ISSN 1740-9888

LTSN Physical Sciences

New Directions

in the teaching of physical sciences

Edited by Paul Chin and Roger Gladwin

Contents

Preface

This publication came about after discussions with Derek Raine at the University of Leicester and staff at LTSN Physical Sciences. Derek was keen to see the development of a publication that enabled academics in the field to share ideas and good practice for teaching and learning in the physical sciences.

In addition to his research interests as a physicist Derek has a long standing interest in the development of good teaching and learning practice in the physical sciences. Derek is a member of the LTSN Physical Sciences Advisory Committee and recently won funding from phase 4 of the Fund for the Development of Teaching and Learning (FDTL). Derek's project is entitled 'Project LeAP' and further information about this work can be found at http://www.le.ac.uk/leap/

New Directions was edited by Paul Chin and Roger Gladwin from the Centre.

May 2003

Foreword

I can understand those of my colleagues who tell me that the best thing I could do for our excellent research department is to stop trying to change our teaching methods. I can sympathise with devoted academics who believe that by remaining constant to their way of teaching they will be in the forefront of the revolution after next. I am aware that even changes for the better are not painless. Unfortunately, by now we should all know that 'if we want things to stay as they are, things will have to change'.

It is a widely held view that our ivory towers insulate us from the real world environment and hence from the direct pressures for change. Therefore, the argument goes, those pressures must be created for us. This leads to the imposition of crude, centrally directed management through targets, through funding tied to specific, often inappropriate objectives, and all the associated unproductive administrative burdens, which signal a lack of trust and undermine the professionalism of academics as teachers.

The premise is quite wrong. The Physical Sciences, along with a number of similar subjects, are subject to real external pressures built into the system. Because of the way research is funded in the UK, largely through university departments on the back of teaching income, the support of an international level research base requires a healthy throughput of physical science graduates. Any argument about whether such graduates are needed is looking through the wrong end of the telescope. These graduates have to be needed; that is, their courses have to be such as to make them needed. It is said, indeed, that it is already the case that more than half of physics graduates go into jobs that are not directly physics-related. (I guess this means jobs in which knowing how to solve the Schrödinger equation is not part of the person specification). There is a similar movement in Chemistry. We have to ensure that they have the graduate skills to be good at those jobs.

Of course, our various departments and universities experience both similar and different pressures, for example the so-called 'maths problem' on the one hand and too many or too few students on the other. But the challenge is largely the same: to produce an output of new generations of students each better equipped than their predecessors, and to do this whatever the input. And, furthermore, to do it in a way that is less disruptive of overall research effort than the centrally directed chasing of targets.

It would also be quite wrong to believe that physics and chemistry are not responding to this challenge at various levels. Courses are indeed changing from the inside in a variety of ways. This very variety means that we have much to learn from each other – not to copy – but to short-circuit the process of invention ab initio. This publication will seek to enable us to share much of our innovation and good practice in an informal way. My hope is that it will develop to be of interest not only to those already committed, but that we can share with those who influence policy, the strength of innovation amongst academics who, given adequate resources and backing, are then just left to get on with the business of improving learning.

Derek Raine
Department of Physics and Astronomy, University of Leicester

Experimenting With Undergraduate Practicals

Summary
In my experience the prescriptive nature of many undergraduate practicals restricts the scope for students to apply and develop their subject-specific knowledge. In addition, the nature of such practicals places limitations on their effectiveness for development of problem solving, team working and transferable skills. In recognition of this, a number of laboratory practicals in physical chemistry have been developed (some from existing traditional scripts) which feature clearly formulated and explicit objectives, but which omit detailed instructions to a greater or lesser extent. One particular aspect of these practicals is that the onus is placed on students to design a viable experimental approach in order to achieve the stated objectives and to reflect critically on their work. In this respect some of the practicals may be considered as structured mini-projects. Another implicit aspect is an attempt to encourage students to de-compartmentalise their subject knowledge (e.g. organic mechanisms in a 'physical' chemistry practical).
The practicals have been used successfully at levels 1 and 2 during the past two years at Keele, and although the approach described has been applied to laboratory work in physical chemistry, there is no reason why it cannot be applied more generally.

Subject area: Physical Science

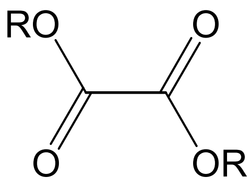
Description
Laboratory practicals in physical chemistry:

(1) The Influence of Ionic Strength on the Rate Constant for the Reaction of Crystal Violet with Hydroxide ion (Level 2)

- Establish the rate law for the reaction.
- Determine the reaction rate constant over a range of ionic strengths.
- Establish whether the experimental results support the reaction mechanism by appropriate analysis of the experimental data.
- Suggest a molecular mechanism for the reaction.

(2) The Influence of Ionic Strength on the Solubility of Barium Iodate (Level 2)
- Determine the solubility product (K_s^o) for $Ba(IO_3)_2.H_2O$.
- Determine mean activity coefficients ($\gamma_\pm$) for Ba^{2+} and IO_3^- over a range of ionic strengths.
- Test the validity of the Debye-Hückel limiting law (DHLL).

(3) The Influence of Temperature on the Intensity of Chemiluminescence from Commercial Lightsticks (Level 1)
- Investigate the influence of temperature on the luminescence intensity of commercial chemiluminescent lightsticks and obtain the activation energy for the overall chemical reaction (figure 1).



$$+ \; H_2O_2 \; + \; \text{Dye} \; = \; 2\,\text{ROH} \; + \; 2\,CO_2 \; + \; \text{Dye} \; + \; h\nu$$

(Ox)

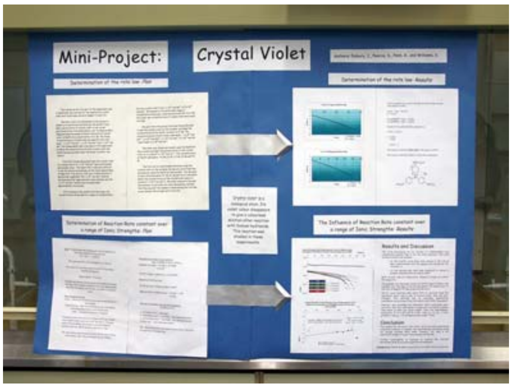
Figure 1 The overall chemical reaction that takes place in chemiluminescent lightsticks. Ox is an oxalate ester and the reaction is base catalysed.

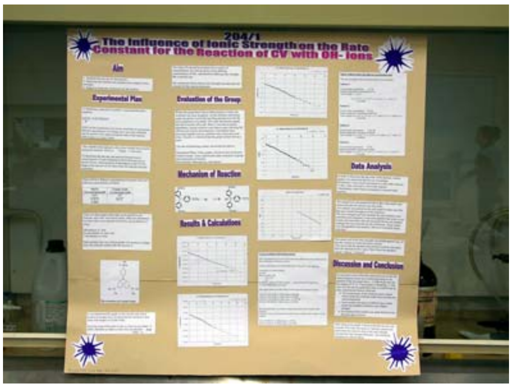
Type of activity

The practicals are designed to provide experience with some, or all, of the following:

- Applying and developing subject-specific knowledge.
- Working effectively in a team.
- Planning your work.
- Designing, planning and carrying out an experiment.
- Learning from your mistakes.
- Plotting graphs and extracting information from graphs using Excel.
- Objective Information retrieval using the WWW.
- COSHH risk assessment.
- Recording and analysing experimental data.
- Use of chemical structure drawing packages.
- Use of online library catalogue.
- Locating a research paper in the Library.
- Extracting information from research papers.
- Critical reflection.
- Preparing and presenting a poster.

Keele University 2nd Year Chemistry Poster Session, November 2002





Keele University 2nd Year Chemistry Poster Session, November 2002

Content covered
Chemistry: reaction kinetics, electrolyte solutions.

Application
The experiments can be used directly in undergraduate physical chemistry laboratory work. However, it is also envisaged that the approach can be adopted more generally for laboratory work in the sciences. More time may have to be allocated than for traditional practicals (e.g. perhaps 10 hours for the level 2 practicals) and it is more demanding (although arguably more stimulating) for demonstrators.

Further comments
Examples of the material are available via the LTSN website at www.physsci.ltsn.ac.uk in the Database of Practicals section. The author is happy to supply additional information if required or to discuss details with interested parties.

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Controversy in the Classroom

Summary
At Glamorgan, we aim to provide a pluralistic account of the physical sciences, recognizing the all-pervasive nature of science within our society. In attempting to account for the various influences brought to bear on both the practice and the dissemination of science, our science modules repeatedly cross the institutionalised boundaries that separate "science" from "history" or "philosophy". So our degrees (Bsc Science and Science Fiction; Bsc Astronomy and Space; and Bsc Science and Science Communication) are courses ***about*** science as much as they are courses ***in*** science, encompassing the many influences brought to bear on the continuous creation and consumption of science.

Subject Area: Astronomy, Physics, Science Fiction and Science Communication

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Science fiction was described by Isaac Asimov as that genre "that deals with the response of human beings to changes in science." It is this response of human beings and society to science as a whole that we examine in the degree programmes we run at Glamorgan: Bsc Science & Science Fiction; Bsc Astronomy & Space; and Bsc Science and Science Communication.

The degree courses arose from the development of an astronomy undergraduate programme that provides a pluralistic account of the physical sciences, recognizing the all-pervasive nature of science within our society. We attempted to account for the multifarious influences brought to bear on the nature and dissemination of science; this inevitably led to our science modules repeatedly crossing the institutionalised boundaries that separate "science" from "history" or "philosophy". So our degrees are courses ***about*** science as much as they are courses ***in*** science, since they encompass the many influences brought to bear on the continuous creation and consumption of science.

The courses make clear the actual, tortuous history of science: its great discoveries, the misapprehensions, and regular stubborn refusals by its practitioners to change course. By teaching not only the findings and products of science, but also communicating its critical method, we hope to better equip academics and science educators with the tools to increase public awareness of, and involvement in science, and provide opportunities for extending science's public franchise.

Since the evolution of science is a complex process, we thought that an interesting way to study it would be to draw upon related disciplines. Traditional scientific accounts are perhaps inhibited from looking at the nature of the links between science and other areas, and their influence upon the growth and dissemination of science. We therefore considered it a natural progression to look at the relationship between science and science fiction.

So just what ***is*** science fiction? Perhaps we should start by making it clear that we recognise the complex nature of SF, and are not naive enough to fix SF as merely literary.

Science fiction is identifiable by the fact that it eases the 'willing suspension of disbelief' on the part of its audience by using an atmosphere of scientific credibility for its imaginative speculations in physical science, space, time, social science, and philosophy.

So science fiction is, in relation to science, a unique genre. It can be regarded as a device for conducting a type of theoretical science - the exploration of imagined worlds. A cosmologist may construct mathematical models of idealised hypothetical universes, and then investigate their properties. Science fiction has more scope. Science fact is supposed to stay within the boundaries of the accepted laws of physics; science fiction may often stray beyond such limits. Nevertheless, the spirit of "What if...?" pervades both enterprises.

