projects. I've also judged a few science fairs at local schools through 'Let's Talk Science'[w2], a Canadian outreach organisation connecting science educators with local graduate student volunteers.

When I was in high school, I would have jumped at the chance to be able to participate in a science fair, but the concept of a science fair like this did not exist in the Netherlands at that time. Whenever we did science projects, the result was a report that we handed in to be graded. There was never a fair with judges and visitors.

The Austrian stand at Science on Stage 1, Geneva

*Image courtesy of Barbara Warmbein*

Is the concept of a science fair something specific to North America rather than Europe? If it is, I don't think it should be. According to a recent evaluation of biomedical publications, research between Canada and Western Europe is comparable at the highest level (Soteriades et al., 2006). This suggests that the ultimate resources for classroom (or extracurricular) science teaching are comparable as well. Why don't more European schools participate in science fairs, or organise their own?

A few talented European students do compete in science fairs: the Intel International Science and Engineering Fair[w3] (ISEF), held yearly in the USA,

BACKGROUND

## The practicalities

If schools organise their own fairs, they are of course free to devise their own rules. Many schools organise their fair at the end of the school year, and assign marks on the basis of the students' presentations. The available options, though, are wide, and it may help to have a little information about how other larger fairs are organised.

### Criteria

The judging criteria are similar for most fairs, and include:

- Originality of the project
- Creativity of approach
- Scientific soundness (use of controls, data analysis)
- Completeness (including references)
- Presentation
- Communication (including ability to answer questions)

Judges are volunteers from the scientific community, and projects are judged by more than one judge.

### Selecting participants

The way in which participants are selected depends on the level of the fair. For school-based or local fairs, all participants may be welcome. For others, there can be fierce competition.

The top international fairs, such as the ISEF (held in the USA) and the EU Young Scientists Contest[w4], accept participants who have previously won a regional or national fair run by a qualified organisation, or, in the case of the EU fair, participants that are nominated by a national organiser.

Examples of European science fairs in which winners are qualified to continue to the ISEF are the BA CREST Science Fair[w5] in the UK and Jugend Forscht[w6] in Germany. Both fairs have application deadlines in late autumn, and organise smaller local fairs in their respective countries. Most fairs require students to be 15-20 years old, and usually the school nominates or enters the participating students. Some fairs allow group projects of more than one student per project.

The size of regional fairs varies enormously, but the pool of participants in regional fairs from which ISEF participants are selected consists of 65,000 young people. Of those, 1500 students from 47 countries are selected to participate in the international fair. The final event of the EU Young Scientists Contest is considerably smaller, with 100 students participating from 38 countries.

### Prizes

The prizes awarded at fairs also vary, but for regional and national fairs, the top award is often selection to participate in a higher-level fair (with regional winners going on to national fairs, and national winners proceeding to the international level). Small monetary awards are also given. BA CREST science-fair winners win money for their schools, whereas Jugend Forscht participants can win €75 in a regional fair and €250 in a national fair.

The ISEF's top prize is a US$50,000 scholarship. Other prizes include field trips, internships, scholarships, and smaller monetary awards per category up to US$3000. The EU Young Scientists Contest has prizes up to €5000, as well as visits to scientific institutions in Europe, including the EIROforum organisations[w7].

hosted more than 40 countries in 2005. This included about 20 European countries, but these countries each have very few local fairs, providing just a small number of students the chance to showcase their projects. This is unfortunate, because in my opinion presenting at a science fair is something every student should experience.

As a judge and visitor to science fairs in Toronto, I've interacted with students from grades 5-12 (ages 10-18). Based on this experience, and from talking with fair organisers, I've noticed several advantages and disadvantages of science fairs over regular in-classroom science education. By outlining these pros and cons, I hope to give interested teachers a starting point for organising their own science fair.

## Advantages of science fairs

### Motivation

Most of the projects presented at science fairs are related either to the students' daily lives or to subjects they're passionate about. Sports, music and the environment are hot topics. This innate interest is a good motivator for students to keep working on their project for several months, and will ultimately help them understand their chosen topic better than they would from a textbook. For example, students might not be interested in reading an assigned homework chapter on conservation of angular momentum, but would gladly find out, on their own time, that this is the principle behind figure-skating turns.

## Research skills

Since students work on their own projects, the background information they need might not be presented in their textbooks. They will have to search for their own information. Finding reliable sources of information is a recurrent issue throughout a student's education, and any practice in literature research is useful not only for science but also for other subjects. Some students get help from local universities in carrying out their science-fair projects. Regulations differ between institutions, but most universities have outreach projects or communication centres that offer advice.

Image courtesy of Barbara Warmbein

A bed of nails at Science on Stage 1, Geneva

## Scientific method

Most students are familiar with the basic concept of the order of hypothesis, experiment and conclusion. Textbook examples and classroom experiments often successfully prove a hypothesis and find a known solution to a common problem. However, the harsh reality of scientific research is that many hypotheses prove to be false. This is a lesson not easily taught, but a concept that becomes immediately apparent to students who fail to prove their hypotheses in science-fair projects. Of the science-fair projects I've judged, I've always been most impressed by the students who encountered such setbacks and not only sought an explanation for the discrepancies, but also tested and proved their new explanations. That is the real scientific method!

## Communication skills

Even though undertaking a science-fair project may take several weeks, the science fair only lasts one day, and the whole project needs to be summarised on one poster. Students are forced to think about the details of their work when they prepare to explain it to the judges. For the larger regional and (inter)national fairs, they might even need to talk to the media. At a science fair in Florida, twelve-year-old Jasmine Roberts made news with her science project on fast food restaurants (Mixon, 2006). After her project was picked up by the media, Jasmine had to answer questions not only from teachers and science fair judges, but also from reporters!

# Disadvantages of science fairs

## Time

The major drawback for students is the time commitment. Since the projects are unique, students will have to carry out the experiments on their own time. This can conflict with other school assignments if not planned well.

Image courtesy of Barbara Warmbein

The UK stand at Science on Stage 1, Geneva

A science fair is also a huge commitment on the part of teachers. For every student, they need to assess if the project is acceptable, help with finding reliable information sources, and give feedback when a student encounters a problem. On top of that, there are numerous other responsibilities involved with getting all the projects displayed and judged.

## Competition

In judged science fairs, there will inevitably be competition between students. Depending on the situation, the competitive element can be either an advantage or a disadvantage (Human, 2006). For some students,

Image courtesy of Barbara Warmbein

Demonstrating earthquakes at Science on Stage 1, Geneva

REVIEW

Eva Amsen's considerations are of great relevance for science teachers all over Europe. They are clearly written and deliver a lasting impression of the author's concerns: science fairs of the kind described are indeed not yet common in European schools.

Over the last few years, the European science teaching festival *Science on Stage* has put forward the idea of a fair as a means to promote best-practice examples of science teaching – but these events are mainly for teachers, not for students. At the student level, I have not yet heard of a fair with judges and visitors in Germany or Europe. For sure, there have been – and still are – high-profile events such as Jugend Forscht (Youth researching) in Germany, in which excellent research projects are presented and awarded on a national level. To reach the national final, the participants have to go through a well-defined set of competitions at the federal-state level. These competitions are very close to the fair sessions that Eva Amsen describes.

However, Jugend Forscht includes the very best of science students only, neglecting and leaving behind the average student. In my view, it is exactly this average student, with an everyday approach to scientific problems, who should be asked to participate in a fair. It is exactly this average student who should be encouraged to dig further into science and to train his/her abilities in using scientific tools and ideas beyond normal classroom lessons. By pushing this rewarding idea of science fairs and helping create the exciting, bristling atmosphere of a local or regional fair with loads of students, teachers, visitors, media representatives and so forth, we could tackle the still decreasing numbers of students who take science in higher secondary education. Setting up such events could also help to increase interest when talking about science in school.

It is to be hoped that Eva Amsen's consideration of science fairs will encourage a science-fair culture amongst European schools as well.

*Tobias Kirschbaum, Germany*

it's a source of motivation, encouraging them to work hard on their projects. For others, however, it has the opposite effect, and the thought of being compared with their peers can be disheartening. At the recent Toronto Science and Technology Fair, I casually talked to some students after I finished judging. When one student heard that I was not going to mark her project, she confided in me: "I didn't really want to be here. My project isn't that good, and I'm sure others have done the same thing." For insecure students, a non-judged, display-only fair may be a better environment. These fairs still have the merit of giving students a chance to show their work without the pressure to compete.

These considerations can hopefully serve as a starting point for teachers who are considering setting up a science fair, or thinking of having their students participate in an existing fair. As a further resource, the ISEF has an online checklist for teachers interested in setting up a science fair.

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w2 - Let's Talk Science: www.letstalkscience.ca

w3 - Intel International Science and Engineering Fair: www.sciserv.org/isef/

w4 - EU Young Scientists Contest: http://ec.europa.eu/research/youngscientists

See also:

Parker S (2006) Something special in the air. *Science in School* **3**: 13-15. www.scienceinschool.org/2006/issue3/youngscientists

w5 - BA CREST Science Fair: www.the-ba.net/the-ba/YPP/BACRESTScienceFair/BACRESTScienceFair2007.htm

w6 - Jugend Forscht: www.jugend-forscht.de

w7 - EIROforum not only publish *Science in School*, but also organise Science on Stage, a series of national events for science teachers, culminating in an international science teaching festival: www.scienceonstage.net

Eva Amsen is a PhD student in biochemistry at the University of Toronto, Canada. In her spare time, she does scientific outreach work with schools and writes about science.

# The Faulkes Telescopes: real-time, remote-control astronomy for schools

Ever wanted to take a closer look at the stars? **Rachel Dodds** from the Faulkes Telescope Project explains how you can do just that – together with your students and without even leaving your classroom!

*Image courtesy of the Faulkes Telescope Project*

Image of the spiral galaxy M65, taken and processed by Nic Szymanek

A study conducted by research and education stakeholders in the UK found that space has "a direct, positive effect on educational and career decisions" and that its inclusion increases motivation in science among students, regardless of gender, age, ability or culture (Spencer & Hulbert, 2006).

The Faulkes Telescope Project was launched in the UK in March 2004 and aims to engage students in real science using the largest entirely robotic telescopes in the world. There are currently two telescopes in operation: one on the island of Maui, Hawaii, and another at Siding Spring in New South Wales, Australia. Although they feature research-quality equipment, the Faulkes Telescopes were built primarily for educational users, with associated support and resources provided by the Faulkes Telescope team. The telescopes are controlled in real time by users via a simple website[w1] that delivers inspiring images of space to the classroom within minutes. This gives all students embarking on astronomy projects access to expertise and state-of-the-art equipment.

More than 450 schools in the UK are currently working with the Faulkes Telescope Project, taking images of distant astronomical objects. But the telescopes offer much more than just pretty pictures; it is when these images are processed that investigative science begins. Using Faulkes Telescope North (Hawaii), students have discovered new asteroids, observed supernovae, and studied other phenomena including mysterious gamma-ray bursts. Telescope targets can be tracked as they move across the sky, variations in brightness can be monitored, and even their chemical composition probed by using different filters. A group of UK schools is even helping astronomers to name an asteroid that they observed with Faulkes Telescope North – the first asteroid to be discovered using the Faulkes Telescopes. The real-time facility, unique to the Faulkes Telescopes, fosters a feeling of ownership over the images among the students. Couple this with the potential for real discovery that the telescopes offer, and the result is a powerful educational resource.

The Faulkes Telescopes can enhance the teaching of many subjects within the classroom, not only the sciences. The most obvious application is in physics, with topics such as light, Earth and the Solar System, and the life cycle of stars offering plenty of opportunity for telescope use, even within restrictive curricula. However, Faulkes Telescopes can also be readily linked to other subjects including information technology, chemistry and technology, and have been used in interdisciplinary projects combin-

The Whirlpool Galaxy. This four-colour image was produced by Daniel Duggan from the Faulkes Telescope Project

This image of the Pillars of Creation in the Eagle nebula was taken by students from Thomas Hills High School, UK, and processed by Tommi Warton, a technician at the school

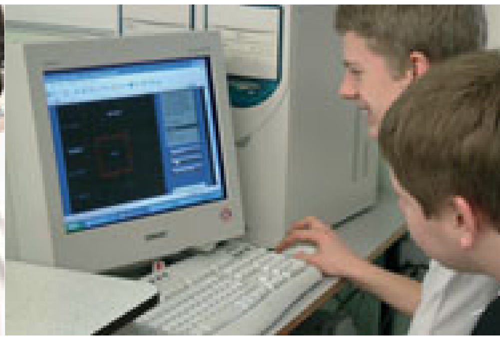
The Faulkes Telescopes each weigh 25 tonnes, stand 8 metres tall with 2 metre primary mirrors, and are contained within a novel clamshell enclosure

*Images courtesy of the Faulkes Telescope Project*

Image of the Triffid nebula, taken and processed by Nic Szymanek

Images courtesy of the Faulkes Telescope Project

The Faulkes Telescope in Russia was launched at Sternberg Astronomy Institute, Lomonosov Moscow State University on 20 September 2006



School students controlling the telescope in real time

Image of Jupiter taken by Kings School Bruton, Somerset, UK

ing the beauty of space with creative writing, art and design, and even music, dance and drama.

