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New Directions

in the Teaching of Physical Sciences

UK Physical Sciences Centre
Department of Chemistry
University of Hull
Hull HU6 7RX
Phone: 01482 465418/465453 Fax: 01482 465418
Email: psc@hull.ac.uk Web: www.heacademy.ac.uk/physsci

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Editorial

New Directions focuses on new developments by practitioners in the field of learning and teaching.

This issue contains articles that cover a range of topics but interestingly the reader will find many connections between them. Our two Reviews, one on work-based learning and one on diagnostic tests, echo themes in our Communications, where there are articles on using diagnostic testing with undergraduate astronomers and developing a web-based resource for work-based learners. Ever popular themes such as assessment, feedback, outreach and problem-based learning can be found, along with several articles that illustrate the use of technology to support pedagogy, including work on recording lectures, by video or screencasting; electronic assessment; electronic voting systems and modelling.

By no means least we have a special article by Derek Raine, from the University of Leicester's Centre for Interdisciplinary Science, who inspired the formation of this publication.

We continue to welcome contributions on new themes or new twists on old ones that will help to inform and inspire members of the physical sciences community (details on page 87).

New Directions is a topical journal published by the UK Physical Sciences Centre in association with πCETL, The Physics Innovations Centre for Excellence in Teaching and Learning.

The journal is issued in paper and electronic formats once per year. It is intended for teachers, researchers, policy makers and other practitioners in physical sciences education.

An editorial board reviews all submissions.

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Editor

Tracey Madden
UK Physical Sciences Centre
Department of Chemistry
University of Hull
Hull HU6 7RX
Tel: 01482 465418
Fax: 01482 465418
Email: t.madden@hull.ac.uk

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Physics – My way

I became a lecturer in astrophysics by chance. As I was completing my postdoc, looking at how one could do quantum field theory in the presence of gravity, I contacted various departments to see if there were any lectureships going. From departments of mathematics I was invariably told that the subject was too physical, and from physics departments that it was too mathematical. Astrophysics seemed a better bet, so I offered to give part of the Oxford undergraduate course on what was then the emerging subject of high energy astrophysics. I think I managed to keep a few pages ahead of the students most days. The result was a job offer from Leicester to teach astrophysics.

Leicester was a very different place then. Many of the people who would become leaders in their fields, and some who wouldn't, were then just starting. But another key difference was the vision, at least in teaching, of the then separate departments of Physics and Astronomy, as mini replicas of Oxbridge, to the point where at least one lecturer used to lecture from his Cambridge undergraduate notes. The problem was that the students, with some notable exceptions, were not. I doubt that many of the 100 lectures a year I used to give were of that much benefit. In fact, I can only remember one. The new-fangled overhead projector was not working so I had to improvise a different lecture on the spot. The reason I know it was a success was that some of the audience brought their friends, not on the course, to the next lecture – with a working OHP (after which I regret to say I didn't see them again). More usually, as one student remarked in passing as she filed out of one of my lectures: "*you have an extraordinary way of making simple things difficult*."

It was, of course, deemed to be entirely the fault of the students that they failed to appreciate the excellent education that was passing over their heads. Student failure was evidence of high standards; although not too much failure: one of my first tasks assigned by the Head of Department was to ensure the right mix of courses on the examination papers, each of which covered a variety of core topics, so that weaker students could avoid the mathematical problems and still pass.

My official staff development was pleasingly minimal: all I can recall is being told not to write across the crack in the blackboards, the fear of so doing having stayed with me ever since. My real education in education was a consultancy with the Open University. The OU uses teams of academics to develop its courses. On the negative side this generated enormous volumes of paperwork; on the positive side it generated enormously useful discussion of what actual OU students could be expected to master in a given time. This seemed such a good idea that it was worth copying.