The genre has always been used as a way of imagining the relationship between science, technology and society, both as an inspirational source guiding the direction of scientific development and a way of popularising and disseminating scientific ideas. The best science fiction tackles deep philosophical or ethical issues and widens the audience's vision of our universe. Works such as *The Time Machine*, *Brave New World*, Yevgeny Zamyatin's *We, A Clockwork Orange, Blade Runner* and *The Matrix*. A number of significant individuals stand out in the history of SF - HG Wells and Arthur C Clarke, of course. But also writers such as Philip K Dick, Kurt Vonnegut and William Gibson.

At each stage of the degree we look at what we call the ‘seminal milestones of science’, and consider their corollary within science fiction. We look at the social and scientific revolutions engendered by the Copernican and Darwinian revolutions, and go on to consider the implications of the twentieth century paradigm shift produced by relativity and quantum theory.

To tease out just a few of the themes that run through the course, in the third year module ‘Life in The Universe’ we consider Copernicus reluctantly setting in train the eventual development of modern cosmology with its attendant possibility of a plurality of inhabited worlds. Coupled with Darwin's demotion of man to mere mortal among the microbes, we've seen the development of possibly the most powerful myth that has captured the imagination in the latter half of the twentieth century: The myth of the existence of extraterrestrial life. The question of whether we are alone in the cosmos has, of course, fascinated and frightened us since the days of Lucretius.

However, only in recent times has the question of extraterrestrial life become such an obsession; and yet clearly this is almost entirely a revolution of the imagination. The true extraterrestrial with its own physical and mental characteristics begins to appear only in the last third of C19th. The birth of the alien in literature is closely tied to developments in late C19th science, most notably evolutionary theory, but also astronomy and the ‘plurality of worlds’ tradition.

Another module, ‘Stars, Science and The Bomb’, looks at the development of one of the triumphs of modern physics: the understanding of the stellar life cycle. But in parallel to this study, we consider the development of the atom and hydrogen bombs, finding that in many cases the players in both dramas were the same physicists. This enables us to tackle major issues relating to science and social change. It also provides a perfect social and scientific backdrop to our consideration of post-apocalyptic fiction in our 'Utopian and Dystopian Futures' module.

The common theme of all our modules is that of the impact of science throughout history, on all areas of life. The founding principle of all our degrees is our belief that in order to understand and enjoy science, it needs to be made relevant. Physics can be regarded as the marker by which we can trace paradigm shifts throughout the ages, and it is the exciting ways in which this impacts in history, art, and fiction that we use to bring science to life.

Our approach to teaching and learning science has always intended to broaden the franchise both for science and for higher education in general. In recent years there has been an explosive growth in the number of students entering higher education, with an increasing proportion of these young people uninterested in studying specialist degrees.

If we are to attract students to science-based courses perhaps we need to recognise that they may wish to study a diet of science, perhaps acquire a degree of scientific literacy. In our view, knowledge of science is absolutely necessary in a participatory democracy. We live in a society utterly dependent on science and high technology; science itself implies social & economic change and such change requires a string of vital decisions. As Carl Sagan asks 'How can a citizen with little or no understanding of science be an informed decision-maker in such a society?'

In support of this, potential students are drawn from a wide mix of backgrounds, including both sciences and arts, though a fascination with the nature and communication of scientific ideas is a common drive. We have had great success with the degree both on campus and, just as importantly, in the local valley communities. We have around 100 students taking our cross-disciplinary science modules at the University, and over 200 associate students enrolled on modules of the degree in one of our many local study centres.

As well as students following one of our full degree programmes, we have many major, minor, joint and combined honours students. Students find that an understanding of the historical and cultural impact of science on society, or conversely, the societal and humanistic context of science, can enrich and deepen their understanding of other, narrower disciplines. Students are also encouraged to submit work that incorporates and relates their other studies to the material learnt on our courses - essay titles have included 'The Symbolism of Comets in Art', 'Space Law', 'Cosmic Influences on The Dark Ages?' and 'Evidence For Design?'.

We have implemented continuous assessment, where students give individual and group presentations (on topics such as 'Is Cosmology a Science?', 'Did The Americans Land on the Moon?' and 'Is There Life Beyond The Earth?'), write book reviews and articles, run seminars and submit essays. This is aimed primarily at producing graduates with a broad understanding of science, its method, its impact on society, and the influences of society on science itself. We emphasise a critical approach, encouraging students to be independent thinkers, and trying to combat the doctrinal, unquestioning acceptance of science as it is so often taught in schools.

We also address issues relating to the status of science itself: Why is science often considered culturally inferior to the arts? Why is science rarely appreciated as a cultural activity at all? If science is to be restored to its rightful place in our cultural heritage then science fiction may help to play an important part in bringing science "...out of the laboratory and into the culture." Science has become far too important on both local and global scales to be left to the concern of scientists alone.

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ChemEnterprise SLP

Summary
A *structured learning package* (SLP) aimed at advanced undergraduate chemists featuring group problem solving and introducing the role of enterprise in a chemical industry business environment. The exercise is based on a real scenario and uses real data to provide opportunities to explore a number of alternative strategies and to communicate conclusions in oral and written report formats.

Subject Area: Chemistry

Description
Student teams represent a chemical company reacting to new, more stringent environmental legislation. They must research a number of end-of-pipe technologies and choose one based on actual cost and performance data. More significantly, they can turn the effluent problem into a new opportunity for their company with wider consequences for their business strategy.

Type of activity
The two-stage activity is paper-based with all materials available from the authors. This includes student handouts, full tutor's notes (with important recommendations on the administration of the exercise and discussion of typical student responses), sample handouts, overheads, and assessment schemes. The majority of up to 40 hours of student work are spent away from the classroom in independent group work.

Classroom sessions are used to introduce the exercise with two subsequent plenaries allowing teams to present their findings and conclusions. Each team gives two talks and delivers two written reports with peer and tutor feedback in between. These form the basis of the assessment of the exercise. The second report is essentially a business plan evaluating two potential future scenarios for the company business, and applying a number of business appraisal techniques and models to these.

Content covered
The effluent stream emerges from a plant producing optical brighteners. Students describe the photochemistry and synthesis of these materials involving various aspects of aromatic chemistry and reactivity. Existing and proposed alternative production routes can be analysed from the perspective of green chemistry.

Various processes in industrial effluent treatment are reviewed and applied such as adsorption, oxidation, ozonation, and electrochemical techniques. Each team in a class is assigned a technology to review. This requires students to find, apply, and present relevant information.

There is a large component of data analysis. This is real data as provided through a number of feasibility studies. Account must also be taken of legal and technical aspects of waste-water management by water boards and the Environment Agency.

Both stages provide opportunities to apply creative solutions to an apparently straightforward problem. This provides opportunities to review the nature of problems and solutions, in general, and discuss the role of enterprise thinking in responding to, and driving, change within a chemical industry business environment.

Appraising new strategies provides experience of applying standard business environment and market models, and dealing with financial implications through discounted cash flow analysis.

Application

We have developed this exercise specifically for 3rd year undergraduates on our 'Chemistry, Management, and Industry' course. They are familiar with the models and accounting principles used in project appraisal that are key elements of the second stage of ChemEnterprise SLP. The first stage requires no such background and could be tackled satisfactorily by chemists, engineers, environmental scientists etc. Many chemistry courses will include some students who have taken management and business options. Just one student with this background in each team should allow the second stage to run smoothly. Furthermore, the tutor's notes provide guidance on sources that can be used to introduce the management models and techniques useful in the second stage so that even this prerequisite can be circumvented.

Students tackle the *structured learning package* (SLP) over a period of 3-4 weeks concurrently with other courses. It can be thought of as replacing labwork over this period. There are opportunities, and we provide some suggestions in the tutor's notes, on how the SLP might be compressed into more of a classroom-based exercise.

Further comments

Our use of the SLP is to provide a high quality experience in which our students can apply, develop, and receive peer and tutor feedback on their personal transferable skills in a realistic chemistry context. Student performance is assessed on this basis. ChemEnterprise SLP also encourages participants to recognise the concept of enterprise in solving technical problems in a commercial environment. We do not fully exploit the opportunities provided to learn chemistry, industrial chemistry and engineering, and aspects of environmental science though clearly the emphasis could be changed to bring these to the fore.

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Reference

Proceedings, Variety in Chemistry Teaching 2002, University of Keele, Sept 2002

Problem Solving Case Studies in Analytical and Applied Chemistry

Summary
We have produced six problem solving case studies which have been designed in order to teach analytical and applied chemistry within a ‘real’ life context by developing problem solving and professional skills. The case studies use the contexts of forensic science, pharmaceuticals, environmental science, and industrial chemistry. They present students with extended problems that are set in a ‘real’ context with incomplete or excessive data, and require independent learning, evaluation of data and information and, in some cases, do not lead to a single ‘correct’ answer. By tackling these cases, students are able to see the relevance of analytical chemistry and so approach the activities with enthusiasm and interest. In order to successfully tackle a case study, students must develop a range of professional skills such as communication, team work, project management, etc.

Subject area: Chemistry

Description
Each case study uses a problem based learning approach in order to develop subject specific knowledge and a range of professional skills. Each case study extends over several class room sessions (typically 4-6) and requires students to carry out independent study (typically 6-12). Although we identify a level at which the case studies may most usefully be used, this does depend on the background of the students, the level of support provided by the tutor and the intended learning outcomes of the module. The case studies are paper based and are provided with a tutors guide and student handouts. The tutor’s guides include an overview of the case, tips for running the activity successfully, an assessment guide and typical sessions plans. A summary of each case study is given here.

New Drugs for Old
This is a problem-based case study concerned with the isolation, identification and synthesis of a pharmaceutical. The students consider the short-term experiments that would be required to isolate and identify the active ingredient in some dried leaves from Malaysia. They then propose the longer-term experiments that would be required to bring the drug to the market place.
The students interpret the NMR, MS and FT-IR spectra to identify a series of isolated components. They then cost the synthesis of the active ingredient from cheap substrates, but realise that this approach is likely to be financially less viable than purchasing it directly.

Suggested level	1st or 2nd level
Context	Analytical and pharmaceutical chemistry
Contact time	4 hours
Independent study	10 hours
Possible assessment	One page project plan, written report, oral presentation.

The Titan Project

This case study concerns the siting of a titanium dioxide plant and evaluation of analytical methods. Students adopt the role of the existing management team of a titanium dioxide plant and are asked to make recommendations on the future of the site to the board. This encourages them to consider industrial chemistry in a broad context of the associated safety, environmental, economic and social issues. They compare the sulphate and chloride processes for TiO_2 production, and finally propose a five-year strategy for the site. The students then consider setting up an Environmental Monitoring Laboratory for the chloride process and must select and evaluate a method of analysis for chloride ions in effluent.