West Monmouth Comprehensive School in South Wales, UK, has been using the telescopes to support students with special needs to acquire basic proficiency in teamwork and presentation skills, while also studying towards a GCSE astronomy qualification (usually taken at the age of 16). The students demonstrated their new skills at a special event in Cardiff in October 2006 with an impressive presentation. Students use video conferencing to communicate with partner schools and astronomers. The lead teacher, Mr Kerry Pendergast, has been a keen amateur astronomer for many years. Speaking about these astronomy activities, he said: "The Faulkes Telescope Project has had a major impact on science at West Monmouth."

The Faulkes Telescope Project does more than just facilitate telescope use: a comprehensive range of support materials and educational resources is also available. The website provides the real-time interface for controlling the telescopes and booking sessions, as well as advice for planning sessions, suggestions for suitable projects, podcasts and an image archive, and acts as a portal to many additional features.

In the UK, free teacher training days are offered at locations nationwide, covering a wide range of topics including image processing and science curriculum links. A new programme of online training is being trialled to complement these courses, and will be available internationally.

The educational arm of the Faulkes Telescope Project already extends beyond the UK. When NASA fired a copper 'bullet' into the Tempel 1 comet in 2005, the first images obtained from Earth were taken by a group of Faulkes Telescope North users from Hawaiian and Icelandic schools, working with Professor Alan Fitzsimmons' team from Queens University in Belfast, Northern Ireland. Further small-scale projects have been established in Malaysia, Israel, Portugal and France, the latter two in conjunction with the European Union 'Hands-On Universe' project[w2]. Since September 2006, a programme to monitor supernova explosions has been piloted by Polish schools, working through the British Council[w3]. Students are involved in measuring changes in the brightness of supernovae – information that can help astronomers understand the processes that govern the death of massive stars.

Another, far larger, British Council-funded project, involving schools and astronomers from Russia, was launched in Moscow in September 2006[w4]. Twenty-four schools from five regions of Russia are working with local astronomers to study galaxies, asteroids and supernovae, and will make a genuine contribution to scientific knowledge. Dr Paul Roche, Director of the Faulkes Telescope Project, said: "Linking bright, motivated students with researchers [in Russia] will provide us with an ideal test of our plans for developing 'real astronomy' programmes across the world." Dr Patrick Fullick from the School of Education at Southampton University, who co-ordinated the British Council project in Russia, believes that "Britain and Russia have much to learn from each other in the fields of science, mathematics and computer education, and closer links can provide great benefits to education in both countries."

The team also hope to partner UK schools with their counterparts overseas to facilitate the exchange of ideas, language skills and cultural awareness, via email, video conferencing and, potentially, visits. A major strength of the telescopes is their ability to promote collaborations not just between different schools in different locations, but also between schools and scientists.

In late 2005, the Faulkes Telescope Project became part of a much bigger programme, the Las Cumbres Observatory Global Telescope Network[w5]. This will ultimately comprise 40 to 50 robotic telescopes of dif-

The Faulkes Telescope Project offers training on the use of the telescopes and their applications in education

ferent sizes, spread across the globe, with several telescopes observing at any one moment, giving a truly global observatory. Although the larger instruments are primarily for research use, this network will also contain dozens of telescopes dedicated to educational use. In addition, the project will train local people to act as 'ambassadors' in their countries, and provide resources and facilities so that they will be able to train others in their area to use the telescopes.

Under the new umbrella of Las Cumbres Observatory Global Telescope Network, the educational programmes currently on offer in the UK through the Faulkes Telescope Project will expand internationally, making use of the increased access to telescopes and geographical locations.

Ultimately, the aim of Las Cumbres Observatory is to offer a free, supported service to users across the world, similar to that currently provided in the UK, and to enrich the education of students from many different cultures and backgrounds through access to exciting investigative science programmes.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## Web references

w1 – For more information about the Faulkes Telescope Project and how to use the facilities with your students, see: www.faulkes-telescope.com

w2 - European Union Hands-On Universe (EU-HOU): www.euhou.net

w3 - The British Council Faulkes Telescope in Poland: www.britishcouncil.org/bg/poland-the-faulkes-telescope.htm

w4 - The British Council Faulkes Telescope in Russia: www.british-council.org/russia-science-faulkes-telescope.htm

w5 - Las Cumbres Observatory Global Telescope Network: www.lcogt.net

## Resources

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Beare R (2004) Astronomy-related content and robotic telescopes in upper secondary physics courses. *School Science Review* **86**: 113-120


REVIEW

This article introduces a wonderful hands-on astronomy activity, well known in the UK and gaining popularity all over the world. Faulkes Telescopes allows teachers and their students to operate a telescope directly from school, taking their own astronomical pictures and giving students an idea of what modern research in astronomy and physics is like.

Of most use to physics and astronomy teachers, the Faulkes Telescope facility also enables interdisciplinary projects, covering not only physics and astronomy, but information technology, image processing and foreign languages.

An international co-operation between schools, investigating a topic in astronomy or astrophysics, would be a perfect outcome of this article – and one that I would be happy to take part in.

*Marco Nicolini, Italy*


*Image courtesy of VIB*

# Scientists@work

Teaching science in the classroom is all very well, but wouldn't it be wonderful to let your students learn for themselves what it's really like to work in a research laboratory? **Sooike Stoops** from the Flanders Institute for Biotechnology (VIB), Belgium, describes a project that does just that!

Science as it is taught at school is often limited to theoretical explanation. Nevertheless, experiments, discoveries and testing new methods are a major part of scientific practice. But what secondary school has a fully equipped laboratory with the latest materials, tools and expertise? The creative solution may seem obvious, but unique in Europe: take a team of youngsters and their teacher to work in a professional lab with scientists who absorb them into their working day and involve them in their ongoing research! This is the formula of scientists@work.

The project is aimed at students (aged 14 and above) and their teachers in secondary education. The emphasis lies on practical experience, contact with professional scientists, involvement in ongoing research, and long-term interaction.

## The project

### Choose your own project

A group of up to 15 students and their teacher come to a working research lab for one day. The visit could be to a research institute, company, university or college ('Hogeschool' in Dutch) laboratory in Flanders (Belgium). They can choose from the list of participating projects that appears on the scientists@work website[w1]. All these projects have been proposed by the scientists themselves, who invite the students to experience a day in the laboratory and to experiment together with them. This gives the students a very good idea of the research that scientists do every day.

In September 2006, students could choose between 68 different projects. Some examples:

- Research on leptin, a key molecule in the regulation of body weight
- How safe is our water?
- Looking for genetic defects in patients with mental retardation
- Nanobodies: invisibly small, but with a huge impact on medical science
- Researching the increase of yield in genetically modified plants
- Pollution and health: will everybody develop cancer?
- Our blood: a wealth of information
- RNA interference in *Caenorhabditis elegans*: how do you determine the function of a gene?
- Gene-expression analysis using the polymerase chain reaction (PCR)

BACKGROUND

## Scientists@work in figures

The project started in 2003-2004 with 37 scientists supervising 79 teams (about 800 students). Since then, scientists@work has grown and in the fourth round (2006-2007), 181 scientists offered 181 teams (almost 2000 students) a day in the lab.

From the two last rounds, it is clear that scientists@work is now a fixture in the world of biology education in Flanders.

*Images courtesy of VIB*

- Zebrafish genetics: looking for new cancer therapies
- What can we learn from fly brains? Something about our own brain?

The diversity of the topics gives every group the opportunity to pick a project that is really of interest to them. Some of the projects submerge the students in the latest technologies, such as gene therapy, RNA interference and nanobodies.

The projects are then assigned to the different participating teams.

### A day in the lab

Enthusiastic scientists show the tricks of the trade to 14- to 18-year-old students and guide them through their first steps in scientific research. They conduct experiments together that the scientists normally use for their daily work. These life-science experiments differ from project to project, depending on the topic. Some techniques may appear in several projects, like PCR, ELISA (enzyme-linked immunosorbent assay), DNA electrophoresis, and so forth. The guiding scientists tell the youngsters about what their lab is working on and about their own projects in particular. Often, a guided tour follows.

### A written report

Afterwards, the students are obliged to submit a report on their experimental work to VIB, the organisers of scientists@work. In this final project from the entire group, the students have to place their work in a social context and in the context of previous and ongoing research in the field.

The youngsters often work for weeks on the final report. Sometimes they renew contact with their host scientists for additional information and they search the Internet for examples or for leads to further research. We also encourage them to contact foreign scientists who are conducting similar research. The scientists@work website[w1] presents brief biographies of scientists who are willing to give students background information on different research topics. Once their report is submitted to VIB, the teams automatically participate in the competition.

### The final event

A jury selects the 10 best reports. All jury members have a scientific background and are actively engaged

BACKGROUND

## Case study

Twenty-four enthusiastic youngsters and their science teachers, from the Heilige Familie school in Sint Niklaas, were invited to Bayer CropSciences in Astene (near Ghent, Belgium) for a scientists@work project related to RNA interference: 'how can we switch off genes?'.

The host scientists prepared a very good introductory slide show explaining the principles of RNA interference and introducing the experiments for the afternoon. We heard some information on what a company like Bayer CropScience is actually doing. For the practical work the students were divided into two groups: 12 students in the laboratory ran their first 'gel' ever to isolate DNA and RNA from tobacco leaves, and the other 12 students gathered in the greenhouse to count phenotypes of cold tolerance, male sterility and so forth. The scientists from the company were very helpful in answering all our questions and the exchange of experiences of both groups was stimulating as well.

In the days and weeks to follow, students and teachers worked hard to put their experiences on paper. No wonder we were all so excited when our work was listed in the top 10 of all scientists@work experiences. Lots of stressed moments followed preparing the slide show and no less during the presentation and the jury's questions, but we did it: we finally ended up as number one! What a great experience and definitely a perfect way to get an impression of 'real-life' scientists. Some of us just needed this last push to become convinced of our choice to continue into science.

*Lieve Ongena, teacher*

in science and science education, whether as teachers, scientists or science communicators. They judge the reports on scientific accuracy and clarity. They also pay attention to the level of effort made by the class: is it a report in the students' own words, or did they copy and paste the information from another source?

The 10 chosen laureates present their work at a final event in the impressive Aula of Ghent University. The scientists who have been guiding the students introduce their team to the public. Each team presents a poster about its project in the exhibition area. In addition, they have seven minutes to present their project with the aid of a brief PowerPoint presentation, and then respond to questions from the jury. This professional jury selects three winners from the 10 finalists.

### Prizes

All the participants of scientists@work receive a memento of a handy rucksack. In addition, the three winning groups receive wonderful prizes: first prize is a five-day trip to Ireland, second prize is a two-day trip to the Ardennes in Belgium, and third prize is a voucher for books or CDs. Both prize trips include a visit to a biotechnological company or research institute.

### The secret of success

The success of the initiative lies in the combination of two major components: hands-on experience in a lab, and a contest. The competition motivates the youngsters to participate and to do their utmost. For many students, this added motivation is all it takes to get them involved, whereas the chance to use high-tech equipment provides an initial fascination for others.

After the experience in the lab, the students discuss their experiments and ideas with each other, the teacher, and the supervising scientists, arriving (without necessarily realising it) at scientific analysis. This proves to be a very strong motivational experience, stimulating interest in science in young people in a way that is very hard to achieve in a normal classroom situation.

Scientists@work is not only an instructive experience for the youngsters, but also an excellent way to fill teachers and scientist supervisors with enthusiasm. The teachers see it as an ideal way to attend a training session (an opportunity that is not often available to them). And the scientists are impressed by the interest and motivation of the groups that visit them.