The first thing was to get some leverage which meant forming a Teaching Committee. It was only at this point that I learnt that people volunteer for committees not to get things done but to be in a position to block them at the earliest possible stage. Nevertheless, I found that if people can be convinced that there are real problems, then they are willing to discuss how to solve them. And the Physics Department had a real problem with the teaching of maths: put simply, two terms of epsilons and deltas followed by an exam paper that could be passed on the basis of A-level maths. The problem with a maths lecture is that after about 5 minutes students need to stop to consolidate, even assuming they are keeping up with the homework. A second problem is that, even if they know what all the words mean, abstract statements can still fail to mean anything significant, so students learn proofs off by heart without seeing why they work. So we got together a team of physics lecturers and maths lecturers and set about designing a text that delivers specific examples ahead of general statements, divided into small segments with diagnostic exercises at each stage. Originally we had audio taped lectures to go alongside the text, instead of live lectures, and we used the staff time to run exercise workshops. Later we replaced the tapes with a weekly survey lecture. We learnt several lessons from this: one was that students can't cope with typing errors; another that it takes an awfully long time to get rid of all of these, but that students wouldn't stop complaining about the course until we did. Another revelation was that, as we reduced the course content to accommodate changing entry levels of knowledge, we discovered that there is no level low enough to ensure that all students will do well: the less motivated students adjust their expectations downwards with the course content! We eventually engineered a flexible pacing through the maths programme, which allows the more motivated student to progress rapidly, while less well prepared students can go at a slower pace. This is one thing that a rigid credit assignment system does not allow. It therefore requires a relatively elaborate interface between what we do and what we say we do. My experience is that university administrators are not interested in what you are doing as long as the forms are filled out efficiently and 'correctly' and it doesn't get them into difficulties. I will not claim that one can get round *any* rules that prevent one doing something worthwhile - I failed to change the daft waste of academic staff time in writing examination papers afresh every year in favour of using carefully honed and tested confidential question banks - but there is (apparently) a lot that can be done if done quietly.

The key to the maths programme was to require the active participation of the students: ideally students get feedback only where they can explain their attempts at problems, because this allows the seats of the misconceptions to be addressed, not just the symptoms. I regret that this has been undermined in recent years by the customer culture which increasingly requires us to provide model answers as if these will enable students to magically 'see where they have gone wrong'.

The next ambition was to introduce team teaching and student-centred learning into the physics core. Here there seemed to be no need to write our own textbook, so we could just concentrate on organising the material and providing support for problem solving. It's always good to underpin initiatives with a theory, so we referred to this as 'resource-based learning' and hired an educational consultant to help us go about it. The resource is a compendium textbook to which all students have access because we give them a copy. This has needed some defending in times of austerity: one Dean claimed that it was illegal, and I had to get legal advice to demonstrate the contrary. The book frees up a lot of staff time from giving dictation (sometimes referred to as 'lecturing') which can be used for teaching (sometimes referred to as 'problem classes', or 'tutorials' at more elitist institutions).

I wish I could remember, but I don't, my first acquaintance with problem based learning (PBL). I can't recall if I found it or if it found me. But once again it grew out of the solution to a problem, here the ineffectiveness of laboratories. I think it is by now well established that students can only hold so much new information in working memory. One therefore has to decide if a practical class is supposed to teach practical skills or physics. Our problem was that, at great expense in terms of staff time and disengagement, the traditional labs were doing neither. PBL, as we do it, requires students to use their acquired practical skills to design experiments and, importantly, to evaluate their results. The design tasks are not on the face of it complex: the first one involves comparing the absorption of two liquids (differently coloured water, of course) by blotting paper. But this in fact turns out to contain several afternoons' worth of useful thought. Students find the evaluation the most demanding, because what they say depends on their results, and, most importantly, their error bars. Not that the implementation has been easy: we have changed features of the programme every year since its inception and it still is not quite right. Nor has it impacted significantly on examination performance, although informally we find that students appear to be better now at tackling problems; or perhaps those that aren't don't survive because there are now no bookwork questions. What it has changed, to some extent, is the way that students now learn to be professional physicists and not just professional students.

Here again we were lucky in securing the acquiescence of the academic staff to go along with our experiments in curriculum design even when they did not believe them. This was greatly helped by the initially modest (and later not so modest) funding we received for the development projects and for piCETL. This enabled us to hire summer students to do the development work, while the staff acted in their favourite role as consultants. My general rule for getting something done is to do it myself as best I can, usually badly, and then get colleagues to tell me how it should be done. This produces much more, much more rapidly, than a simple request.