Suggested level	1st or 2nd level
Context	Analytical chemistry, Industrial chemistry
Contact time	4 hours
Independent study	10 hours
Assessment	Oral presentations, review of methods, individual exercises

A Dip in the Dribble

This case study is set within the context of an investigation of the environmental impact of river pollution. A fire in a warehouse has resulted in diquat dibromide and *p*-octylphenol entering the River Dribble. Students determine the cause of the incident and review the probable environmental impact of the chemicals released. Then they consider possible methods of analysis and, finally, commission a monitoring programme for diquat dibromide and *p*-octylphenol in the river by selecting a contract analysis company from the information supplied.

Suggested level	2nd level onwards
Context	Analytical and environmental chemistry
Contact time	4 hours
Independent study	10 hours
Assessment	Review, oral presentation, group or individual report,

The Pale Horse

This case study uses the context of a forensic investigation of a suspicious death. It operates by supplying information in the form of reports from various official agencies (police, pathologist and forensic laboratory). The students request analysis of the various types of evidence collected in order to determine the cause of death, mode of administration of poison and suggest the identity of the possible perpetrators.

Suggested level	2nd level onwards
Context	Analytical chemistry and forensic science
Contact time	5 hours
Independent study	10 hours
Assessment	Case summary, oral presentations, group or individual report

Tales of the Riverbank

This case study is set within the context of the investigation of environmental problems along a river system. Students assume the role of the investigation team following a complaint about a reduction in the number and size of fish caught along the river. By considering both temporal and spatial factors, the students identify an array of possible causes. As further data and information is made available, the groups are required to consider environmental issues, pollution, sampling, analytical techniques, water quality, data analysis / interpretation, toxicity, and remediation.

Suggested level	2^{nd} level onwards
Context	Analytical chemistry and environmental chemistry
Contact time	5-6 hours
Independent study	12 hours
Assessment	Oral presentations, group report

Launch a Lab
This uses the context of a small contract analysis company that is tendering for a large new contract for the analysis of organic pollutants in ground water. The students act as part of the management team whose task is to ensure that the company can deliver a high quality service with a suitable profit margin if they secure the contract. The must consider issues such as validation, accreditation, marketing, buying equipment and lab design. As new staff are required to deliver the expanded service, students advertise a post and interview candidates. They also apply for a job advertised by other students and are interviewed for the post.

Suggested level	2^{nd} level onwards
Context	Analytical chemistry and professional skills
Contact time	5 hours
Independent study	10 hours
Assessment	Oral presentation, poster, CV, interviews and interviewing

Type of activity
Problem solving case study. Paper based. Students work in small groups throughout.

Content covered

A Dip in the Dribble	Analytical, environmental and industrial chemistry
Launch-a-Lab	Industrial chemistry and advanced professional skills
New Drugs for Old	Pharmaceutical and analytical chemistry
Tales of the Riverbank	Analytical chemistry and environmental science
The Pale Horse	Analytical chemistry and forensic science
The Titan Project	Industrial and analytical chemistry

Application
The case studies are designed to be flexible. Consequently, they may be used as a complete package or individual activities may be used within different contexts. They have been successfully used in modules on analytical chemistry, forensic science, environmental chemistry, industrial chemistry and professional skills.

Further comments
This project was funded by the Royal Society of Chemistry Analytical Chemistry Trust Fund

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Using Spreadsheets to Teach Quantum Theory

Summary
Quantum theory is a key part of the physical and chemical sciences. Traditionally, the teaching of quantum theory has relied heavily on the use of calculus to solve the Schrödinger equation for a limited number of special cases. This approach is not suitable for students who are weak in mathematics, for example, many students who are majoring in biochemistry, biological sciences, etc.

Spreadsheets generate approximate numerical solutions and graphical descriptions of the Schrödinger equation to develop a qualitative appreciation of quantum mechanics.

Subject area: Chemistry, Physics

Description
The aim here is to teach the qualitative results that arise from applying mathematics to physical and chemical systems, but without the mathematical rigour: "teaching maths without the maths". The "new calculus" advocates the "rule of four" (numerical, graphical, symbolic and verbal descriptions) to deepen students' conceptual understanding (1). Students who have a weak background in mathematics do not have the knowledge of calculus required for the usual symbolic algebra approach to quantum theory. This case study illustrates how a combination of numerical, graphical and verbal descriptions can be used to overcome the lack of symbolic knowledge or ability.

Type of activity
A spreadsheet is used to obtain graphical (i.e. numerical) solutions for the Schrödinger Equation in one dimension.
The instructor can introduce the spreadsheet in class to illustrate how boundary conditions force waves to be quantised.

More able students can construct the spreadsheet in a computer-laboratory exercise or assignment; less able students will be given a completed spreadsheet.
Students can then perform numerical experiments using the spreadsheet to determine:
- How the energy of the wavefunction affects its wavelength and overall shape;
- How the underlying potential energy function affects the wavelength and overall shape of the wavefunction.

More able students can then relate the numerically determined wavefunction shape to the exact (mathematical) solutions.

Content covered
The basic content is quantum mechanics, but extensions to other topics are indicated below.

Application

Numerical solutions of the one-dimensional Schrödinger equation using spreadsheets are used to illustrate in the following topics and concepts.

Quantum mechanics:

- The boundary conditions place restrictions on the wavelength of the wavefunction, resulting in quantisation. Most trial energies will not result in valid wavefunctions; (Figure 1)

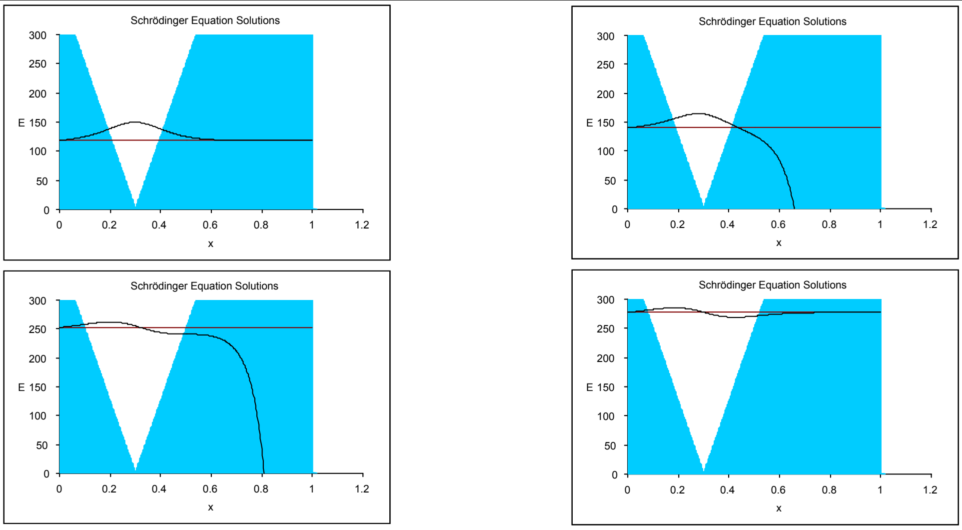

Figure 1: Most energies do not result in valid solutions of the Schrödinger Equation.

- Different potential wells (electron-in-a-box - the Kuhn model, harmonic oscillator, Morse oscillator, a "triangular" well, quartic potential well, etc) all have similarities in the wavefunction shape (number of nodes, number of lobes, etc), although the detailed wavefunction shape may be different. Note that in this context, use of calculus reinforces the differences between various potentials and the misconception that some potentials have no solutions (because they do not have an analytic or closed form wavefunction). (Figure 2)

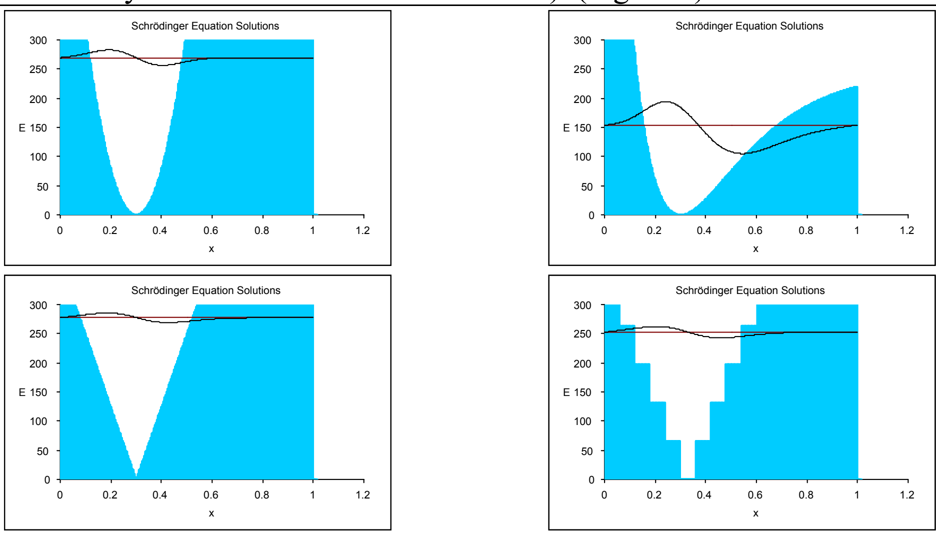

Figure 2: Potential wells of varying shapes still have wavefunctions of similar shapes. In each case, the 2nd-lowest-energy wavefunction is shown. Some of these wavefunction do not have analytic or closed form solutions.

Reaction dynamics:

- Use of a potential well with a barrier (Kronig-Penney model or Eckert potential) illustrates tunnelling. (Figure 3)

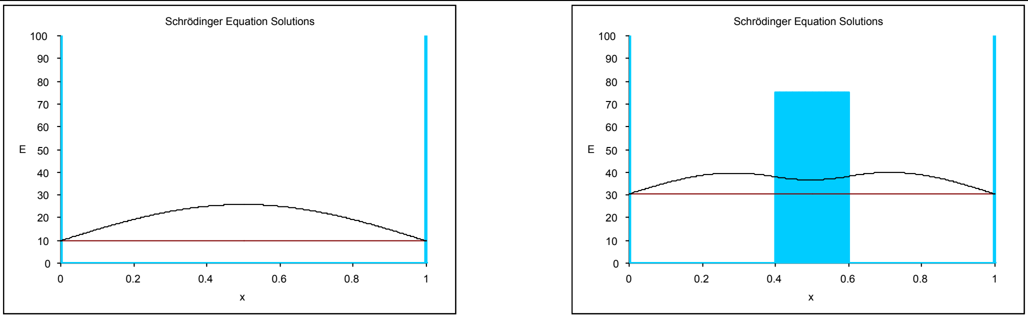

Figure 3: Wavefunctions can tunnel through barriers.

Organic conjugated π systems:

- The Kuhn model (electron-in-a-box) was originally developed to describe conjugated π systems. The wavefunction energies decrease as the box size increases: "delocalisation lowers energy".