*Image courtesy of VIB*

BACKGROUND

## Spreading the idea...

If you would like to set up a similar project in your own country, the scientists@work organisers are happy to offer advice. Contact Sooike Stoops (sooike.stoops@vib.be).

### Scientists@work = more scientists?

At 14 years old, you may already have a preference for a particular course of study: science, technology, languages and so on. But whether you will actually choose a (biological) scientific subject to study at university remains to be seen. For a number of students, participation in scientists@work has been the stimulus for choosing to study biology or bioengineering. The majority of participants in scientists@work will perhaps go on to study something else. Still, they have experienced what it means to 'do scientific research'. And that's important too, because it enables us to become well informed citizens who allot scientific research its rightful – important – place in our society. Even today, research too often restricts itself to the tall ivory towers and hopeful news articles. Understanding how cells and organs function, and how diseases originate and can be cured, helps youngsters to put (life) sciences in the right perspective. At the same time, by steeping themselves in these things for a day, students also notice that the path of the scientist is not always strewn with roses.

### Web references

w1 - All relevant information on scientists@work is available online: www.scientistsatwork.be. This main site is in Dutch, but a summary in English is available here: www.vib.be/InfoEdu/EN/School+competition/scientistsatwork

Scientists@work is a school project of VIB (the Flanders Institute for Biotechnology): www.vib.be

REVIEW

This article describes a brilliant idea and a successful method to introduce students to the realities of the working day of modern biology researchers: students, accompanied by a teacher, spend a day working with a research scientist in an authentic research laboratory environment. It is a productive, yet relatively simple process, and can be applied to any country with even the smallest biological research laboratory.

The information provided in the article can inspire interested scientists to organise similar projects in other science disciplines. For example, chemistry teachers might consider programmes that involve pharmaceutical companies or other major chemical labs. Also, it shows how to take advantage of competitions to attract students' interest and motivate them to participate in projects that will help them learn about science.

Projects like scientists@work not only serve to stimulate interest in science in young people and to potentially 'recruit' future scientists but also emphasise a number of other important issues that relate to scientific research, including: its true value in our life and its impact on society, its nature as an endeavour that requires communication and collaboration among scientists across borders, and the fact that it is not a secret kept hidden from the general public. Furthermore, such projects benefit everyone involved: students, teachers and research scientists.

*Michalis Hadjimarcou, Cyprus*

# Plant hallucinogens as magical medicines

*"Were such things here as we do speak about?*
*Or have we eaten on the insane root*
*That takes the reason prisoner?"*

*Shakespeare, Macbeth I.iii*

Public domain image; image source: Wikimedia Commons


Johannes Praetorius: Witches' Sabbath (Blockes-Berges Verrichtung), Leipzig, 1668

Thus wonders Banquo, who witnessed, together with Macbeth, the witches' sabbath and the first foretelling of their future at the beginning of Shakespeare's play. The apparitions were either true – or a hallucination. By giving these two options in 1606, at the height of the witch-hunt in Europe, Shakespeare not only provides a reasonable interpretation of the state of bewitchment, i.e. of delirious dreams, but also points to a possible cause of this insanity. There are poisonous plants that, upon contact or ingestion, cloud our mind and make us experience unreal sensations. As the deplorable persecution of witches tells us, most Europeans unfortunately lacked such botanical knowledge at that time.

## Plants of the family Solanaceae

The "insane root" may well have been mandrake (*Mandragora officinarum*), the most famous magic plant of the Mediterranean, sold at high prices in markets north of the Alps. Since the root can resemble a human body, mandrake was believed to contain a spirit that brings fortune and guards against evil those who own or carry the root. However, it was a dangerous business to dig up the plant, as it would issue a deadly shriek when taken from the earth. For this purpose, people were advised to fasten a dog to the half-exposed root and let the animal draw the plant out, a

Did witches once soar through the night sky on broomsticks? Or were they hallucinating after eating or touching certain plants? **Angelika Börsch-Haubold** explains how modern pharmacology helps us to understand the action of many toxic plants – some of which are still used in medicine.

*Public domain image; image source: Wikimedia Commons*

Picture of a man collecting the mandrake root with the help of a dog (*Tacuinum sanitatis*, manuscript, 1390)

ritual that is often depicted in medieval books (left). Hundreds of years later, Goethe's Mephistopheles makes fun of this superstition: "Da stehen sie umher und staunen, vertrauen nicht dem hohen Fund; der eine faselt von Alraunen, der andre von dem Schwarzen Hund." ('There they stand and marvel, not believing in the precious find; one drivels of mandrake, the other of the Black Dog.' Goethe, *Faust* II, Act I).

Mandrake and other plants of the nightshade family (Solanaceae) contain alkaloids that block nerve impulses, which may lead to hallucinations. Although the cellular and molecular mechanism of action was only explained at the end of the 20th century, the pharmacological effects of these plants were already described by the Greco-Roman physicians Dioscurides (1st century AD) and Galenus (circa 129-199) and, from the 16th century onwards, by authors of herbal medicine books in local languages. The plants deadly nightshade (*Atropa belladonna*) and henbane (*Hyoscyamus niger*; below) are indigenous to middle and northern Europe and were therefore readily available for medicinal use or narcotic and poisonous abuse. The physician Leonhart Fuchs explains in his *New Kreüterbuch* (printed in 1543) how to apply parts of these plants as sleeping agents and painkillers. In addition, he warns of their narcotic and toxic effects (box on page 52). He also groups the plant thorn-apple (*Datura stramonium*; below), which had recently been brought to Europe by travellers from India or Mexico, botanically correctly with the nightshades, but admits his ignorance of its medicinal usage.

## Witch ointments

If ever there were women experimenting with poisonous plants, and if ever they did anything other than use their knowledge to heal sick people who could not afford to (or maybe wisely chose not to) see a doctor, they may have used black or deadly nightshade and henbane as powerful ingredients in their medicines. Unfortunately, there are no direct sources for the recipes of witches' concoctions. As is known from the literature condemning magic rituals, so-called 'witch ointments' were used to anoint a broomstick or a chair as a prerequisite for riding through the air and dancing at the witches' sabbath (box on page 53; image left). Such an ointment was reputedly given to the accused directly by the Devil or by an older woman who was already a member of the witches' circle.

The recipes that have survived were written down by physicians. For example, Johannes Hartlieb, explaining the seven magic arts to the duke Johann of Brandenburg-Kulmbach in 1456, names six plants for the prepa-

Plants of the family Solanaceae

Deadly nightshade (*Atropa belladonna*)

Thorn-apple (*Datura stramonium*)

Henbane (*Hyoscyamus niger*)

*Images courtesy of Kurt Stueber, Chilepine, and Bdk; source of images: Wikimedia Commons* ration of *unguentum pharelis* (box on page 53). Although the plants were believed to possess magic powers, they are relatively harmless. Hartlieb had studied both theology and medicine, as was usual at the time, and the purpose of his writing is to prove that all witchcraft and magic is a lie. He therefore may have left out any narcotic ingredients on purpose.

Other physicians, however, most of them writing centuries later, name the plants of the family of nightshades along with the highly toxic wolfsbane (*Aconitum napellus*), hemlock (*Conium maculatum*), and the sleep-inducing opium poppy (*Papaver somniferum*) as ingredients for witches' medicines. They seem to have put together everything that was poisonous, and ethnologists of the 19th century, recreating witches' ointments and applying them to their skin, indeed experienced disturbing hallucinations with all the side effects on the nervous system that a contemporary pharmacologist would expect.

Witches probably did not read the medical literature of their time, but we can safely assume that they knew of the hallucinogenic effects of the plants that grew in their neighbourhood. Henbane was already used by Germanic tribes to increase the intoxicating action of their ale. It was banned as an ingredient of beer in 1507/1516 in Bavaria, and after that its use in narcotic drinks was, at least in southern Germany, illegal. Deadly nightshade was also widely known. Its common name, 'belladonna', alludes to the practice of Italian Renaissance women who dilated their pupils with eye drops to make them look sexually attractive. If these women also ingested deadly nightshade, they would have experienced euphoria due to a stimulation of the central nervous system.

## The pharmacology of nightshade plants

Today the action of deadly nightshade, henbane, and thorn-apple is understood in molecular detail. They all contain the alkaloids atropine and scopolamine, two closely related substances which interfere with the parasympathetic nervous system. Under parasympathetic stimulation, the heart-beat slows, smooth muscles (the involuntary muscles of inner organs) contract, digestion juices flow, and glands produce watery fluids (saliva, tears, bronchial mucous; Table 1). The neurotransmitter acetylcholine couples these nerve signals to the effector cells by activating muscarinic receptors, which in turn trig-

BACKGROUND

## Leonhart Fuchs' *New Kreüterbuch* (new book of herbs), Basel 1543

### About mandrake

...The apples as you sniff and taste them/ bring about the sleep. Such power has also their juice. But you shall not use too much/ because otherwise they kill.... Because the internal use of mandrake is very dangerous/ it is better to bring about the sleep/ if need be/ using the apples and fruits of it/ by just tasting them/ and not taking them into the body.

### About nightshade

...The other one we named Maddening Herb [deadly nightshade]. Others call it Swine Herb/ and think it is the woody nightshade/ but not without great error/ as this herb is a deadly plant/ and cannot be ingested without harm/ as is possible with the woody nightshade. However, it might be the third sex of mandrake.... Without doubt the Maddening Herb has the power of the fourth nightshade/ which makes mad and foolish/ because it is a deadly herb for human/ as given by experience. I also know certainly of two children/ who have eaten the berries/ which taste quite sweet/ and they died soon thereafter/ although they had been lively and healthy before....

### About henbane

Many call henbane also Swine Beans and Sleeping Herb.... Henbane ground freshly alone/ or mixed with malted barley and applied/ takes away all sorts of pains. The juice pressed from the herb/ a handkerchief wetted therein/ and put onto the hot/ running and painful eyes/ quenches the heat/ stops the flow and their pain. The juice or the seed oil put into the ears/ quenches the stinging therein/ and the pain. But use these with great care.... A foot bath made from henbane/ brings sleep.... The roots of Henbane boiled in vinegar and held in the mouth for some time/ takes away the great and bad aches of teeth. In summary/ the green Henbane leaves/ the seeds/ and juice/ which not only make man mad and foolish/ but also the beasts/ must not be used internally/ but only externally to stop the pain/ and to bring sleep/ and if used at all then only with good modesty.

**Note:** The original German text is available in the online version of this article[w1].

ger changes within the cell that are related to the physiological response of the organ. For example, the intracellular $Ca^{2+}$ concentration increases, which is necessary for muscle contraction and secretion.

Atropine and scopolamine chemically resemble the neurotransmitter acetylcholine. They also bind to muscarinic receptors but fail to stimulate the cell (i.e., act as antagonists). Thus, nerve transmission is blocked. Since acetylcholine is an important neurotransmitter in the brain as well, antagonism of muscarinic receptors also causes central effects. At low doses (0.5-1 mg), atropine leads to mild excitation, whereas scopolamine is responsible for drowsiness, fatigue, dreamless sleep and euphoria. The ingestion of higher doses causes restlessness and hallucinations. Poisoning with about 10 mg of atropine (less for children) leads to central depression of life functions, which may progress to coma, circulatory collapse and respiratory failure (Table 1).

## Medical use of atropine and related drugs

Atropine, scopolamine and synthetic analogues are still used as medicines, mainly to inhibit the effects of the parasympathetic nervous system. In order to prevent disturbing side effects, either the substances are applied locally (eye drops for the examination of the retina, inhalation for respiratory diseases), or specific receptor blockers are developed (tablets blocking gastric acid secretion to treat peptic and duodenal ulcers; box on page 54).

Blocking the action of acetylcholine also improves the motion disorder Parkinsons' disease. However, since the introduction of more specific drugs acting on dopamine pathways, atropine derivatives are used only to treat early symptoms or as additional therapy.

The most important use of atropine today is as an antidote for poisoning by the alkaloid muscarine (present in certain mushrooms) or by organophosphate insecticides. Both substances overstimulate the parasympathetic system. To antagonise toxic effects, atropine is injected for up to 48 hours. The doctor monitors the patient closely, giving a new injection as soon as muscarinic symptoms reappear, but not too early so as to prevent atropine toxicity.