PBL assumes a particular model of how students learn which prioritises the need to know as the motivator of doing. It doesn't tell us anything about the way that students learn *physics*. It is interesting how little interest most educators in HE have in this. In an elitists educational system it probably didn't matter: as long as enough students survived to teach the next generation the system would be self-perpetuating. In a mass system it matters a great deal if a lot of precious resource is being used to little effect. Physics education research (PER) has shown how we can build up students' understanding of basic physics by careful and detailed sequencing of activities. I have yet to be convinced that this does not suck the life out of physics or that it can produce a love of physics or promote creativity.

I believe a better approach to enthusing a wider cohort in physics is to generate an enthusiasm for science in general. Thus, instead of trying to change the students, a 40 year experiment that has barely changed recruitment to science, we try to change the curriculum. Science is not a lot of boring historical knowledge that has to be suffered before we get to the interesting things, even if this is how it is traditionally taught. Science is solving problems, intellectual ones as well as applications. Most unsolved problems within a discipline are unapproachable by undergraduates. We can invent model problems, as we do in PBL. Or we can recognise that many interesting problems can be found across the disciplines. This brings us to the Centre for Interdisciplinary Science at Leicester which runs the interdisciplinary science undergraduate programme. This embodies my vision of an undergraduate programme in natural science by guided research. The programme covers a range of learning objectives in Biology, Chemistry, Earth Sciences and Physics with opportunities to specialise, taught through interdisciplinary problems. The support for this programme through the IOP and the HEFCE STEM initiative has been crucial. The administration, pedagogy and financial model as well as the content is all innovative and has been constructed as we went along. The external support has been critical, not least in allowing the creation of the Centre by the expedient of informing the University post room that it existed (and appointing myself as its director).

Integrated Science has existed in Canada, the US, Ireland and almost certainly elsewhere as level 1 programmes for many years. It is now established at McMaster in Canada and at Leicester as a full degree programme. I see it not just as a way of embedding physics in science programmes, but as a way of retaining applied physics research within physics departments. However, it is not the only way of simulating physics. Beyond the applications of physics in interdisciplinary science problems, the techniques and concepts of physics have increasing applications in social sciences. If we embrace this it will bring a new cohort of students to physics though the interface of physics and the social sciences.

Physics is based on experiment; so too should physics education be. Physics experiments, if they fail, can be repeated. In a sense educational experiments can't be and that, as well as the effort involved in changing things, can induce a fear of failure. Educational experiments take a long time, so the funding always runs out before they can be seen to be successful. And they require energy. One of my HoD's said to me after a Departmental review, "*we've probably had enough innovation here*." We haven't. The environment is always changing so the only way to stay at the top is to change with it. This might not be a sufficient condition for a thriving physics education, but it sure is necessary.

Derek Raine
Centre for Interdisciplinary Science
University of Leicester
Leicester
LE1 7RH
jdr@lei.ac.uk

An introduction to the recent literature on approaches to work-based learning

Tom Lemanski*, Ruth Mewis and Tina Overton
Department of Chemistry
University of Hull
Hull
HU6 7RX
***t.lemanski@2004.hull.ac.uk**

Abstract

The term work-based learning is widely used throughout the literature, academia and industry to describe a multiplicity of approaches by which one can learn through work. The complex nature of work-based learning can often lead to confusion when designing courses which aim to implement such an approach.