Spectroscopy:

- Changing from a harmonic oscillator to a Morse oscillator both increases anharmonicity and lowers the wavefunction energies. The widening of the well again illustrates "delocalisation lowers energy" (Figure 4)

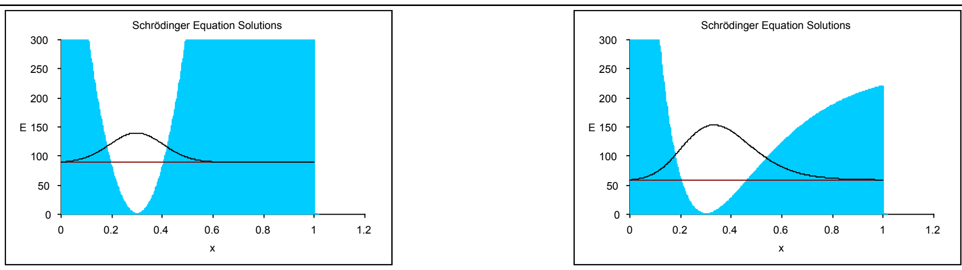

Figure 4: Comparison of wavefunctions and energies for a harmonic oscillator and a Morse oscillator; "delocalisation lowers energy".

- Changing the shape of the potential well alters the spacing of the wavefunction energies.
- Trial energies that are very close to exact energies result in wavefunctions that are very close to the allowed wavefunction; the lifetime of the "almost-right" wavefunctions will be longer the closer the wavefunction shape is to the "true" solution, resulting in the "lifetime-broadening" ($\Delta E\ \Delta t$) form of the Heisenberg Uncertainty Principle.

Conductivity of solids:

- Use of a series of square wells separated by barriers (extended Kronig-Penney model) illustrates that interactions between wells split energy levels. As the number of wells increases, the (single-well) energy splits into a quasi-continuous band of energies, giving rise to the band theory for conductors and semi-conductors.

Further comments

The approach of this case study work can also be related to Gardner's theory of multiple intelligences (2). The Logical-Mathematical intelligence is only one of several "intelligences". By changing the emphasis away from mathematical calculus, to a numerical-experimental activity, the activity now favours the learning styles (3) of those students who favour Spatial or Bodily-Kinaesthetic intelligences. A combination of this spreadsheet approach with the traditional calculus-based approach will enable more students (and students of more types of learning styles) to study quantum mechanics.

Spreadsheets are preferred over more sophisticated packages (Mathematica, MathCad, etc) because the former are more widely used ("worldware") and the learning curve for the latter is much steeper (4).

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Teaching practical astronomy at a professional observatory

Summary
In 1988 Southampton University established a new Programme of Study, Physics-with-Astronomy and it was felt to be essential to provide the students with detailed practical experience in observational astronomy. The obvious difficulties of scheduling and successfully executing observational work from the UK led to the establishment of an annual Field Trip to the Observatario del Teide at Izana in Tenerife, Spain. The course allows 12 second-year astronomy students to visit the observatory in Tenerife every Easter vacation for one week.

Subject area: Astronomy

Structure & timetable
The structure of the main component of this course is built around a six night stay at the observatory run by the Instituto de Astrofisica de Canarias which consists of a collection of day and night time telescopes, together with a suite of experiments studying the cosmic microwave background. It is located at an altitude of 2400m about 1 hours drive from La Laguna.

Accommodation and catering is provided on-site, so the astronomical experience is a total one for the students. The course normally starts by arriving around midday allowing a period of familiarisation in day time before work will begin that night. The evening meal occurs around 7pm and the students are expected to commence work just after sunset i.e. about 8.30pm. Observations will continue, weather permitting, till dawn (around 7am) with a “night lunch” break occurring around 1am. Though the first night is normally particularly challenging as people are adjusting their body clocks to a night time schedule, students and staff quickly settle into an effective routine which will last for all 6 nights.

The students are divided up into groups of 3-4 and will spend a whole night working at one of several observational locations. These locations have varied over the years depending upon astronomical circumstances (availability of comets, planets etc). The following have been, and hopefully will continue to be used:

Figure 1 Astronomy students attaching a ST-6 CCD camera to the 0.5m Mons telescope

The 0.5m Mons telescope has provided the core of our programme upon which we mount a SBIG ST-6 CCD camera with BVRI Johnson filters. This configuration permits observations of both extended objects (e.g. stellar clusters, galaxies & nebulae). The filters permit quantifiable results to be obtained and this is strongly encouraged in general on this course. By using standard Johnson filters the students are able to obtained Hertzsprung-Russell diagrams of open and globular clusters, colour studies of different types of galaxies and compare their results directly with the published literature

1. The Vacuum Newtonian provides an excellent facility for planetary work due to its exceptionally long focal. The design of this telescope is ideal for detailed studies on Jupiter, Saturn and the moon. The students carry out photographic work using 35mm cameras mounted on this system with the objectives of recording Jovian moon rotation, as well as high quality images of all of these systems (to record, for example, the rotation rate of Jupiter by following the Red Spot).

2. A portable Meade LX200 telescope provides a third location for more general familiarisation of the sky and wide-field photographic imaging. Mounting of 35mm cameras on the back is straightforward.

3. In addition to night time work, the students are able to spend late afternoons carrying out solar studies using the same LX200 with a Thousand Oaks glass solar filter. The objectives are to photographically record sunspot locations, sunspot development and differential solar motion by taking images over several days and pooling the data from all groups.

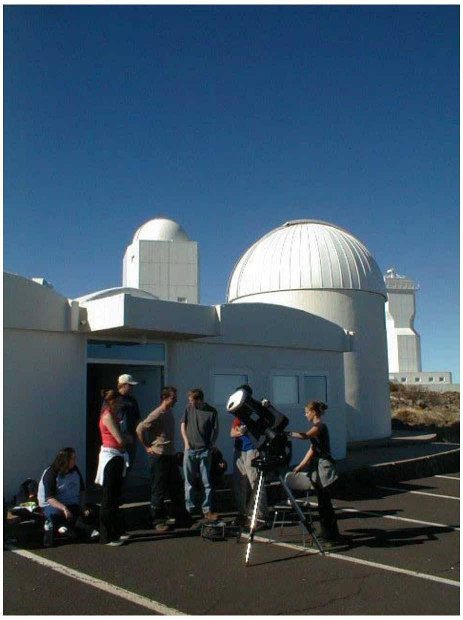

Figure 2 Astronomy students carrying out solar photographic measurements using an LX200 telescope with a solar filter

A photographic darkroom supports many of the above activities. The students are trained to carry out developing and printing of black and white photography. They process their own films and print up their results during the week. In some cases it is essential to develop films almost immediately to provide the necessary feedback on the correct exposure times required. Though this kind of image recording is rapidly diminishing in popularity at all levels, it nonetheless provides a rigorous and scientifically demanding test of their skills.

On return to Southampton the students are set two objectives to encourage the analysis and interpretation of their data under more considered circumstances. These objectives are, firstly, to produce an A1 poster for presentation at an in-house conference, and secondly to write an essay discussing some other aspect of their work.

Learning outcomes
After participating on this course it is expected that our students should be able to:

1. work in small teams with each member having a specific responsibility

2. employ practical skills in operating complex equipment often under difficult weather conditions (e.g. cold temperatures and brisk winds)

3. operate a telescope and find their way around the sky in celestial co-ordinates

4. process data using image processing programmes on PCs.

5. present the results of their work verbally, illustratively and in writing.

Feedback
This type of intensive course is excellent for obtaining feedback on student progress and learning. Contact between the staff and students are extensive and prolonged, and

there are many opportunities to observe student progress and to spot difficulties in the learning process. It is also often very straightforward to adapt the process in real time so as to bypass the cause of any serious difficulties. The details of the course have evolved over its lifetime, but there have been many examples of major improvements being made because of the close observation of the students at work.

More formally, we issue all students a standard questionnaire at the end of their course to obtain more balanced reflective feedback. The results of these questionnaires have always revealed an exceptionally high rating for this course and considerable student satisfaction with what they have achieved. They find the course to be extremely demanding, but they enjoy the unusual challenges presented by a programme that is so different to all their other traditional laboratory or lecture based programmes.

Conclusions

This course has proved an exceptionally successful way of teaching practical astronomical observation techniques to astronomy undergraduates. It has stimulated many of them to pursue the subject in much greater depth than they had previously planned, including inspiring many to study for PhDs in this area. Variations on this course are being actively explored, or have already been established, by several other universities.

Acknowledgements

We gratefully acknowledge the considerable assistance provided by many staff who have helped with this course over the years, in particular Dr Ismael Perez Fournon of the University of La Laguna and the Instituto de Astrofisica de Canarias.

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Software Resources for Remedial Physics Teaching in UK University Chemistry Departments

Summary
There is a substantial minority of students who do not have the necessary physics background to tackle parts of most first year physical chemistry courses and for whom some kind of remedial action is required.
Software tools have been developed to address the problem with priority being assigned to topics most frequently occurring in the curricula. After discussion with colleagues, the topic of ‘Particles and Waves in Chemistry’ was selected. The tools consist of simulations (and high quality diagrams with relevant animations) designed to accompany tutorials or workshops. They are not ‘stand-alone’ programs and assume that the teacher has covered the basic groundwork. In this way, the material does not impose any learning style and should be treated as a simple resource similar to an illustration or photograph. Substantial numbers of numerical problems (in practice, an infinite number) are included for use as reinforcement learning tools – a technique that has been shown to be extremely effective in tackling specific numerical shortcomings.
Given that the overwhelming majority of the targeted students have chosen to avoid physics, great care has been taken to ensure that the context enclosing the materials is identifiable as chemistry only.

Subject area: Chemistry

Description
Software tools have been developed to help chemistry students with elementary problems in physics. These consist of simulations (and high quality diagrams with relevant animations) designed to accompany tutorials or workshops. They are not ‘stand-alone’ programs and assume that the teacher has covered the basic groundwork. Substantial numbers of numerical problems are included for use as reinforcement learning materials.

Type of activity
Simulation. Numerical practice.

Content covered
1. Electromagnetic waves.
2. Wavelength and frequency.
3. The electromagnetic spectrum.
4. Radiation energy.
5. Atomic spectroscopy.
6. The hydrogen atom spectrum.
7. Interference.
8. Diffraction.
9. De Broglie wavelength.
10. The photoelectric effect.

Application

The tools have been designed to accompany tutorials or workshops together with a large number of numerical problems suitable for self-study. In addition the teacher may,

a. Specify the precision required.
b. Determine whether or not to insist on the correct precision being used.
c. Allow the students to control their own precision.
d. Determine the type of answer checking employed,
    1. Level 1 answer checking responds by quoting the correct answer.
    2. Level 2 answer checking responds with the accuracy - exact, within 1%, within 5% and above 5%.

    Level 3 is more complex and gives a student three attempts at getting the answer right by responding with the accuracy figures used in level 2. Exact answers and those within 1% are regarded as correct, whilst beyond 5% the student must try again. When level 3 checking is operative then the program keeps a record of student progress.
e. Completely replace the text with his/her own version.