CLASSROOM ACTIVITY

## Trial protocol – witches' ointment

**Heinrich Kramer/Institoris, Malleus maleficarum, Strasbourg 1486, Ch. II(3)**

The way of flying is the following: as became clear from above, the witches have to prepare a salve from the boiled limbs of children, especially from those whom they have murdered before baptism, and rub it onto any chair or piece of wood following the instructions by the demon, whereupon they immediately rise into the air...

**Johannes Hartlieb, The book of all forbidden arts, Munich 1456, Ch. 32**

How the riding through the air is accomplished. For these rides men and women, especially the demons, use a salve called 'unguentum pharelis'. They prepare it from seven herbs, each of which is collected on the day belonging to the herb. On Sunday, they pick and dig Solsequium, on Monday Lunariam, on Tuesday Verbenam, on Wednesday Mercurialem, on Thursday Barbam Jovis, on Friday Capillos Veneris. They make the salve by mixing these with quite a lot of birds' blood, and also animal lard. I do not write down details, so as to harm no one. Whenever they want to, they rub it on benches or chairs, rakes or oven forks and fly away. This is nothing but necromancy, which is strongly forbidden.

**Classroom activity:**

1. Look up the plants that are mentioned in Hartlieb's recipe in botany books, books on plant medicines and the Internet. What properties do they have? Solsequium ("following the sun") could be either *Heliotropium europaeum* or one of the magical plants *Calendula officinalis*, *Cichorium intybus* or *Taraxacum officinale*. Barba Jovis is *Sempervivum tectorum*, and Capillus Veneris is probably the fern *Adiantum capillus-veneris*.
2. Find out about plants of the family Solanaceae. Are they all poisonous? How do the properties of the Solanaceae family compare with those of the plants mentioned in Hartlieb's recipe?
3. What would you feel if you were to apply a witches' ointment to your skin?

**Note:** The original German text is available in the online version of this article[w1].

## Conclusion

Today, we have difficulties understanding the deep, sincere belief in witchcraft and in the reality of magic that governed Europe for centuries. It is even more puzzling to realise that the heyday of witch-hunting happened in the 16th and 17th centuries, a time when the Sun was put in the centre of the universe and Renaissance artists drew muscular, naked human bodies right in the heart of the Vatican. Unfortunately, most of our scientist colleagues of 500 years ago did not speak up and solve the mysteries of night flights on broomsticks, although they – like Shakespeare – were almost certainly familiar with the hallucinogenic effects of some plants. But why did the 'witches' themselves not explain where their dreams came from? I suspect that very few of those who were accused, tortured and burnt had actually experienced hallucinations caused by toxic plants – or indeed by anything else. In the face of the estimated 60,000 victims in Europe, one could believe that the Devil himself had had a hand in it.

## Web references

w1- The original German texts are available in the online version of this article: www.scienceinschool.org /2007/issue4/witchmedicine

## Resources


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CLASSROOM ACTIVITY

## Effects and side effects of drugs that block the muscarinic receptor

For this exercise, you will need information about the effects and side effects of some anti-muscarinic drugs. Ask your local pharmacist to lend you the *European Pharmacopoeia* or to photocopy the customer information supplied with antimuscarinic drugs (see the list below for examples).

Your students should use this information to consider the effects and side effects of anti-muscarinic drugs. Are they due to the blocking of nerve transmission? Which effects are peripheral and which are central? Using the information in Table 1, students should be able to identify which effects and side effects of the drugs are caused by muscarinic receptor blockers.

Some examples of suitable answers include:

1. Eye drops containing atropine, scopolamine, homatropine or tropicamide are used to dilate the pupils for the examination of the retina. Ocular side effects are photosensitivity and blurred vision.
2. The specific muscarinic M1 receptor antagonist pirenzepine selectively inhibits gastric acid secretion and is used to treat gastric ulcers. However, it can cause a dry mouth, blurred vision, photophobia and difficulty in urination.
3. Ipratropium bromide dilates the smooth muscles in the respiratory tract and alleviates symptoms in asthma. The atropine molecule is chemically changed to contain a charged residue. This prevents the substance from passing into the brain, and central side effects are missing. The local application by aerosol inhalation also helps to restrict unwanted effects.
4. Benztropine or diphenhydramine are used against mild symptoms of Parkinson's disease or as adjunct to the dopamine therapy of Parkinson's disease. Adverse effects are constipation, urinary retention and blurred vision. In addition, sedation and mental confusion have been reported in the elderly.
5. Scopolamine is highly effective for preventing motion sickness when used prophylactically. This is a central effect of the belladonna alkaloid. The drug is incorporated into a multilayered adhesive unit and put directly onto the skin. Common side effects are dry mouth, drowsiness and blurred vision. Psychotic episodes are very rare.

Table 1: Effects of the neurotransmitter acetylcholine and the muscarinic receptor blockers atropine and scopolamine

| Organ | Acetylcholine | Atropine, Scopolamine |
|---|---|---|
| **Eye** | contraction of sphincter muscle;<br>contraction of ciliary muscle for near vision;<br>↑ secretion by lacrimal glands | dilation of pupils (mydriasis);<br>blurring of near vision (cycloplegia);<br>dry eye |
| **Heart** | ↓ heart rate; ↓ contractility | ↑ heart rate (tachycardia);<br>cardiac arrhythmias |
| **Lung** | contraction of tracheal and bronchial muscle;<br>↑ secretion by bronchial glands (watery mucous) | dilation of bronchioles;<br>↓ secretion: dry mucous membranes |
| **Stomach<br>Intestine** | ↑ tone and motility;<br>relaxation of sphincters;<br>↑ secretion by digestive glands | ↓ motor activity;<br><br>↓ secretory function |
| **Urinary bladder** | contraction of muscles of the bladder wall;<br>relaxation of sphincter muscle | difficulty in urination |
| **Skin** | ↑ secretion by sweat glands | ↓ sweat: skin flushed, hot, dry, and scarlet (body temperature ↑) |
| **Mouth** | ↑ watery secretion of saliva | dry mouth, difficulties in swallowing, thirst |
| **Brain** | medulla and higher cerebral centres regulate the vagus nerve | restlessness and fatigue; headache; hallucinations, delirium, followed by coma, circulatory collapse and respiratory failure |

REVIEW

People who think that teaching or learning science at school is boring would surely change their mind if they read this article. Angelika Börsch-Haubold takes us on an exciting journey across English and German literature, history, botany, human physiology and biochemistry to explore facts and myths of witch medicine.

Even if the addressed subject is a specific one, the style of the article is engaging, clear and precise and the information provided is supported by a rich set of documents: quotations, original texts with translations, tables, pictures and literature references.

The article and the proposed classroom activities (on the quoted plants and on the side effects of antimuscarinic drugs) are particularly suitable for upper secondary school but, with a little simplification, they can be adapted for lower secondary school within science and humanities curricula.

In fact the interdisciplinary approach is a relevant feature of this material and gives the possibility to extend the proposed activities to different fields (biology, chemistry, history) and to discuss relevant issues like the problem of drug abuse (health education).

Finally the methodology used by the author can be applied to address other scientific subjects with a wider cultural approach, giving them a deeper meaning and an extra appeal.

So, if you need a special lesson for Halloween… keep this article to hand!

*Giulia Realdon, Italy*

# Is traditional engineering the right system with which to manipulate our world?

We are relative newcomers on Earth and still have a lot to learn. **Julian Vincent** from the University of Bath, UK, investigates some of the lessons we can learn from the living world.


The hooks on a burdock seed head

Engineering is probably humankind's greatest achievement. And like all high-profile activities, it is in danger of becoming our downfall. It's not that we are too good at it, it's that we hardly realise that there are alternatives. A new study which compares engineering and the living world as problem-solving systems suggests that we have the tools for sustainable living, but are not using them properly (Vincent et al., 2006). We don't necessarily have to go down an overtly 'green' path, but we need to reorganise current techniques with a different emphasis.

Engineering is a subset of human behaviour. It increases our ability to survive, especially under hostile conditions such as extreme temperatures. Animals and plants are able to survive such conditions because they possess extreme adaptations. For instance, the feathers of the gentoo penguin (*Pygoscelis papua*) can support a temperature difference of about 60°C across a thickness of 2 cm or so (Dawson et al., 1999); a penguin has a body temperature of 38°C and can survive in temperatures between -30 and -60°C. The desert cockroach (*Arenivaga investigata*) can harvest water from apparently dry air (O'Donnell, 1982). However, whereas individual species of animals and plants each have only a few adaptations, and so are found in well-defined habitats, humans can assume a wide variety of survival mechanisms, changing them as the environment changes. Thus, humans are not limited in climatic range, and have overrun the Earth. However, current methods of providing protection or isolation from the climate, such as houses, heating, air conditioning, waterproofing and protection from floods, are energy expensive, accounting for nearly half of our current energy usage.

Some of these mechanisms are being copied or adapted from nature, and form part of the emerging study of biomimetics (also known as biomimicry, bionics or bio-inspired design). Velcro is the archetype, inspired by the hooked seeds of burdock (*Arctium minus*) (see images). Superhydrophobicity is another

Image courtesy of Pismire; image source Wikimedia Commons

Gentoo penguin (*Pygoscelis papua*)

example, driven by observations of the lotus leaf (*Nelumbo nucifera*), to which no water-based material can stick, and which can be cleaned simply by pouring water over it (see image; Barthlott & Neinhuis, 1997). Other examples are the non-sticky adhesive hairs on the feet of the gecko (for instance *Hemidactylus garnotii*), with which it can climb vertical walls (Autumn et al., 2001). Our adhesives would soon become non-sticky with the accumulation of dust but somehow the gecko's feet clean themselves (Hansen & Autumn, 2005). Other examples are the shapes of trees which, because they mould themselves to prevent any weak points, inspire the design of strong components for use in motor cars; non-reflective surfaces based on the moth-eye and the leaves of plants growing in deep shade, neither of which can afford to lose light by reflecting it. The list continues. These are all examples of biological engineering: the solution of living organisms to the problems posed by survival – the same problems, essentially, which we have solved using engineering.

In recent years, members of our research group have been comparing strategies to see whether biology has better or different solutions to the problems of survival. To do this, we used a collection of 40 'inventive principles' which Genrich Altshuller, a Russian inventor and thinker, devised to represent the manipulations by which engineers solve problems. He and his colleagues gleaned these by studying successful patents, categorising them in terms of the problem that had been solved and the means of solution. The list forms part of a problem-solving system called TRIZ (Altshuller, 1988).

A problem arises if you want something, but you are prevented from achieving this desire. Plato pointed this out several thousand years ago. Altshuller also realised this, but reformulated and formalised the idea by producing a list of categories that covered all possible results and their conflicts. He then showed that a good invention is successful because it

CLASSROOM ACTIVITY

## A biomimetic challenge

Get your students involved in biomimetics! Here are two challenges from the *Science in School* editor:

1. Can you think of a plant, animal or micro-organism that has solved a problem with which humans still struggle? Do you know what the biological solution to the problem is? How do you think humans might use this?
2. Draw or paint a picture of how a plant, animal or micro-organism has evolved to survive in a hostile environment.

Send us your ideas and/or pictures by 30 June 2007, and we will publish our favourite entries together with Professor Vincent's responses. Don't forget to tell us your name, age, school and country. Include the text 'Biomimetics challenge' in the subject line of your email and send it to: editor@scienceinschool.org

Image courtesy of robot2000/Pixelquelle.de

Image courtesy of Wilhelm Barthlott, University of Bonn

Left: The lotus effect

Right: Water-based glue running off a lotus leaf

resolves a conflict with a new concept rather than with a compromise that satisfies nobody. Significantly, he listed the ways – the inventive principles – by which the conflict could be manipulated in order to achieve this resolution.

All this was a bit complex for us in our aim to compare biology and technology. Altshuller had help, and together they analysed some 3 million patents. We had less time and fewer people, so we simplified his system, and stated that there are six basic things that we can change in order to resolve a conflict. These are:

- Substance (the material from which something is made)
- Structure (the way the materials are arranged)
- Energy (the source of energy, or the amount of energy, whether more or less)
- Space (space occupied by the system, or space available for it to work)
- Time (the order in which things might happen, or the time required for something to be done)
- Information (the control mechanism and things which influence it).

One of our findings is that biology solves the same types of problem that we solve with engineering, but the method of doing so is similar only 12% of the time. For example, in arthropods the forces in the cuticle, which can come from internal or external sources, are detected by the change in shape of holes placed in the most highly loaded areas and which extend through the cuticle. In engineering, a hole is considered dangerous as it can be the start of a crack, so forces are more likely to be measured by a separate strain gauge. But the arthropod's cuticular hole is very carefully designed with great attention to detail, is totally safe, and is considerably more sensitive than a strain gauge. We could incorporate such devices, but our engineering rules and preconceptions do not consider such a possibility.

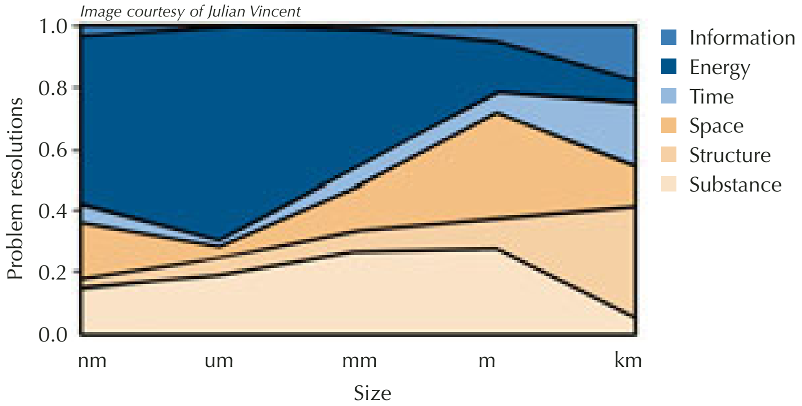
We had a more important result (see graphs). We arranged the solutions according to the size of the system, ranging from nanometres to kilometres and spanning 12 orders of magnitude. We then found even larger differences between technology and biology. In technology, at the micrometre to centimetre level, we solve 70% of problems by manipulating energy in some way. Note that this does not refer to the *amount* of energy. Examples might be increasing the speed of reaction by increasing temperature, using pneumatic or hydraulic delivery or control of energy, or reducing the energy requirement by allowing a component to resonate.

Image courtesy of Bryan Weinstein / iStockphoto

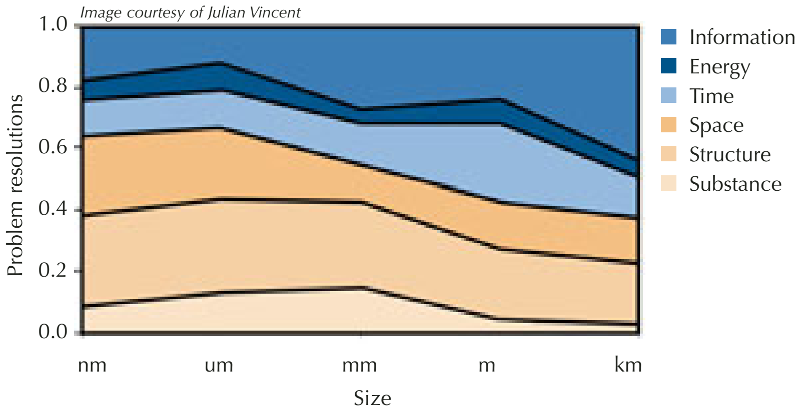
Velcro

Nonetheless, when we saw that biology relies on changes in energy no more than 5% of the time, we realised that this is an important difference. In biology, change is effected by imbuing everything with information, starting from the DNA molecule. The proteins that DNA encodes also contain that information and allow the organism to interact with its environment, which represents another source of information. Proteins and their products then interact and 'self-assemble' in defined ways to form organelles, tissues, organs and organisms. The ordered arrangement of these levels of organisation, and the behaviour of the resulting organisms, all rely upon their embedded information and reflect it in the patterns that we observe. None of this occurs in the standard methods of engineering, although the idea of self-replicating machines has been around for some time. Adrian Bowyer, a member of our team, is running a project in which the computer programme for making a rapid prototyping machine can be downloaded from the Internet and read by a rapid prototyping machine. This machine will then be able to make a copy not only of itself, but also of (notionally) anything else. More details of this disruptive idea are available from the RepRap website[w1]. Nevertheless, all patterns in the manufactured world are the result of conditions imposed by an engineer at some level.

Another difference is that technology is very reliant on materials – for instance, we use over 350 types of




Solving problems in technology. In order to resolve a difficulty, we have to manipulate one or more of the six classes of function. The appropriate class changes with size




Solving problems in biology. In order to resolve a difficulty, organisms manipulate one or more of the six classes of function. The appropriate class seems not to be dependent on size, suggesting that the distribution has a fractal component

polymer in engineering. Biology has just two – protein and polysaccharide. But these are so variable, because of the information they contain, that they can achieve more than any man-made polymer. That information allows them to self-assemble into structures, such as the cell wall of a plant or the cuticle of an insect or lobster, which provide yet more functional versatility. In addition, with only two polymers to deal with, recycling is relatively easy. Current waste reclamation allows us to separate only about six polymers (Table 1) with any reliability. But these six represent most of the functionality we require. Why do we have so many polymers? We should select our materials for their ease of sorting and recycling. Their functionality can be increased even further by copying nature and assembling them into structures such as foams and honeycombs, or combinations and permutations of such structures.

We are only at the beginning of the study of biomimetics and how to make the best use of the technological tricks we can learn from biology, but already we have discovered ways to challenge technology and revealed

Table 1: The six separable plastics

| Name | Abbreviation | Stiffness | Use | Comments |
|---|---|---|---|---|
| **Low-density polyethylene** | LDPE | Flexible | Films, bags | |
| **High-density polyethylene** | HDPE | Rigid | Films, bottles | |
| **Polypropylene** | PP | Rigid | Films, sheets, bottles | Tough, light, cheap |
| **Polyethylene terephthalate** | PET | Rigid | Films, sheets bottles | |
| **Polystyrene** | PS | Rigid | Films, rigid sheets | Easy to replace |
| **Polyvinylchloride** | PVC | Rigid and flexible | Films, sheets, bottles | Easy to replace |

REVIEW

By reading this article you will learn some new synonymous terms: *biomimetics*, *biomimicry*, *bionics* and *bioinspired design*. They are all words describing how living creatures are used as models or inspiration for engineers when developing new materials or constructions. Animals and plants are very well adapted to their environment because they have solved challenges related to their survival, for example isolation from extreme heat or cold. They have evolved materials and strategies which are very well suited for certain aspects of their life, such as reproduction, feeding, protection and so forth. Professor Vincent gives us examples of so-called biological tricks that can be useful in engineering. By comparing basic elements within biology and technology, scientists and engineers will achieve a better understanding for resolving their problems. There are plenty of things we can learn from nature!

Don't forget to study and involve your students in the two challenges at the end of the article!

*Sølve Marie Tegner Stenmark, Norway*

ways that biological organisms – the great survivors – answer the same problems in a sustainable manner. Now we have to set about changing technology to ensure our survival – although humans have successfully colonised a wider range of environments than any other species, they have done so in a very inefficient way, at enormous environmental cost.

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w1 - RepRep website: http://reprap.org


## Resources

For an example of recent biomimetic research into spider silk, see:

Cicognani G, Capellas M (2007) Silken, stretchy and stronger than steel! *Science in School* **4** : 15-17. www.scienceinschool.org/2007/issue4/spidersilk


Professor Julian F. V. Vincent is the director of the Centre for Biomimetic and Natural Technologies at the University of Bath, UK.

# Fusion in the Universe: we are all stardust

**Henri Boffin** and **Douglas Pierce-Price** from ESO, in Garching, Germany, investigate our celestial ancestry.

The next time you gaze at stars during an evening stroll, you should spare some companionable thoughts for these glowing balls wandering silently in the vast Universe. For you are looking, in a sense, at your ancestors: humans, all other living creatures on Earth – and Earth itself – are children of the stars! Most of the elements of which we are made or which allow us to live – carbon, oxygen, nitrogen and many others – were created in stars. Even the fluorine that makes our teeth strong!

Matter as we know it is composed of three-quarters hydrogen and roughly one-quarter helium. All the other elements come only in tiny amounts, and astronomers tend to call these trace elements simply 'metals', even if the elements are not really metallic. The hydrogen and helium were created right at the start, in the very first minutes of the existence of the Universe. Less than one second after the Big Bang, the event through which everything came into being, fleeting energetic particles were 'frozen' into the future components of atomic nuclei: protons and neutrons. The 'freezing' was very relative, however, as the temperature at that instant was still several hundreds of billions of degrees!

During the first second after the Big Bang, the temperature was so high that protons and neutrons were in equilibrium. Soon, however, the temperature dropped below a critical value, and neutrons started to decay, each producing a proton, an electron and an anti-neutrino. This decay was possible because neutrons have a higher mass than protons. The Universe would quickly have become devoid of neutrons were it not for a reaction that 'preserved' them, by combining a neutron and a proton to form a deuteron, the nucleus of deuterium.


Image courtesy of ESO

The Dumbbell nebula, consisting of very rarefied gas that has been ejected from the hot central star (visible on this image), in one of its last evolutionary stages

Deuterium is also called heavy hydrogen and is most famous for its importance in the nuclear bombs that the Germans tried to make during World War II. Once deuterons have formed, other heavier nuclei can form. When two deuterons collide, they produce a neutron and a helium nucleus – in its light helium-3 variant, consisting of one neutron and two protons. The process may then continue one step further, producing the more common helium-4 nucleus, consisting of two neutrons and two protons. Almost all the neutrons in the Universe end up in normal helium-4 nuclei, but a few helium nuclei combine into heavier nuclei, giving a small amount of lithium-7.

So, three parts hydrogen, one part helium-4, a little deuterium and helium-3, and a pinch of lithium. A few minutes after the Big Bang, the great cosmic soup has been prepared, the basis of all the other ingredients yet to come in the Universe: stars, planets and, eventually, life. Amazingly, the preparation of this soup is so simple that even the least experienced cook could try it. In fact, the balance of ingredients depends on a single parameter: the initial density of protons and neutrons. When astronomers measured the amount of these elements in the Universe, they found values that agreed very well with those predicted by the theory. This close agreement was one of the nails in the coffin of opponents to the Big Bang theory.

But what about the heavier elements? If they were not created in the first moments of the Universe, where do they come from and when were they created? The answer lies in the stars.

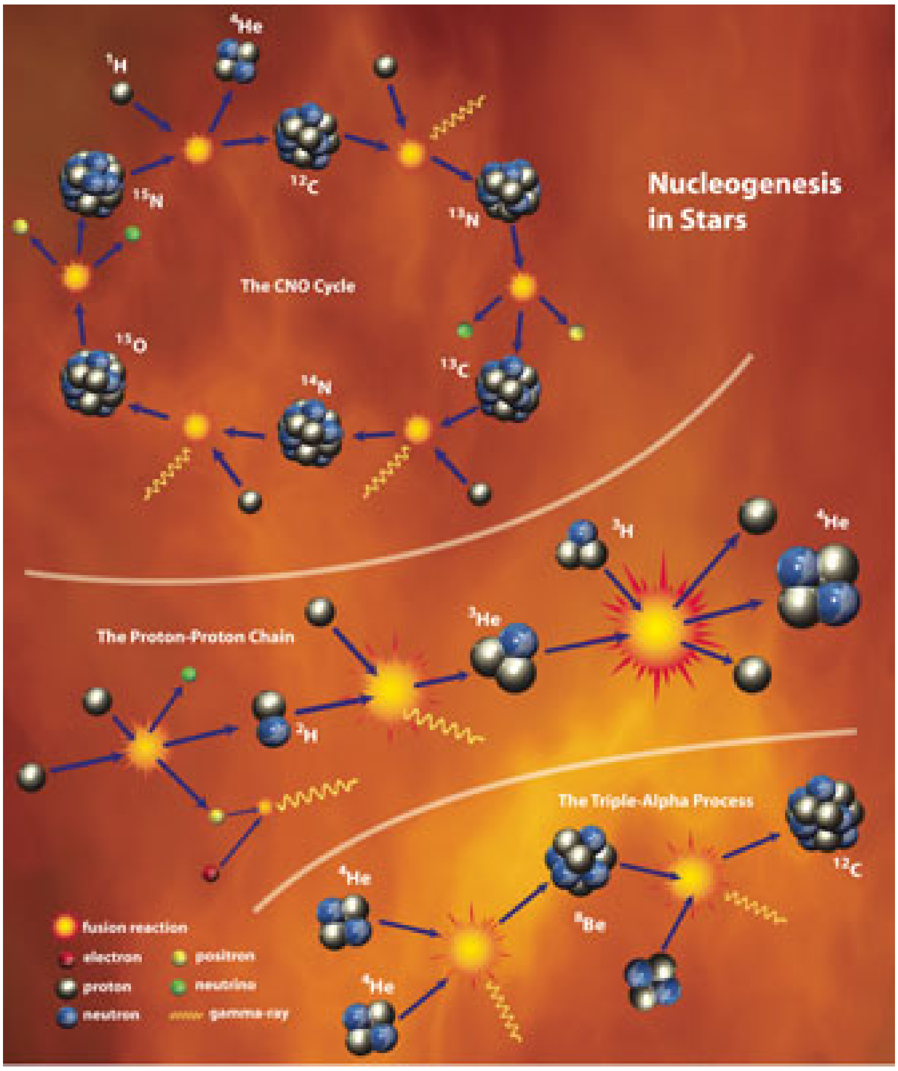
In the interiors of stars, temperature and density are high enough to overcome the forces that cause atomic nuclei to repel each other, allowing them, instead, to fuse. In Issue 3 of *Science in School*, we saw that the power of the Sun comes from the fusion of hydrogen nuclei to form helium in its inner core (Westra, 2006). The same happens in all stars that are in the 'main sequence', the stage at which they burn hydrogen.