Further comments

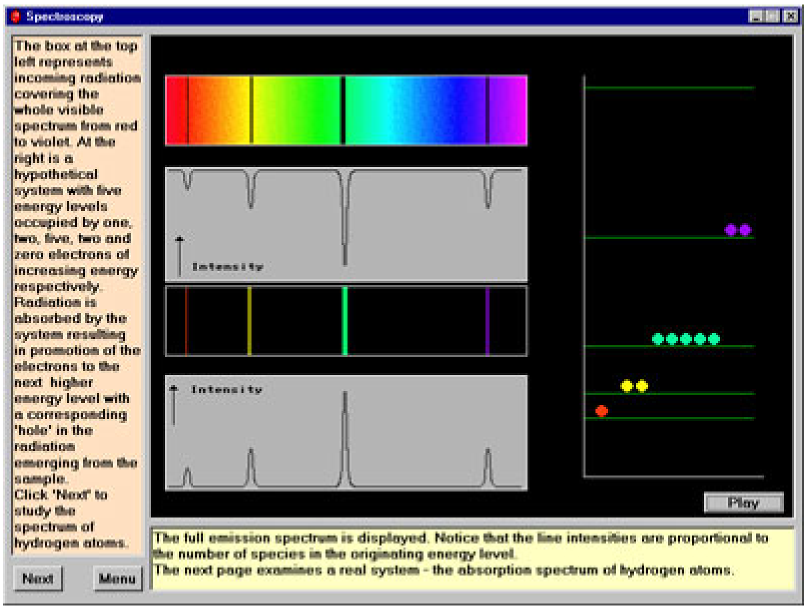

Figure 1 An animation illustrating the generation of atomic spectra by electronic excitation

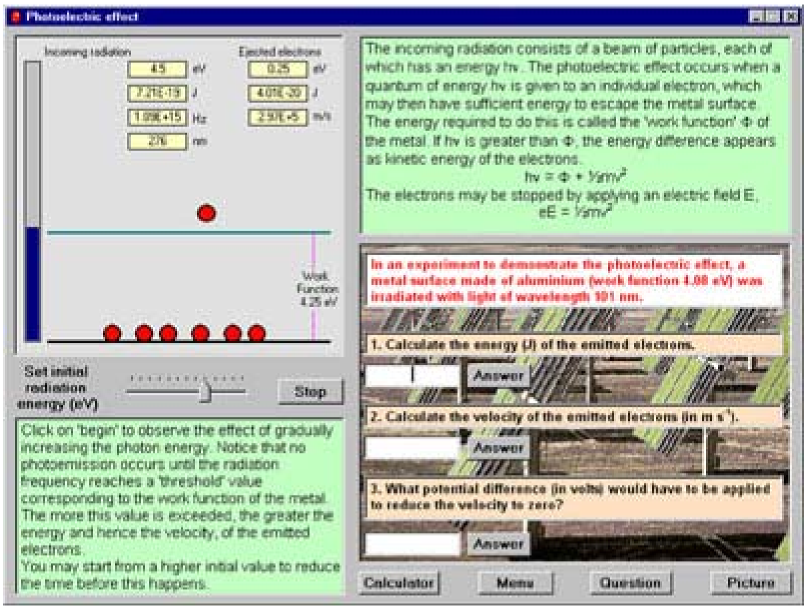

Figure 2 A simulation of the photoelectric effect illustrating the 'threshold energy'. A typical numeric problem has been requested.

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URL
http://www.physsci.ltsn.ac.uk/devprojs/reports/phys_soft_res.htm
Development project: Software Resources for Remedial Physics Teaching in UK University Chemistry Departments

http://www.physsci.ltsn.ac.uk/devprojs/Gcsephys.htm
Briefing paper: The Physics Problem

ftp://ftp.liv.ac.uk/FTPANON/ftpanon1/ftp/pub/chemistry/ltsn/physics
Link to software cited in article

The Concept of the Pre-lecture

Summary

This article reviews previously published work demonstrating how pre-lecture support for students can help improve end of year examination performance.

Subject area: Physical Sciences

Description

At the start of each lecture course, one lecture was replaced by a pre-lecture. In this, a quick check of background knowledge allowed students to classify themselves as needing help or able to offer help. Students then worked in pairs on material designed to revise the background material necessary to make sense of the lecture course.

End of year examination performance showed that student performance was no longer related to entry qualifications in chemistry: the least well qualified did as well as the better qualified.

This was observed for two successive years but, for the next three years pre-lectures were not offered. Student performance fell despite the increased lecture time and the least well qualified did significantly worse than the better qualified.

In the sixth year, new teaching materials were introduced, designed to mimic the pre-lecture concept. Again, the least well qualified did as well as the better qualified.

Type of activity

A set of Teaching Materials (called Chemorganisers) available at:
http://www.gla.ac.uk/centres/scienceeducation/Chemorg/ChemorganisersHomePage.html
Project covered the years 1993-1999

Application

Numerous aspects of chemistry, set at introductory level but the idea applies to any discipline. Students can be referred to the materials.
Pre-lectures are easy to set up in any discipline, and have been shown to be highly effective.

Author(s)

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Interactive Physics: A virtual library of simulations for use in Physics Undergraduate Teaching

Summary
This report outlines the design and deployment of a virtual (online) library of interactive simulations (principally Java applets) designed to be used in Undergraduate Physics teaching. The project was funded by an LTSN Physical Sciences Project Development Grant in 2001.

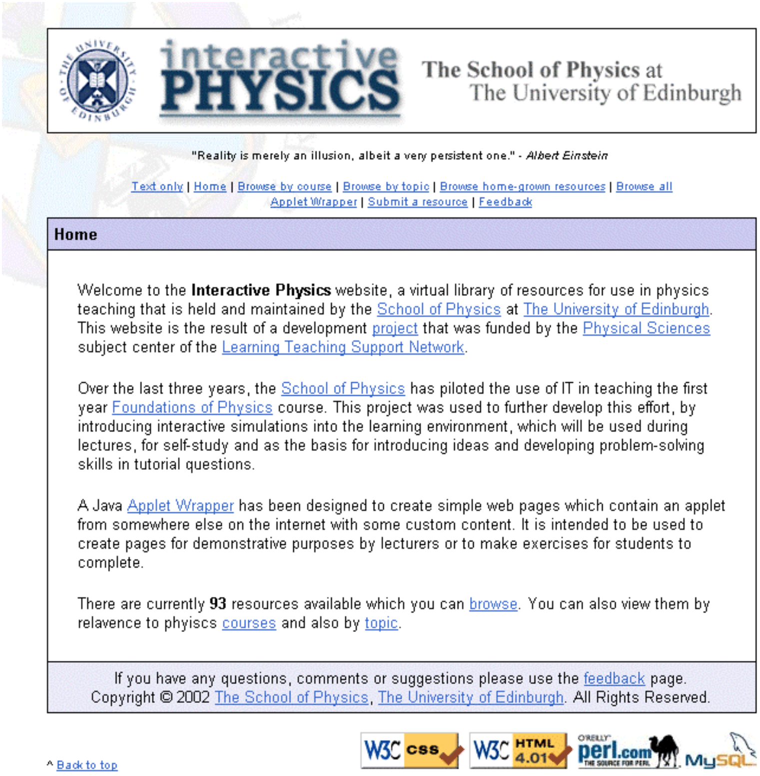
Subject area: Physics

Description
The use of Computers and Information Technology (`C&IT') in teaching has genuine potential to enrich the teaching-learning experience, a fact that is borne out by its widespread, but not always effective, implementation across the HE sector. Our view of the role of C&IT in the teaching of the Physical Sciences is that it should form part of a coherent learning environment, where technology is used to augment and enrich, rather than supplant, the more traditional methods of teaching. Our views are mirrored by the student community, who quite rightly expect a varied educational environment, firmly rooted in the face-to-face staff-student contact of a real (as opposed to `virtual') University campus.

Our experience with the use of C&IT thus far has demonstrated the truth in the old adage that a picture `speaks a thousand words'. Better than a picture is a moving picture, and the incorporation of moving images into - via video or simulation - course material, textbooks, web resources etc is now becoming the norm. Our use of video clips and simulations during lectures has been generally well-received by our students and many find it a valuable aid to their understanding of concepts. The `best of all worlds' situation is one in which the student has such a visual representation available, but in addition also has the ability to affect or `steer' the simulation via their own intervention. In this way, the static presentation of a visual resource becomes an interactive experience.

Pedagogically, simulations can be immensely valuable if they are used in a manner based on a good understanding of student thought processes. They can enable students to form connections between the many and varied representations that we use in Physics, such as equations, diagrams, tables, vector plots etc. They can be used to cement the fact that the equations we use represent relationships between observations and measurements, that they are not just for the calculation of a quantity. Simulations can enable students to build mental pictures (`models') of physical systems and they can use these models as a vehicle to describe and convey their understanding to each other. Finally, simulations offer an engaging, hands-on, active learning experience that puts the student in control of events and can lead to a deeper learning.

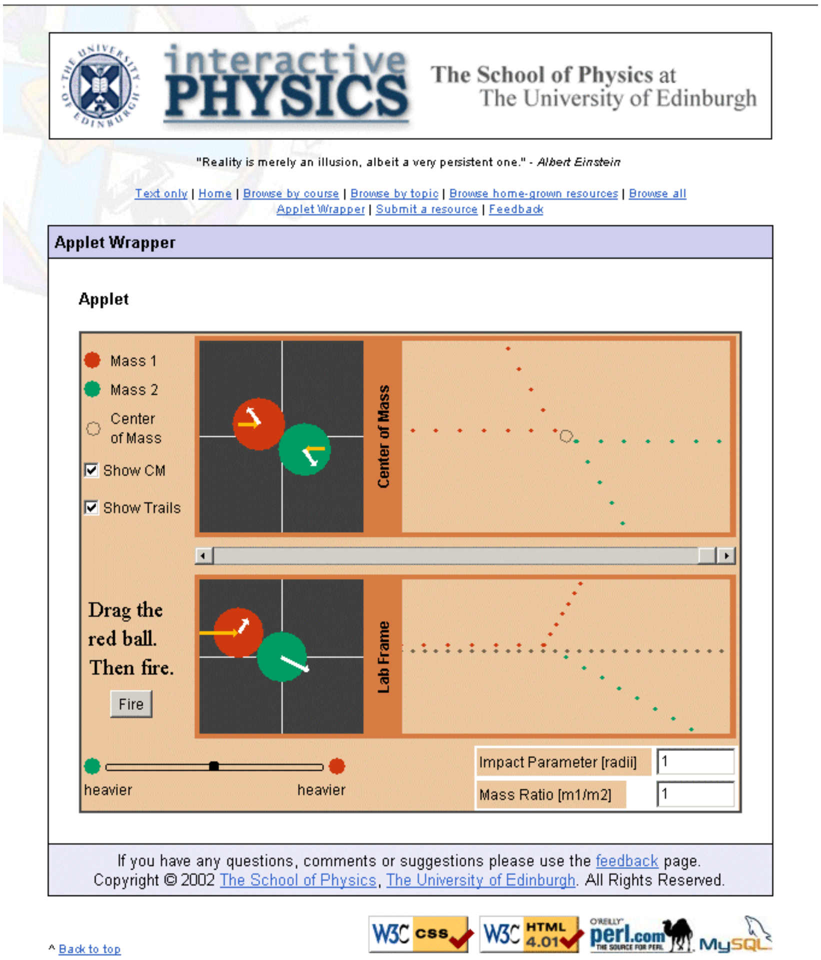
With that rationale in mind, we have designed a virtual library to house interactive simulations (chiefly at present Java applets, but also Flash animations) that may be utilised in undergraduate Physics teaching. The key design feature is that of a *virtual* library, i.e. the applets themselves exist remotely (wherever they may be on the WWW) and we maintain placeholders to them and other resources (see below on use scenarios). The library is searchable in a variety of ways allowing different library users to locate resources in different ways. The following image is a screenshot of the applet library homepage



Type of activity

- The main technical details of the Interactive Physics Applet database are summarised below:
- The applet library (database) exists as a relational (MySQL) database
- Perl / cgi scripts (1200 lines) query the database on the fly, creating customised web pages, depending on how the user wants the information presented, e.g. ordered by course, by topic, full listing etc.
- The database is managed remotely using the ODBC protocol through Microsoft Access 2000. This allows modification of database content and design in a transparent way.
- The scripts and database design is fully documented to enable transfer of management responsibilities to different people. The separation of content (database) and presentation (script-generated Web pages) enables easy reuse of the project's components.
- The script automatically checks whether or not links are dead or alive and adjusts the displayed web page that is delivered to the user accordingly.
- Users are encouraged to report bad resources and can easily do so (e.g. bad links, inaccurate description etc).
- Newly-added resources are flagged so that users can see recent additions. Users can also suggest additions to the site.

- An Applet Wrapper has been created, which the user views as a series of step-by-step instructions. This enables a non-expert to create high impact web pages with Applets embedded in them for offline use, without detailed knowledge of the html language. The following screenshot shows a wrapped applet without any detailed notes for use :



Content covered

Initially, the library's remit was to house resources for a foundation level course (1st year) in classical Physics (mechanics, dynamics, energy, kinematics and waves) taught at the University of Edinburgh. Although the library entries are geared towards more introductory material, there is a gradual percolation through to more advanced material, such as quantum theory, relativity etc.

The framework in place is such that there is provision to house applets / resources relevant to any aspect of undergraduate physics. The tools developed are inherently generic, and as such may be relatively easily transferred to other Physical sciences, e.g. Chemistry, Engineering etc.

Application
There are principally two different user scenarios:

1. The student
The database is designed in such a way that students may search the database either by topic or by course, and view the relevant resources. Hyperlinks to the applet's source page enable the students to make use of other resources that may have been developed with the applet in question (e.g. exercises)

2. The lecturer
This approach to browsing the material is also available to lecturers. In addition, there is the capability to create a "wrapped-up" web page with the applet embedded in it, surrounded by learning material such as commentary, exercises and points to note, without a detailed knowledge of how to write raw html. This "applet wrapper" is available on the database and may be used to wrap up any applet in a series of easy to follow steps. The resulting web page is then able to be saved locally for use in a lecture, tutorial or for posting on a course website. For those with some knowledge of html, it may be possible (depending on how the applet was written) to customise the local ("wrapped up") version of the applet by altering parameters in the <APPLET> html tag.

Further comments
The future: This project has been extremely successful, with all of the aims being met on a very modest budget and a resource of real capability and usability for the academic community has been produced. Future development will include extending the number and range of applets in the database and more home-grown material to fill in what we perceive to be the gaps in material available remotely on the web. For this, we intend to seek further funding. The possibility of transferring this generically to other subjects (e.g. chemistry and engineering) is also being explored.

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Heriot-Watt SCHOOLS Physics Laboratory

Summary
A collaborative venture, set up by the Physics Department of Heriot-Watt University, Edinburgh, to provide practical support for school Physics departments in carrying out and assessing the practical elements of SQA Higher and Advanced Higher Physics. The venture allows school students to work in a university environment and in this way strengthens the links between school and university.

Subject area: Physics

Description
The work provides practical support for school Physics departments in carrying out and assessing the practical elements of the Scottish Qualifications Authority Higher and Advanced Higher Physics syllabuses and in so doing strengthens the links between school and university.

Type of activity
Laboratory work related to the SQA Higher and Advanced Higher Physics syllabuses.

Content covered
Practical experimental work for assessment and moderation in each of the three Units of the SQA Higher and Advanced Higher Physics Courses.
Practical experimental work for assessment and moderation for the Physics Investigations half-unit for the SQA Advanced Higher Physics Course.

Application
The SCHOOLS Physics Laboratory was set up in the Physics Department of Heriot-Watt University to provide schools with practical help in carrying out the experimental aspects of both the Higher and the Advanced Higher Physics Courses. It does this by giving school students the opportunity to carry out experimental work in the Physics Department of the University, using prepared experimental worksheets or 'scripts'. These scripts have been written in such a way as to enable students to carry out the experimental work even before the relevant theory has been covered by the teacher in class.

The Higher Physics Course consists of three Units – 'Mechanics and Properties of Matter', Electricity and Electronics' and 'Radiation and Matter'. For each of these Units, students were required to perform practical work and submit a report of one experimental activity. (This requirement has subsequently been amended to only one report from any one of the three Units of the complete Course.) This requirement is known as the 'Learning Outcome 3' or 'LO3' report. A similar requirement exists for the 2½ theory Units of the Advanced Higher Physics Course. In addition, the Advanced Higher Course contains a half Unit (20 hours nominally) called 'Physics Investigation'.

When the SCHOOLS Laboratory was first set up, in November 2000, the work carried out by students in the laboratory was aimed primarily at those experiments relating to the Advanced Higher Course that were difficult, if not impossible, for schools to carry out, and which were suitable for LO3 assessments. For example, the 'Cavendish-Boys determination of the gravitational constant *G*', requires apparatus not generally available in schools and is too time-consuming to carry out at school. The 'Coulomb's Law' apparatus is too delicate (and too expensive) to be set up in a school classroom that may have a junior class coming in immediately after its use by responsible seniors. For an accurate determination of the 'Force on a current-carrying conductor', a balance with a capability of measuring a small fraction of a gram is needed. Such a balance may well use up the complete funding allocation of a school Physics department for one year. In the SCHOOLS laboratory several of the experiments that have been set up are interfaced to dedicated computers. To tie up computers in this way is impossible in most school Physics departments.

The SCHOOLS Laboratory has since been extended in its scope, to include experimental work related to the content of the Higher Physics Course, although, in general, schools are more able to cope with these needs since the equipment requirements are not so demanding either in cost or complexity.

A more recent expansion of the SCHOOLS Laboratory has been into the area of Advanced Higher Physics Investigations. This has been in response to the many requests received from schools to provide some much-needed help with the Physics Investigations half-unit. One way of meeting the requirements of this half unit is for the school students to carry out a series of short experiments linked to each other, in a particular area of Physics. This is the approach that has been used in the SCHOOLS Laboratory. The students from a particular school will typically spend three days, perhaps in consecutive weeks, working on themed experiments. Some of the Investigations that have been successfully carried out include Polarisation of Light; The Wavelength of Light; Inverse Square Law Relationships; Gravity; Factors Affecting the Force on a Current Carrying Conductor; Sound Investigations; Rotational Dynamics.

In using the SCHOOLS Laboratory, there are many benefits to the school Physics department, to the school students individually, and to the Physics Department of Heriot-Watt University. The school Physics department benefits because the experiments that the school students carry out are all closely related to the theory work in the Higher or Advanced Higher Course. The experiments meet the criteria required by the SQA for the assessment of Learning Outcome 3 or the Physics Investigations Unit as appropriate, so reducing the assessment burden on school Physics departments. As already explained, the experiments are, in general, the ones that for various reasons, schools have difficulty in offering to school students.

The school students benefit because they are given the opportunity to carry out experiments that they may not be able to do otherwise. Since all of the experiments are either computer-interfaced or use computers for data-handling, students become familiar with a greater variety of equipment and computer hardware and software. The SCHOOLS Laboratory is housed in the first-year undergraduate laboratory in the Physics Department of Heriot-Watt, so school students work in a university teaching laboratory and can begin to experience university life at first hand. The school students can also take the opportunity to speak to members of the university staff as well as undergraduate and postgraduate students.

Heriot-Watt Physics Department benefits from the closer liaison with school Physics teachers and students in schools. The SCHOOLS Laboratory offers an opportunity for the University to ‘open its doors’, in a very practical way, to its possible future undergraduates.

Such has been the success of the SCHOOLS Laboratory, that geography has not proved to be a constraint. As well as schools in the immediate vicinity of the University making use of the facilities offered, there have been visits, and indeed return visits in subsequent years, from schools as far away as Islay and Fortrose on the Black Isle. Both of these visits involved an overnight stay.

One Physics teacher, on a return visit to use the SCHOOLS Laboratory, commented that the passes achieved by his Advanced Higher class of the previous year had been the best he had ever achieved in his teaching career. While this success could not be entirely attributed to the visit to the SCHOOLS Laboratory, he was of the opinion that the experience that has been offered to that class had been a contributory factor in their success.

Figure 1 School and university students working together in the SCHOOLS Laboratory, with staff

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Web-based experiments in physics and chemistry

Summary
Experiments are being developed which can be accessed remotely by students at schools and colleges. These experiments, which are interactive and allow users to communicate with real equipment (not simulations) through the Internet, are intended to enhance a range of courses in the physical sciences.

Subject area: Physical Science

Description
The project is intended to expand the range of experiments which can be carried out by students in schools, colleges and Universities by allowing access to equipment which cannot be provided in the students' home institutions.

Type of activity
Remote experiments are being developed. These will be available with on-line instructions designed to allow stand-alone experiments to be run. In addition, detailed descriptions of the equipment and how it may be used will be available for students (and teachers) wishing to design and run their own experiments. We also intend to develop generic software to be made available to interested users in educational institutions so that they can place equipment on the Internet in a relatively straightforward fashion.

Content covered
Content will depend upon perceived need. At present we have a small optical rig available which generates data for use in an "analysis of errors" experiment. Collaborators in schools are being sought to provide input into experiments which would be of help in illustrating A-level and pre-A-level courses.

Application

1. To expand the range of experiments which can be covered as part of school and college science courses.
2. To provide remote access to experiments for students unable to complete a normal laboratory course.
3. To allow Universities and schools to minimize costs by sharing experiments which would otherwise be duplicated across several institutions.