The mechanism by which stars produce helium from hydrogen depends on the mass of the star: stars of the same or smaller mass than the Sun convert hydrogen into helium mostly through the 'proton-proton chain' (see image). In more massive stars, the main mechanism is the 'CNO cycle', in which carbon, nitrogen and oxygen atoms act as catalysts for the fusion of hydrogen into helium (see image).

The CNO cycle raises an apparent paradox: if the carbon, nitrogen and oxygen elements are themselves produced in stars, how can they be used as catalysts to fuse hydrogen into helium? This solution lies in the fact that stars form from the remains of previous generations of stars. The very first stars did indeed contain only hydrogen and helium, which they converted into heavier elements. These heavier elements were liberated into the interstellar medium when the stars exploded as supernovae. The interstellar medium became progressively enriched in carbon, nitrogen and oxygen, and the next generation of stars formed with a small amount of these elements, enough to act as catalysts.

During the main sequence, the longest period in the life of a star, hydrogen is thus converted into helium. Eventually, hydrogen is depleted in the centre of the star, where burning occurs, and the star evolves, becoming larger, cooler, and redder –

*Image courtesy of Mark Tiele Westra*




Nucleogenesis in stars

BACKGROUND

## A genius' prediction

The 'triple-alpha process' (see image) is an example of helium capture. It is a two-step reaction in which a carbon nucleus is formed from three helium nuclei. First, two alpha-particles (helium nuclei) collide to form a beryllium-8 nucleus. This is unstable and decays very rapidly. On the face of it, it is unlikely that a third helium nucleus could be captured before the beryllium-8 decays. To create significant amounts of carbon in the Universe, some *additional* factor which makes a successful combination more likely would be needed.

But, we know that carbon is created – if it were not, then we humans, and all life on Earth, would not be here to discuss it, and you would not be reading this article! Using this simple but profound argument, the famous British astronomer Fred Hoyle (1915-2001), in a characteristic stroke of genius, *predicted* that some additional helping factor must indeed exist. Scientists turned to laboratory experiments and, sure enough, discovered a previously unknown 'resonance', a matching of energy levels between the beryllium-8 and helium-4 nuclei, and the carbon-12 nucleus that they form. This resonance greatly increases the probability of a successful combination, just as Hoyle predicted. This is a fascinating example of a scientific prediction being made from an argument based on the simple fact that scientists (and life itself) even exist to think about it.

a 'red giant'. After a brief phase, the temperature and density in the core increase sufficiently for new reactions to occur. This time, it is helium that starts to burn. Two helium nuclei can fuse to form a beryllium nucleus. Although beryllium nuclei are unstable, and most will rapidly disintegrate, some will collide with another helium nucleus, forming carbon. The net result is thus that three helium nuclei form a carbon nucleus. A fraction of the carbon nuclei thus formed collide with further helium nuclei to form oxygen. In the cores of these giant stars, therefore, helium is converted to a mixture of carbon and oxygen.

For stars only a few times bigger than our Sun, this will be the end. Once this carbon-oxygen core has formed, the star ejects its outer envelope in the form of a 'planetary nebula', leaving behind a white dwarf.

For more massive stars, however, the adventure continues. The gravitational force exerted by such a star is still strong, causing the core to contract further, thereby increasing the density and the temperature so that further nuclear reactions, leading to yet heavier elements, are possible. In this way, elements such as neon, magnesium and silicon, and later sulphur, chlorine and calcium are produced. All these elements have a number of nucleons that is a multiple of four, as they come from the combination of helium nuclei. As the helium nucleus is also called an alpha-particle, these elements are known as alpha-elements and are more abundant than other heavier elements.

However, helium capture is not the only possible process by which heavier elements are formed. Nuclei can also, more rarely, capture other particles, such as neutrons, protons and deuterons. In this way, a variety of elements, such as fluorine or sodium, can be produced. These elements, however, are present in smaller quantities.

Finally, nickel-56 can be formed in the alpha-process (by the combination of helium nuclei). This nucleus – with 28 protons and 28 neutrons – is unstable, and spontaneously decays into iron-56, which has a stable 26 protons and 30 neutrons. Up to this point, all the reactions that have taken place in the star have produced energy, which allowed the star to continue its life and 'fight' against gravity. But with the formation of iron-56, this is no longer possible. Being the most stable nucleus that exists – it has the highest nuclear binding energy – iron-56 can only be transformed into other elements by putting energy in, rather than getting energy out. The star cannot use these nuclear reactions to support itself. The production of a core of iron in a massive star is thus a prophecy of doom: the star can no longer fight against gravity. It collapses, and the ensuing rebound and shock wave end its life in a grandiose and dramatic explosion: a supernova. By exploding, the star will cast into the interstellar medium all the elements it has created – and others it will create just before dying. But that is another story....

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### Resources

For more information about ESO (the European Organisation for Astronomical Research in the Southern Hemisphere) and its educational projects, visit: www.eso.org/outreach/eduoff/

# You're researching what? Toothpaste?


Linda Sellou, a French PhD student at Bristol University, UK, tells **Sai Pathmanathan**, a science education journalist, what she thought of her school science and what she's up to now...

When did you first become interested in science? Was it sparked by a particular event? Linda remembers:

"It was when I went to 'la cité de la science' [city of science] in Paris for the first time. I was quite young (still at primary school) but I remember being fascinated by the reactions in which there was a change of colour and thinking that liquid nitrogen looked very cool! From then, my interest grew gradually until secondary school where I found out that food and cosmetics were related to chemistry!"

Most girls love their make-up, but how many would make the link between chemistry and cosmetics, and how many young girls are inspired to study science after school? Linda feels she is a very fortunate individual. School science not only allowed her to discover what science is all about, but also made it more accessible and showed her how science is applied in everyday life. She was even more excited when it was time for practical work. And without school science, Linda wouldn't be where she is today, enjoying scientific research.

"Science is everywhere around you, I like being able to understand what is going on in my life!"

When most of us think of cosmetics, eye-shadow, mascara and bright red lipstick all spring to mind. No one thinks about toothpaste. Yet there are scientists researching the properties and components of toothpaste, and Linda is one of them. She is currently researching the abrasiveness of toothpaste: the roughness of different types of silica particles found in the paste. She studies the structure of these particles and how they scratch the teeth. For toothpaste manufacturers, it is vital to know as much information as possible about the components. Toothpaste works by removing the protein layer (pellicle) formed on the surface of the teeth after exposure to saliva, which would otherwise cause tooth decay. To remove this pellicle, an abrasive toothpaste is needed, but the paste cannot be too abrasive, or the dentine (at the gum margin) will wear away.

Linda began by making and characterising a toothpaste base composed of silica, sorbitol, polyethylene glycol, sodium dodecyl sulphate, sodium carboxymethyl cellulose and water. In commercially available toothpastes, flavour and fluoride are also added. She tests both the abrasiveness and the cleaning efficacy of the toothpaste base *in vitro*, using a brushing machine with a lateral motion. Using extracted teeth, it would have been possible to test the toothpaste on slices of dentine, but Linda found it more practical to use a Perspex (polymethylmethacrylate) model, which has similar physical properties to dentine. For the abrasiveness test, she brushes the Perspex plate for a certain time using the toothpaste base and calculates the abrasiveness index by quantifying the reflectance of the Perspex before and after brushing. To measure how effective the toothpaste is at cleaning teeth, Linda performs similar tests using previously stained hydroxyapatite (apatite crystals of calcium and phosphate, $[Ca_{10}(PO_4)_6(OH)_6]$), which is the main component of enamel. By comparing toothpaste bases containing different types of silica particles, Linda can find the ideal toothpaste components."Basically, the issue is to provide maximum tooth cleaning and

Image courtesy of Tim Harrison

Linda Sellou

minimum tooth abrasion. I find it interesting simply because it directly touches everyone – twice a day!"

Linda always knew she wanted to study chemistry. After the Baccalaureat, she sat the competitive exams to enter university, the 'Ecole Nationale Supérieure de Chimie de Lille', to study physical chemistry. In her final year of study, she moved to the University of Bristol, UK, as an ERASMUS student. Her research project was on fragrances, based at the Bristol Colloid Centre. And when, at the end of the year, the centre offered Linda a PhD studentship with them to research toothpaste, she didn't hesitate to accept.

Linda was quite lucky with the way everything fell into place. She realises that others may not be quite so fortunate, but she advises them not to give up: "Stick to what you want to do and never be discouraged by what people say." Linda recommends to anyone wishing to follow a similar career path that they take time to decide which field to specialise in, and choose appropriate school and undergraduate science projects. Of course, talking to people in the field helps.

Linda believes that background, status or education should not prevent any student from following their dreams. "I come from the suburbs of Paris ('banlieue'), which are traditionally where immigrants, in particular low-income families, have settled. The 'banlieue' are often characterised as sensitive areas, and were the site of well publicised riots in 2005. Because of the situation in which the children grow up, they are not always aware of the options they have in education or are discouraged before they even start. Sadly, some teachers also underestimate the abilities of pupils from these areas, and do not think we are capable of further education.

"At college, my mathematics and physics teachers told me I was not good enough to apply for 'classes préparatoires' or to become an 'ingénieure' in chemistry ('classes préparatoires' are preparatory courses for the competitive entrance examinations to one of the 'grandes ecoles', elite higher education institutions. An 'ingénieur' is a graduate of one of the grandes ecoles). The only encouragement I got was from my French-language teacher! My parents, however, were very supportive although they do not know anything at all about science or even higher education. My mum is a housewife and my dad is a building painter who emigrated from Algeria 40 years ago, but they've always encouraged me even though they couldn't understand what I was doing. To be honest, at first I was a bit confused by the conflicting messages, but then I decided not to listen to the teachers and carried on working even harder."

Today, the situation in schools in the 'banlieue' is far from perfect but there have been improvements, such as more tutoring and counselling on a regular basis at secondary school. Linda believes that this is the key, especially if there is nobody at home who is able to help.

But science is not all hard work and exams. And you don't need to be a Hollywood actress to win awards. Last October, Linda won one of only four poster prizes at the 12$^{th}$ IACIS International Conference on Surface and Colloid Science in Beijing. "Being only a second-year PhD student, I found it so gratifying and reassuring to have my work appreciated and recognised. It gives me a real boost to work even harder and make further discoveries."

But Linda admits that the image of science could be improved. "Sometimes people think that science is hard work and boring. It also seems to have this nerdy image. I am not saying it is not hard work; of course we work hard. But science, particularly chemistry, can be very enjoyable and is accessible to everyone. It all depends on how it is approached. Teachers, of course, play a major role in this. For example, my three little sisters think science is too hard, just numbers, equations and formulae, because that is the way they are taught at school. But when I tell them that chemistry is all around us, from their clothes, toiletries and medicines to their favourite foods, they are surprised. They ask me why they are not told this at school. Although applications of science are obvious to the teachers, they are not always so clear to the students.

"When I introduce myself to people, I say I am doing a PhD in chemistry. People rarely ask what I am researching because they think they won't understand. But when I tell them my research is all about toothpaste, they smile or even laugh because it is simple, applied and they know what it is!"

Many scientists are great communicators, and Linda is no exception. While studying for her degree in France, she worked with the UIC, a French chemical industry association. Linda would visit schools with someone from the chemical industry to give talks on chemistry in general and its applications. Now in Bristol, Linda is an active science and engineering ambassador in a scheme supported by SETNET[w1].

This scheme links schools and school students with organisations involved in science, technology, engineering and mathematics (STEM), providing young people with relevant and exciting activities and schemes. The ambassadors are drawn from diverse STEM backgrounds all over the UK, including employers, lab technicians, academics and postgraduate students. They share their enthusiasm and passion for their subjects, supporting school activities and hoping to inspire children from primary and secondary schools. The benefits of the scheme are diverse, providing extra support for teachers, allowing them to develop more varied teaching and learning styles, and to update their knowledge of contemporary science and technology, as well as the research process. To the students, the ambassadors bring a different approach and perspective, often more accessible and interesting for pupils, but also challenging.

"I enjoy working as a science and engineering ambassador very much. I am learning and developing communication skills but above all I feel good passing on my knowledge, helping students discover new things, sharing my interest with them and watching them enjoy the whole experience. Pupils can relate science to their everyday life and they are motivated and enthusiastic to learn more and hopefully I've inspired them to do a career in science."

So what's next for Linda? She'd like to discover more and publish her work. But more importantly, she'd like to travel, something that is generally not difficult in academia. "Perhaps Australia. I am very keen on discovering other cultures and I am also interested in learning about other fields, like biochemistry. In the meantime, I'll carry on working with schools and maybe set up some links between British and French schools and scientists!"

## Web references

w1 - SETNET website: www.setnet.org.uk


Image courtesy of Tim Harrison

# *Erin Brockovich*

Films about science or even pseudo-science can be powerful tools in the classroom. **Jenna Stevens** from the CISCI project provides a toolkit for using the film *Erin Brockovich* in chemistry and ecology lessons.

## Description of the film

Erin Brockovich is struggling to make ends meet as a single mother with three children when she meets attorney Ed Masry and convinces him to give her a job in his firm. When filing the paperwork for a real-estate case, she decides to investigate further because the owners of the property have some unusual health issues. After much research, she discovers that these health problems are due to the presence of chromium in the area's groundwater and that this is affecting the health of the whole community. She finds herself with a massive case against the large corporation that is causing the chromium pollution and works tirelessly to unite the community in an effort to stop the corporation and get the people the compensation they deserve.

Table 1: *Erin Brockovich* details

| | |
|---|---|
| *Title* | *Erin Brockovich* |
| *Year* | 2000 |
| *Film producer* | Jersey Films |
| *Director* | Steven Soderbergh |
| *Cast* | Julia Roberts, David Brisbin, Dawn Didawick, Albert Finney |
| *Scientific subject and topic* | Chemistry and ecology |
| *Website* | Filmography links and data courtesy of The Internet Movie Database<br>www.imdb.com/title/tt0195685/ |

## Description of scene

When Erin visits a professor at a nearby college to learn more about chromium, she finds out that there are actually several kinds of chromium, the most harmful of which can cause a wide variety of very serious health problems after prolonged exposure. The professor also tells Erin that chromium(VI) is in the water used to cool piston engines at factories to prevent corrosion.

## Basic level

Hexavalent chromium, also referred to as chromium(VI), Cr(VI), chromium-6 or $Cr^{6+}$, is a very dangerous form of chromium, as described by the professor in this scene. In this movie, Cr(VI) is ingested by the residents in the area due to its presence in their water. Among the health problems caused by ingesting Cr(VI) are various forms of cancer, respiratory diseases, kidney failure, gastrointestinal conditions, reproductive problems, as well as nosebleeds, headaches, benign (non-cancerous) tumours and hair loss. The workers in plants where Cr(VI) is used also experience health problems when it comes into contact with their skin or when they inhale it.

Throughout the movie, different medical cases of residents are brought

Table 2: *Erin Brockovich* details

| | |
|---|---|
| *Time interval* | 31:32-33:00 in Chapter 13 |
| *Scientific keywords* | Chromium, piston engines, corrosion |
| *Title of scene* | What kind of chromium is it? |

up and many of these side effects are present. One character in particular, Donna Jensen, has had multiple benign tumours as well as cancer.

## Advanced level

### Chromium(VI)

Chromium is a transition metal that can have different oxidation states resulting in different properties and reactions with other chemicals. Two common forms of chromium are trivalent chromium (Cr(III)) and hexavalent chromium. Trivalent chromium is more common in natural settings and commonly found in soil, whereas Cr(VI) can be found in industrial settings and is not as safe as Cr(III). When ingested, Cr(VI) can cause problems in various systems of the body, including but not limited to the liver and kidneys, the reproductive system and the respiratory system. It is believed to cause cancer in these systems, but there is controversy over this due to evidence that Cr(VI) becomes Cr(III) when it enters the stomach.

### Industrial use of chromium(VI)

Cr(VI) is used in the industrial setting to make dyes and pigments as well as bricks for furnaces, and also to tan leather and preserve wood. The Pacific Gas & Electric Company (PG&E) used it in their piston engines to prevent corrosion. As suggested by the professor in the film, Cr(VI) is added to the water that is used to cool the engines. This is what caused the contamination of the groundwater in the areas surrounding the PG&E plant.

### Corrosion

Corrosion is a result of reactions between a material, typically a metal, and its environment, resulting in an oxide (e.g. MgO) or salt (e.g. $MgCl^2$) of the metal. This causes the metal to become weak. In an industrial setting, this must be protected against to preserve machines made of metal.

## Scientific level

Chromium is primarily found in the Cr(III) form as sediments and is insoluble in water. However, dissolved chromium is typically in the Cr(VI) form. Drinking-water levels of Cr(VI) are usually less than 2 parts per billion. Tests of the area on which the movie was based have revealed 6 to 8 parts per billion of Cr(VI) in the drinking water, confirming there was an excess amount present. In water, Cr(VI) typically exists in the monomeric or bimeric state, such as in $HCrO_4^-$ and $Cr_2O_7^{2-}$. These can cause discolouration of the water to a yellow or orange tint, however, at such small concentrations the colour change would be expected to be unnoticeable. The World Health Organization has recommended that the maximum allowable concentration limit for drinking water should be set at 0.05mg/L.

PG&E had large cooling towers to remove excess heat produced from their generators. The cooling towers would accumulate corrosion or mineral deposits over time. However, adding sodium dichromate (Cr(VI)) greatly reduces mineral build-up and corrosion. Eventually, the Cr(VI) degrades and is reduced to Cr(III), which is inefficient at inhibiting corrosion. PG&E put their waste coolant into shallow dredge ponds.

The sandy soil allowed the waste coolant to leach into the groundwater and wells of the town of Hinkley, where the plant was based. The town's residents used this water as drinking and bathing water. In the industrial setting, the presence of Cr(VI) in the air is of increasing concern for workers. Recently, the standard for a safe level set by the Occupational Safety & Health Administration of Cr(VI) in the air was changed from 52 $\mu g/m^3$ of air to 5 $\mu g/m^3$ of air. This should be a step towards safer working environments for plant workers.

Cr(VI) is so dangerous in the body because it can easily cross cell membranes (whereas Cr(III) has a difficult time crossing cell membranes), causing multiple problems inside cells. Cr(VI) can cause mutations in DNA and selectively targets a small subsection of genes. Within cells, Cr(VI) is reduced to Cr(III), where it is necessary for regulating glucose levels. Inside cells, Cr(III) is not as harmless as it is outside cells. Once inside the cell, Cr(III) accumulates in organ tissue, causing health problems and potential organ failure.

## Resources

### CISCI

For more information about the CISCI project, visit the CISCI website: www.cisci.net

Alternatively, see *Launch event of Cinema and Science (CISCI)* on page 9.

### Link to Trailer Site:

Trailers courtesy of The Internet Movie Database: http://us.imdb.com/title/tt0195685/trailers

### Buy DVD

DVD – Erin Brockovich (UK): www.amazon.co.uk/exec/obidos/ASIN/B00004W4GT/026-6092405-9376435

DVD – Erin Brockovich (USA): www.amazon.com/gp/product/B00003CXFV/qid=1141187035/sr=8-1/ref=pd_bbs_1/104-7855840-6710367?%5Fencoding=UTF8&v=glance&n=130

### Website about film:

http://en.wikipedia.org/wiki/Erin_Brockovich_%28film%29

### Websites about the person Erin Brockovich

http://en.wikipedia.org/wiki/Erin_Brockovich

www.quackwatch.org/01QuackeryRelatedTopics/brockovich.html

### Websites about chromium

http://en.wikipedia.org/wiki/Chromium

www.dartmouth.edu/~toxmetal/TXSHcr.shtml

### Websites about hexavalent chromium

http://en.wikipedia.org/wiki/Hexavalent_chromium

http://searchwarp.com/swa14619.htm

www.etc.org/technologicalandenvironmentalissues/chemicalsofconcern/chromium_6/

http://wcaslab.com/tech/hexchrom.htm

www.clu-in.org/contaminantfocus/default.focus/sec/chromium_VI/cat/Overview/

### Website about corrosion

http://en.wikipedia.org/wiki/Corrosion

### Website about piston engines

http://en.wikipedia.org/wiki/Piston_engines

# *Molecular Biology of the Cell** and *Molecular Biology of the Cell: A Problems Approach*⁺

***By Bruce Alberts, Alexander Johnson, Julian Lewis, Martin Raff, Keith Roberts and Peter Walter**

**⁺By Tim Hunt and John Wilson**

**Reviewed by Bernhard Haubold, Fachhochschule Weihenstephan, Germany**

The success of an academic discipline has a lot to do with the attractiveness of its founding ideas and discoveries. These in turn reach the next generation of practitioners through textbooks. Three years after the completion of the Human Genome Project, it is safe to say that molecular cell biology is a success story. The fourth edition of its premiere textbook, *Molecular Biology of the Cell* (*MBoC*), has been out for some time now (it was published in 2002), but it is still well worth drawing attention to this marvellous teaching device.

What is your favourite discovery in molecular biology since you last studied the subject at school or university? My list includes the realisation in the late 1990s that non-coding RNA plays a central role in cell regulation, the high-resolution 3D structure of ribosomes in 2001, and the first draft of the sequence of the human genome in 2001. All three topics are dealt with in *MBoC*. In fact, genomics is treated in several places, starting on the cover, which shows a portion of the human genome sequence.

Apart from its comprehensiveness, *MBoC* is crammed with attractive illustrations embedded in clear and carefully paced explanatory prose. This feature makes the book useful for readers with diverse levels of proficiency. For example, the panels summarising the chemical constituents of cells are useful for students preparing for university entry exams, whereas the chapter on cancer contains a lot of material that will be news to all but the experts in the field.

All of this richness is distributed over four parts containing 25 chapters and adds up to a tome comprising substantially more than 1,500 pages. If you find books of this size too heavy to carry, let alone read, fear not, for you can turn to the abridged version of *MBoC*, published as *Essential Cell Biology* by the same team of authors as the parent volume.

There is a strange paradox about good textbooks, however. The easier they make it for the reader to assimilate complex new ideas, the more they distort the process by which the discoveries presented on their glossy pages were actually made. And it is this process of discovery, which is usually nothing but anarchic, that is at the heart of the attraction of the natural sciences.

For this reason, Tim Hunt (2001 Nobel laureate) and John Wilson have written a companion book to *MBoC*: *Molecular Biology of the Cell: A Problems Approach*. The book consists of 1,389 problems supplementing chapters 1-8 and 10-18 of *MBoC*. In addition, it contains detailed answers to half of the problems; the answers to the other half are available to instructors from the publisher without fuss. As Hunt and Wilson write, their problems can be read as a "running commentary on *MBoC*". They range from simple true/false questions to concise presentations of the decisive data contained in classical research papers. An example of a typical true/false statement is "Since introns are largely genetic 'junk', they do not have to be removed precisely." As to research, the beautiful experiment by Meselson and Stahl published in 1958, which established the semi-conservative nature of DNA replication, serves as the basis for several problems. In addition, there are also a large number of problems designed to test the reader's ability to perform the kind of order of magnitude estimations expected of working cell biologists. For example, how long are the DNA molecules contained in the nucleus of a single human cell? (Answer: roughly 2 m.) Such computations are never mathematically challenging, but always biologically illuminating.