Further comments
This project has developed from a long-standing Internet-based experiment at Oxford University. In view of the financial pressures which all types of educational institutions now experience, the provision of some experiments *via* the Internet would appear to be a cost-effective way of allowing students to tackle experiments which require sophisticated or expensive equipment. Although the Internet was not designed as a medium to run experiments, it has become progressively better suited to this

purpose as the speed of connections has increased. The software problems of connecting equipment are mainly independent of the type of equipment, and a major feature of this project is the aim of creating software which could be used by relatively inexperienced teachers to link equipment to the net. Although we feel it would be very undesirable to replace all practical elements of a science course with web-based experiments, the opportunity to enhance and expand an existing course by using remote experiments is one which we feel that many teachers would welcome.

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Enterprise in Physical Science

Summary
With an increasing emphasis on enterprise and innovation in government directives, it is timely to consider the embedding of enterprise activities within the physical science curriculum. We have piloted a course "Physics in an Enterprise Culture", and are now expanding to embrace project work and dual degree schemes.

Subject area: Physical Science

Description
The work is concerned with embedding and enhancing enterprise skills in the undergraduate curriculum through option courses, project work and ultimately dual degree schemes.

Type of activity
Currently an option module is available at level 3: "Physics in an Enterprise Culture".
Dual degrees (BSc and MPhys) will come on stream in September 2003 "Physics (or Chemistry) with Enterprise Management".
Group project work at level 3.
Summer placements in Sheffield or Silicon Valley.

Content covered
Project Proposal: research proposal mechanisms in UK academia. Why are formal proposals used? The EPSRC "standard" proposal form and Case for Support .Making your proposal for a Laboratory Experiment. Peer review. Prioritisation.
Patents, Protection and Marketing: What is a patent? Why are patents needed? Is a good idea enough? How is a prototype developed and marketed? What makes a commercially successful product?
Product Dissection: Have you ever wondered what is inside a walkman? Or a mobile phone? Or a camera? What were the challenges in putting these components together? This theme involves the "dissection" of a product to find out how it operates and what its limitations are. What opportunities remain for further development? Case studies.

Application
This model is transferable to any Physical Science discipline, with appropriate choice of exemplars.

Many physical science graduates go in to the SME environment, which requires the rapid application of new knowledge in highly competitive fields. This brief exposure provides students with the essentials of what they need to know for such a working environment.

Further comments
The option course has proved very popular with our students. They found the process of project proposal and refereeing very revealing in terms of how to persuade others

of the merit of your own case, and how to critically review the suggestions of others. The product dissection gave students the opportunity to think how the core physics studied has been used in modern day technology, to realise the limitations that remain to be overcome (e.g. battery technology), and the highly competitive market place. We found it of immense value to bring in a physics entrepreneur to meet with the students and present a case study of his own company.
It has also been important to have under continual development a web site of resources which may be used to seek out information and stimulate ideas.

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A Chemistry Scale-up Exercise

Summary
Second year students take a bench scale synthesis and work out how to scale it up. They simulate the process with salt and water to determine practical handling problems and thereby develop a set of instructions for process operators.

Subject area: Chemistry

Description

There is considerable activity in the chemical industry in making relatively small amounts of chemical products for special purposes, say from a kilogram to a few tonnes. Many companies synthesise materials in single batches or short campaigns as required. To scale up a synthesis from gram (or less) to kilogram or more brings practical problems of material handling, safety and general organization which are not addressed by standard laboratory classes in chemistry or chemical engineering. Nevertheless, it is a task the graduate might well face in industry.

For the past five years, undergraduates in Chemical Engineering, and the Joint Honours degree Chemical Engineering and Chemistry, at the University of Sheffield have carried out practical exercises based on this problem. The long version actually involves synthesis of a kilogram of product, using similar quantities of toxic, corrosive, flammable chemicals. This requires suitable facilities and has some cost. However the short version uses nothing other than salt and water, and thus could be carried out with minimal cost and safety concerns, while still addressing much of the educational value.

Activity

Short Laboratory (3 to 5 hours)
Groups of 3 students are provided with a bench-scale synthesis from a textbook and directed to scale it up. We have a 50-litre flask and mantle, with stirrer, feed funnel, cooling coils and condenser. This could be adapted to distillation, or material could be transferred to an adjacent distillation apparatus. There is also a filter press. However, much of the educational aims could be achieved with 2-litre or 5-litre vessels and a large Buchner filter, and this report is made for departments who wish to consider the more modest scale.

The first task is to determine the minimum and maximum working volume of the main vessel, and compare this with the amount which occurs in the bench scale. A large spherical vessel needs a certain minimum volume for the stirrer to be effective, but should not be filled to more than two-thirds full, particularly if is to be refluxed. A good scale factor will give convenient quantities for measuring out on the large scale. Students should understand what each component is for, and the chemistry involved: it is not enough to blindly multiply. Reagents may need to be present in a ratio determined by stoichiometry - others such as a solvent may be less critical.

The students then make up a stepwise set of instructions. There should only be one action per step and it should be specific. E.g. "Switch on the agitator." "Slowly add 2 litres of 35% aqueous HCl." "Switch on the heating coils." "Heat up to 60 °C." "Switch off the heating coils."

The next stage is to mimic the process, but using sodium chloride in place of any solid and water in place of any liquid. The aim is to determine how long it will take to carry out each step and the practical implications. This may require some subsidiary tests. If the original instructions say "reflux for 3 hours" there is no need to actually do this: just write down this step and go on to the next one. However, how long does it take to get to boiling point? This can be estimated by extrapolating from a heating curve (taking into account the boiling point of the solvent used). Ideally, students should correct for the different specific heat of the solvent compared with water.

However, it must be stressed that a key feature is practical handling. Students are often surprised that sodium chloride does not instantly dissolve, or that wet solid is sticky. Successful scale-up may actually require things to be done in a different order. Typically, to dissolve solid requires there to be sufficient liquid for the stirrer to be effective and then to add the solid slowly so that it is dispersed.

If salt and water cause difficulty, what about corrosive chemicals such as phosphorus pentoxide or benzyl chloride? How could the handling be modified for safety? In a 5-hour lab the students may actually act out these procedures; in a 3-hour lab it is a matter for discussion.

The student's target achievement is a revised set of instructions which include safety requirements and a reasonable estimate of the time for each step, including measuring out of chemicals. The laboratory report includes this, plus the work and thought they put in to get it. As an option, they may be required to carry out a COSHH assessment.

Note that with some syntheses it may not be possible to simulate all of it because of lack of equipment or time. The demonstrator should suggest a suitable starting and/or stopping point in the synthesis. The other steps should be estimated.

Long Laboratory (3 sessions of 3 to 8 hours)

In this the students actually carry out the synthesis as follows. In the first session, they carry out the bench scale following the laboratory recipe, but observe it carefully and make notes. This is where it is helpful to have three people. They may also carry out subsidiary tests, noting matters such as temperature rise, emission of fumes, difficulty in dissolving.

They prepare a stepwise protocol and go through it in the second session, using sodium chloride and water. This enables them to sort out problems of organization and timing. (Or indeed, miscalculation of volume!) They prepare a revised plan and a COSHH assessment, which has to be agreed by a member of staff.

In the third session, the students actually carry out the synthesis. This can provide a great sense of achievement or possibly a harsh lesson! Naturally they have to be well supervised and fulfil all necessary safety requirements. It may be appropriate for a member of technical staff to carry out certain operations.

Further comments

Clearly, few departments will have the resources to carry out pilot scale chemistry. We only provide the long lab experience to 12 students a year. However, scale-up is a useful art to appreciate and can be readily simulated with low cost and low risk using salt and water. Current chemical laboratory practice commonly involves semi-micro or less, so even dissolving up tens of grams of salt in a litre of water may be worthwhile. Certainly, thinking about what is happening both chemically and physically would be helpful for students intending to work in the manufacturing part of industry.

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Interactive Teaching Units in Physics

Summary
The concept of the interactive teaching unit first emerged in the late 1970s (Reid, 1978; Johnstone and Reid, 1979) arising from a major research project which was seeking to explore the development of attitudes relating to the themes covered in the study of chemistry. From this project, a sound educational underpinning was developed (Johnstone and Reid, 1981).

Much later, the use of interactive units has been extended to skills development, social issues awareness and the applications of science subjects in real-life situations (Reid, 1999; Clarkeburn *et al*., 2000; Lennon, *et al*., 2002). Sets of units were developed in chemistry and biology and, more recently, a range of four teaching units in physics was developed under LTSN funding.

Subject area: Physics

An interactive teaching unit is a free standing teaching resource where students have to solve a problem. The problem is based on a real-life situation with varying degrees of simplification and simulation. The units are short (typically from 1 hour to 3 hours) and designed to fit into traditional tutorial and laboratory timings. Students usually work in small groups.

By experiencing different views of the same issue, students are encouraged to recognise the many facets of real-life decision taking and to accept that decisions often have to be made on the basis of incomplete information. Students will also have opportunities to assess data presented in several forms, to weigh arguments, to contribute to a group discussion, to present arguments based on gathered evidence and to listen to the arguments proposed by others. They should begin to see the place of such skills in the context of their education in physics and in the world of work.

The project developed and tested teaching units for use at level 1 of undergraduate courses in physics. They do not seek to teach physics but to apply physics into real-life situations. They involve paper-based group work and contain a full tutor's guide. They are relatively short, being suitable for tutorial use. While focussing on physics applications, their use involves group discussion, debate and argument as well as opportunities for developing presentational skills. Supplementary activities are suggested. The features of the units are:

(1) They are based on real-life problems
(2) Students work in small groups, with opportunities for students to practise team work and communication skills.
(3) Students have to apply their subject knowledge and experience in developing possible solutions, reflecting experiences that might occur in the world of work.
(4) They are paper-based and are fairly short, making them economical in materials and in time.

(5) They can be used to replace traditional teaching in that the same subject matter is covered or they can be used to reinforce and apply subject teaching
(6) They are self contained, with complete tutors guides. The guides offer clear instructions about how the units can be used, with background information, 'answers' where appropriate, and suggestions for extension activities.

The four units are:

Renewing Energy	After a brief introduction, students work in collaborative groups of three to assess the key features of a range of primary sources of energy in order to make a recommendation about national policy to meet the requirements of the Renewables Obligation, a Parliamentary Order which came into effect in 2001, compelling all electricity suppliers to source at last 10% of their power from renewable sources by 2010.
Mobile Phones	After a brief introduction, students work in role play groups representing various view points to develop a policy for the installation of phone masts on an imaginary island where competing interests are strong.
Fibre Optics	Students are required to consider the essential physics of the use of fibre optics and then, working in small groups, they assess data provided on various materials and make selections of materials for various applications: communications and endoscopes.
Colour	After an introduction which deals with the nature of colour in terms of spectra, incident light and colour perception, students work in pairs to look at one primary colour, seeking to select potential colours for use in road signs. They come together to exchange their findings and come up with a set of three colours which are suitable for use. Colour matching functions are considered as a supplement.