*MBoC* is a prime example of what a good textbook in the biological sciences should be: comprehensive, vivid and up-to-date. However, it is Wilson and Hunt's companion volume that makes *MBoC* truly special. Whether you are looking for interesting class problems or just wish to test your own understanding of cell biology, *The Problems Approach* is the closest you can get to experiencing the excitement of research without exchanging the safety of your armchair for the vagaries of the laboratory.

### Details

**Molecular Biology of the Cell**
Publisher: Garland Science
Publication year: 2002
ISBN: 9780815340720
**Molecular Biology of the Cell: A Problems Approach**
Publisher: Garland Science
Publication year: 2002
ISBN: 9780815335771

# The Third Man of the Double Helix

## By Maurice Wilkins

**Reviewed by Friedlinde Krotscheck, Internationale Gesamthochschule Heidelberg, Germany**

In this autobiographical book, Maurice Wilkins presents the chronological story of the discovery of DNA structure in 1953. As *The Third Man of the Double Helix*, Wilkins is well placed to describe the complex scientific background and people involved in the breakthrough that earned him and fellow scientists Francis Crick and James Watson the 1962 Nobel Prize in Physiology or Medicine.

Since it is an autobiography, Wilkins puts himself in the centre by stressing his own point of view. Disturbed by concerns that Rosalind Franklin was not given the credit she deserved for her part in the discovery, he states in the preface that "this book is in some way my attempt to respond to these questions, and to tell my side of the story." And that is precisely what Wilkins does, presenting his viewpoint while including his own shortcomings and those of others who worked for decades on the question of how the cell copies genetic information.

The title suggests a rather exciting detective story, but the book starts off at a much slower pace by leading the reader through the author's family tree. It takes some patience not to skip this first chapter completely. By chapter two, Wilkins has begun to describe his educational background, painstakingly building up the story to make the reader understand why he worked for some time on the development of the atomic bomb in Berkeley, California, in the early 1940s. Finally, he describes the research team under Professor Randall at King's College, London, also called 'Randall's Circus'. From then on, *The Third Man* evolves and keeps the reader in suspense. The book ends with the very simple conclusion that if Wilkins and Rosalind Franklin had been a more compatible team, they would have found the solution to the DNA structure much earlier.

This historic event is an excellent example of the necessity of teamwork across science subjects, interdisciplinary exchanges and group co-operation. With today's competition for research funding, it is even more difficult to work selflessly for the common good. Wilkins' message is to focus first on the idealistic advancement of science and to put one's own fame on the backburner. Students need to learn to work co-operatively in groups, to gain knowledge from each other and to accept other opinions. Creative criticism leads to discussions and these might lead to solutions.

*The Third Man of the Double Helix* would appeal to teachers and high-school students of biology. However, to get the full picture of this landmark discovery, one should also read Jim Watson's book *The Discovery of the Double Helix* and Brenda Maddox's *Rosalind Franklin*.

The historic relevance of all three books is especially important for younger teaching faculty who were not contemporary witnesses to this period of scientific progress.

### Details

Publisher: Oxford University Press
Publication year: 2005
ISBN: 9780192806673

# *Rhythms of Life: The Biological Clocks That Control the Daily Lives of Every Living Thing*

## By Leon Kreitzman and Russell Foster

**Reviewed by Michalis Hadjimarcou, Cyprus**

*Rhythms of Life* is a successful attempt to present what is currently known about time cycles in living creatures. It is a book about biological clocks, that is, the biological mechanisms that enable all organisms from bacteria to worms, plants, birds and mammals, including humans, to 'tell' the time. This extraordinary ability in organisms allows the exhibition of rhythmic behaviour that can be presented in cycles of a single day (circadian) or longer than one day (infradian).

Time is embedded in genes and, therefore, cells are able to tell the time, making it possible for an organism's physiological and biochemical functions to follow a rhythmic pattern in synchrony with daily, monthly or yearly changes in the environment. Vital bodily processes, such as sleep, heart-beat, blood pressure, liver function, body temperature and hormone production, change according to the time of day – which is naturally determined by the position of the Sun in the sky and the resulting alternation of day and night, light and darkness. Similarly, certain behaviours in organisms, such as mating, migration, hibernation and flowering, are exhibited in cycles of months or even years, in response to temperature and humidity changes, food availability and many other predictable environmental cues.

The dependence on the biological clock becomes evident to humans when they try to override the ancient time patterns dictated by their internal timer, by engaging in unnatural behaviours such as travelling fast across multiple time zones or working 'unfriendly' shifts. As a consequence, they experience a variety of symptoms that range from mild jet-lag to potentially life-threatening conditions such as depression and sleep disorders.

Although *Rhythms of Life* could be classified as a biology book, it is not intended to be read strictly by biologists. The content of the book is scientific but the language is quite simple, so that anybody with a minimal understanding of biology could benefit from reading this book. Of course, it contains a great deal of up-to-date information about biological clocks and rhythms, making it more suitable for people with a strong interest in this topic. Consequently, the casual reader who just wants to know about biological clocks and rhythms, and how they affect humans, might find the book to be a little heavy. This disadvantage can be at least partially compensated by the fact that the reader can focus on small selections from the book and still attain a good understanding of the issues being discussed. Also, the short glossary of common terms may prove quite useful to the lay reader who is determined to get the most out of the book. In any case, a good starting point in *Rhythms of Life* is the excellent introduction, which starts with a general overview of biological clocks and rhythms and then goes on to summarise the information in each of the 14 chapters.

At first glance, *Rhythms of Life* does not present itself as a handy teaching tool. It is not the kind of book a teacher can simply take into the classroom and use as the main didactic material. Nevertheless, with a little imagination and the desire to explore alternative forms of teaching materials and methods, the teacher can find *Rhythms of Life* to be a useful source of information for teaching a variety of science topics, mostly in the field of advanced high-school biology.

In fact, biological clocks and rhythms offer a unique opportunity to investigate a variety of common phenomena, by studying the many parameters involved in and responsible for their appearance from the perspective of the different sub-disciplines of biology. For example, *evolution* can explain how rhythms may have developed as adaptive mechanisms to the cyclical and predictable changes observed on Earth for millions of years. *Physiology* and *molecular biology* can cope with the dissemination of how the clock mechanism works. *Genetics* can help unravel the details regarding the way a specific rhythmic behaviour is controlled through the concerted interaction between genes, proteins and neurotransmitters. All these and many more investigative approaches could be applied to the study of a rhythmic phenomenon as simple as sleep, in the form of small projects carried out by advanced high-school biology students.

To readers who are not so concerned with the scientific details of rhythms but rather prefer to take advantage of the applicable information derived from this knowledge, the book offers a valuable gift. The table in Appendix I provides specific information about numerous rhythms in humans which affect the body and mind performance, the susceptibility to disease and the general biochemistry of the body. Therefore, all those determined to optimise the effectiveness of their daily routine should take into account the timing of their rhythms when planning their everyday schedule. Finally, for those forced to hop across multiple time zones frequently, Appendix II contains sound scientific advice on how to minimise the symptoms of jet-lag.

Apart from the presentation of scientific information, the most important contribution of *Rhythms of Life* is, perhaps, a message directed to any reader, be it a science teacher, a student or the lay public. Despite their technological advances, from the perspective of biology, humans are mammals. As such, their decision to live in a 24-hour/7-day society brings them in conflict with their basic biology. This often causes excessive stress on the physical health and mental well-being of the individual, a situation that may sometimes lead to catastrophic results.

## Details

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Publication year: 2005

ISBN: 9781861975713

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University of Reading

# Investigating Plant evolution

## PCR of chloroplast DNA

The polymerase chain reaction (PCR) is one of the most important and powerful methods in molecular biology. It enables millions of copies of specific DNA sequences to be made easily and quickly. The technique and variations of it are used extensively in medicine, molecular genetics, forensic science and pure research.

This practical kit provides materials for the simple extraction of chloroplast DNA from plant tissue, its amplification by the PCR and gel electrophoresis of the PCR product.

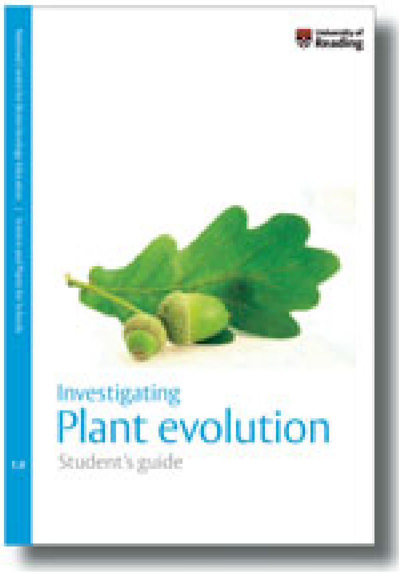
Students can use plants of their choice and identify possible evolutionary relationships between different species. This mirrors the molecular methods used in modern plant taxonomy.

This activity presents an ideal opportunity for open-ended investigations by individual students or groups.

### Kit contents

The kit contains the consumable materials for the extraction, amplification and gel electrophoresis of 16 chloroplast DNA samples plus one negative control. The kit includes:

- 4 plant DNA extraction cards, punches and cutting boards
- Reagents needed for extracting plant DNA
- Disposable microcentrifuge tubes
- 2 floating tube holders
- Primers for the PCR
- 17 'Ready-to-Go' PCR reaction beads
- 1 fixed-volume 20 µL Minipipet
- 1 mL syringes and graduated tips
- 8 sheets of carbon fibre electrode material
- 2 g DNA electrophoresis-grade agarose
- 50 mL TBE buffer (10 x concentrate)
- 8 x 1.5 mL bromophenol blue loading dye
- 25 µg 1 kb DNA 'ruler'
- 50 mL Azure A stain for DNA (2 x concentrate)
- Instructions and background information




*You will also need equipment for DNA gel electrophoresis and water baths or a thermal cycler for the PCR. A 'Base unit' containing eight sets of electrophoresis equipment can be purchased from the NCBE, as can a 36 volt mains transformer. Individual replacement items are also available.*

This practical protocol was developed in association with *Science and Plants for Schools.*

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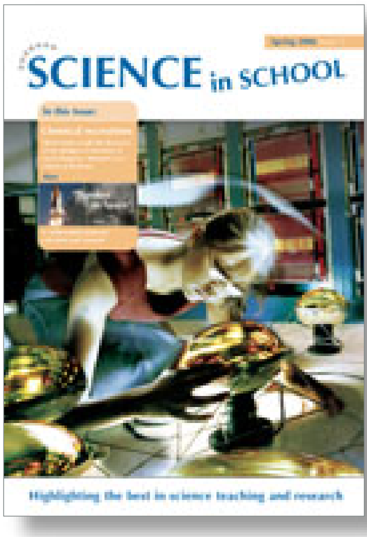

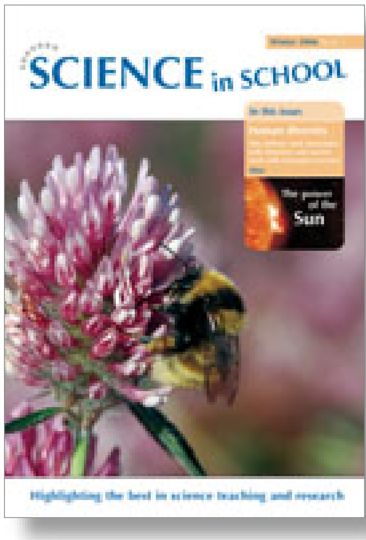


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You may use paints, pencils, crayons, charcoal – even a computer. The choice is yours. But no sculptures or other 3D entries, please!

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- Teachers
- Students aged 10-14
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Entries should include the artist's full name, email address, school and country. Teachers should list the subjects they teach, and students should include their age. All entries must be accompanied by a statement confirming that the artwork is original and your own work. We regret that we cannot respond individually to entrants or return postal entries.

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

The winners will be announced in Issue 6 of *Science in School*, to be published in Autumn 2007. One or more winning entries will be reproduced on the front cover, identified as the artist's work. We reserve the right to edit the images as appropriate.

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