The main aim of the units is not to teach about themes in physics but students are required to use their knowledge of the relevant physics to interpret information in order to take decisions and make choices. They will begin to see how the principles of physics are applied in taking decisions which will affect all our lives. At the end of units, students may be expected to achieve aims like:

(a) Being more aware of the physics related to the topic, and the issues surrounding interpretation.
(b) Gaining experience in understanding and interpreting data.
(c) Appreciating that there may be several factors which have to be considered in taking decisions relating to physics.
(d) Understanding that practical decisions have to take account of physical realities and social acceptability.
(e) Accepting that discussion and compromise are part of commercial decision taking.

In addition, students will gain valuable experience in skills like group working, discussing and negotiating, make presentations verbally or in writing.

The units are designed to be integrated into teaching programmes and not seen as an add on. The tutor's role is more of a manager and not the provider of information, an important change but not always easy at the outset. Debriefing afterwards is essential and this offers a useful time of reflection about the physics, the issues and the way solutions can be found. The suggested extension activities allow students to apply the ideas under consideration.

With the earliest set of interactive units, there was extensive evaluation and subsequent units have been evaluated in varying ways for a wide range of purposes. Overall, a consistent observation is that students DO participate with enthusiasm. Although the units do not primarily seek to teach a subject, the evidence is that they are quite effective in teaching subject matter (although not necessarily better than any other way). Growth of skills is observed (like team working and communication skills) while attitudes of social awareness develop markedly. There is clear evidence that there is what has been called a ‘softening’ of a physical science as the participants begin to appreciate the way science and lifestyle interact. The open-ended nature of units may be important. Students are found to be positively disposed to the units, to the teaching style and to the subject matter. This particular set of units was trialled with a few groups of students and there was open discussion afterwards with them. Minor adjustments were made in the light of the student reactions.

Further comments

The physics units were developed and written by Graham Watt and appreciation is also expressed to Andrew Davies and Rex Whitehead for invaluable support in the project.

The physics units can be downloaded at:
http://www.physsci.ltsn.ac.uk/pubsfinx.asp?ID=168

Details about the units in chemistry and biology can be obtained from the author (N.Reid@mis.gla.ac.uk).

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Practicing Science Practice

Summary
We describe a core course for fourth year undergraduate masters students in which they run an internet journal, writing, submitting and refereeing short papers on physics and astrophysics.

Subject area: Physical Science

Description
The course is intended to (a) reinforce core material in physics, astronomy and space science by encouraging students to apply it in novel contexts (b) to promote an understanding of the way scientific research is communicated (c) to encourage group work

Type of activity
General physics, astrophysics and space science. Students produce an internet journal.

Content covered
General physics, astrophysics and space science.

Application
This is applicable in any area (subject to the difficulty of thinking up suitable open-ended problems at an appropriate level). It provides an interesting way of achieving the three aims under the course description.

Further comments
The web element provides easy access to material and allows this to be organised in an efficient manner (compared with the paper-based version of the initial trials). Realistically it does not eliminate the need for printed copies, for example for editorial board meetings.

Student responses vary greatly. There is a long learning curve followed sometimes by an overwhelming gush of trivia and in some years by a number of high level original contributions. Clear guidelines are essential for refereeing to avoid the extremes of uncritical acceptance or overly hostile evaluations.

There is one facilitated meeting a week of the groups (for about 90 minutes); otherwise students work in their own time. The module is 10 credits (75 hours).

Staff development is required to prevent academic facilitators from providing too many detailed answers.

Feedback was obtained from a class meeting. Suggestions were largely confined to technical aspects of scheduling and marking. In the first year of implementation there were some comments along the lines of ‘why are we doing this instead of being taught something properly', but these have not been re-iterated in later years (formally or informally) following explicit discussion of the course aims in the induction session.

The project was supported by an LTSN development grant.

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A Computer Program to Simulate NMR Multiplets

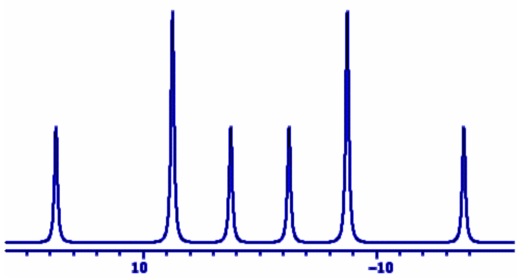
Summary
Program Mltiplet for Windows calculates first order nuclear magnetic resonance multiplets for spin systems consisting of spin-half nuclei, and draws them on a PC screen. It is offered free of charge.

Subject area: Chemistry

Description
Mltiplet for Windows is a new computer program which we offer free of charge for teaching NMR Spectroscopy.

Type of activity
A conversational DOS version of Mltiplet was written as an easily used simulation tool, useful in learning to interpret Nuclear Magnetic Resonance spectra of molecules in solution. After over ten years of use, this has now been translated into a full Windows application, with a 'feel' more familiar for today's students. Both the new Windows version and the old DOS version are being offered for download.

Content covered
Starting from numbers of nuclei and NMR coupling constants in a molecule, Mltiplet draws the expected multiplet, which the chemist can compare with what has been observed using the NMR spectrometer.



It can be used to simulate the simplest multiplets, but it can equally show the most complex first-order multiplets interpreted in chemical research. While the program generates quite realistic lineshapes, it assumes that the multiplet is completely first order, with intensities of peaks given by Pascal's triangle of binomial coefficients. This is as universally taught in introductory courses on NMR.

Application
Mltiplet was devised to be used in a drylab environment. Students learn to use tools, such as computer programs, which are the same or similar to those used in research, for working on research-relevant problems in a supervised co-operative group environment. At the introductory level, students can use Mltiplet to find out what happens to the appearance of a multiplet as coupling constants are varied, and to understand the meaning of terms like 'doublet of triplets'. In more advanced courses,

they can use it to confirm their hand analysis of presented real spectra, thus adding an element of experiment into what would otherwise be a once-through procedure with numerical results. They learn, by trial and error, how to see complex multiplets, and extract coupling constants from them.

Further comments

While Mltiplet was written as a learning tool for university undergraduates, and has been used mainly at first and second year levels of our honours chemistry courses, it finds occasional use in synthetic chemistry research. We now propose that it can be used also at the secondary school sixth form level, at the very beginning of teaching and learning about NMR. In contrast to the several full simulation and spectrum fitting programs available, in some cases at considerable cost, Mltiplet is not only available free of charge, but it is also extremely easy to download, install, and use. It is envisaged that students may wish to install it in their own PCs, as well as using it in the classroom.

Full notes on use and installation are given on the website below. Detailed instructions and several examples are compiled into the Help facility of the Windows version of the program.

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Web Based Resources for Forensic Science

Summary
The aim of this work was to produce four web-based problem-solving activities in the areas of arson, drug smuggling, poisoning and horse doping. Much of the work was carried out by four MChem students as part of their final year projects. As these were students on chemistry programmes, the content was based within chemical analysis aspects of forensic science, with additional coverage of related areas such as, for example, fingerprinting, forensic psychology etc.

Subject area: Chemistry

The aim of the project was to produce interactive web-based packages which would present students with a problem scenario within forensic science. The students solve the problem by working through the information given in the resource, by bringing additional information to the problem and by carrying out an experiment in the laboratory. All of the web-based aspects of the packages are interactive, requiring students to answer questions of retrieve information.

Fire Investigation
This package is based on a real life case of arson at a nightclub. The website consists of background information on arson, arsonists, accelerants, methods of laying fires etc. The detailed chemistry and methods of detection of some common accelerants are also included. The students read interviews and witness statements and can compare fingerprints in order to determine possible motive and opportunity. They are then directed into the laboratory. There, they analyse specimens of samples taken from the scene: carpet and curtains soaked in the accelerant used. They must extract the sample and analyse by chromatography in order to determine the identity of the accelerant or mixture of accelerants. This information should enable the students to identify the culprit/s.

Horse Doping
This package is based around a true case in which a trainer was banned after his horse failed a drugs test for caffeine after he fed the horse chocolate M&M's. There is sufficient caffeine in chocolate to give a false positive result if enough are ingested. The package contains background information on doping and methods of detection and analysis. It operates by engaging students in the investigation of 'suspect' race results. Once suspect winners or losers are identified the students are directed into the laboratory where they analyse several samples of 'horse urine' for caffeine levels. The results of this analysis enable them to determine which, if any, of the horses may have been doped.

Drug Smuggling
This package is based upon the identification of white powders smuggled into Hull via a car on the ferry. The package contains background information on common

illegal drugs, their biological effects and methods of detection and analysis. The scenario is based around the search of three vehicles leaving the North Sea Ferry terminal. The students are able to ‘search’ the boot of the car and the contents of any luggage. One car contains excessive amounts of vodka. On closer investigation this is seen to contain a white sediment, which the students can identify as cocaine by interpretation of the results of instrumental chemical analysis.

Death by Poisoning
The package is based on the suspected murder by poisoning, of an industrial chemist. The site contains background information of many organic poisons, along with details of methods of detection and analysis. The scenario is based around the discovery of the body of a chemist in his office. Students must examine the scene of crime, fingerprint evidence and evaluate interviews and statements in order to identify possible motives and opportunities of those close to the deceased. The results of the chemical analysis of the contents of the deceased medicine bottles and toxicology results enable the students to determine the cause of death, method of administration of poison and suggest possible perpetrators.

All of the resources have been trialled with undergraduates with very positive results. They enjoyed the forensic science applications and engaged with the web resource enthusiastically. The two packages with the laboratory element within them have been adopted in the department. They provide an alternative means of making experimental chemistry more relevant and act as effective pre-lab exercises.

Type of activity
Web-based problem solving. Students work individually or in small groups.

Content covered
Analytical chemistry in a forensic context

Application
These resources could be used within forensic science or analytical chemistry modules. Two of them (Horse Doping and Fire Investigation) have optional laboratory activities and can be use as a pre-lab, experimental and post-lab package.

Further comments
The arson, horse doping and poisoning package have been mounted on the chemistry department’s web page under resources for UCAS students. The level is such that students at the secondary/tertiary interface should be able to tackle some of the problems.

I am grateful to the creative efforts of Liam Hook (Exemplarchem award winner), Iain Howland, Martin McMahan and Helen May in producing these resources and Stephen Summerfield for technical advice.

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This publication is one of a number of new and ongoing initiatives from the Subject Centre to promote and disseminate good teaching and learning practice within the physical sciences.

There is a lot of innovation within the community but not always the opportunity to share it with like minded colleagues. New Directions came about as a way of addressing this issue. By publishing successful examples of effective practice we hope to help colleagues avoid re-inventing the wheel and enable people to share ideas and experience. Another benefit of this publication is that many examples are not restricted to any one discipline but can provide inspiration across the whole of the physical sciences.

What is routine for one colleague may appear innovative to another so this publication aims to promote this work, even if it may not appear to be cutting edge to the person concerned. Therefore, whilst future publications of New Directions will aim to promote innovative ideas, we also welcome tried and tested approaches that have proved successful in supporting teaching and learning practice.

LTSN Physical Sciences

. . . supporting learning and teaching in chemistry, physics and astronomy

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