This review will focus on:

- *The rationale for conducting work-based learning.*
- *The varieties of approaches to work-based learning that are currently implemented.*
- *Student opinions of work-based learning;.*
- *How to resolve any implementation and communication issues.*

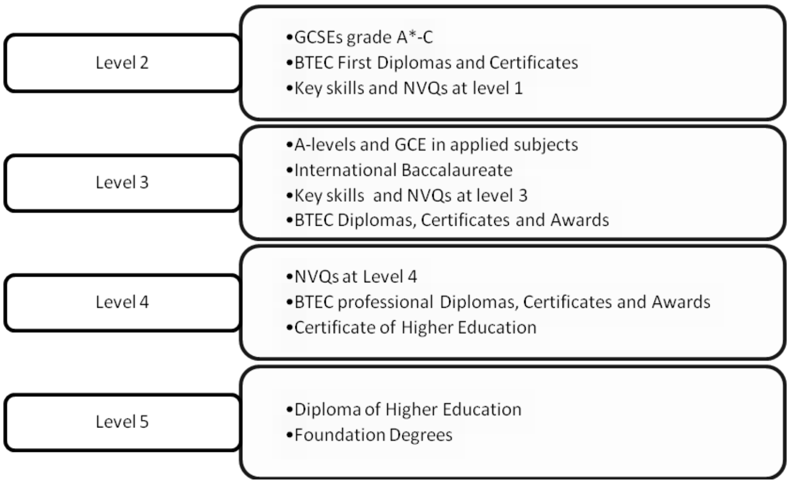
There are many approaches to developing work-based learning modules, courses and projects that utilise learning at, learning for, and learning through work. This paper aims to review the literature in these areas.

Identifying the need

Many reports identify the need to upskill the workforce,[1-3] with the Leitch Review of Skills[2] setting short and long term goals for education in the UK as outlined further within this section. The Cogent Skills Review[1] analyses in great depth the many aspects affecting the major STEM-based industries. It outlines future priorities for each industry whilst considering the role of Sector Skills Councils in increasing the skills of the workforce within the chemicals, pharmaceuticals, oil and gas, nuclear, polymer and petroleum industries.[1]

The Leitch Review of Skills sets an ambitious target, that by 2020 the UK will be within the top eight worldwide for each skill level, with emphasis on delivering qualifications to a far higher percentage of the workforce.

The Leitch Review of Skills sets an ambitious target, that by 2020 the UK will be within the top eight worldwide for each skill level, with emphasis on delivering qualifications to a far higher percentage of the workforce. The targets aim for over 90% of adults qualified to above Level 2 whilst also shifting the balance of skills from Level 2 to Level 3 as well as increasing those with Level 4 qualifications and skills from 29% to 40%, combined with increasing the number of adult apprenticeships.[2] The skill levels are defined by the National Qualifications Framework (NQF), which is illustrated in Figure 1.[4]



Level 2	•GCSEs grade A*-C •BTEC First Diplomas and Certificates •Key skills and NVQs at level 1
Level 3	•A-levels and GCE in applied subjects •International Baccalaureate •Key skills and NVQs at level 3 •BTEC Diplomas, Certificates and Awards
Level 4	•NVQs at Level 4 •BTEC professional Diplomas, Certificates and Awards •Certificate of Higher Education
Level 5	•Diploma of Higher Education •Foundation Degrees

Figure 1: Skills levels, as defined by the National Qualifications Framework.[4]

The level of upskilling described in the Leitch Review means that a greater partnership between educational institutions and employers is required. Levels 4 and above are of interest for HEIs where collaboration with industry is traditionally not common.

The following recommendations are reproduced directly from the Review of Skills:[2]

- *'Increase adult skills across all levels.'*
- *'Route all public funding for adult vocational skills in England, apart from community learning, through Train to Gain and Learner Accounts by 2010.'*
- *'Strengthen employer voice.'*
- *'Increase employer engagement and investment in skills.'*
- *'Launch a new "Pledge" for employers to voluntarily commit to train all eligible employers up to Level 2 in the workplace.'*
- *'Increase employer investment in Level 3 and 4 qualifications in the workplace.'*
- *'Increase people's aspirations and awareness of the value of skills to them and their families.'*
- *'Create a new integrated employment and skills service.'*

The Leitch Review anticipates that Sector Skills Councils (SSCs) play an integral role in the approval of vocational qualifications. This allows for cooperation between employers and SSCs to produce qualifications that benefit industries. These courses may be delivered at established institutions and may include work-based learning qualifications and will attract public funding.[2]

The 2009 Skills for Growth report highlights and reiterates the importance of increasing the standard and number of technicians within industry,[3] increasing the number of formalised qualifications obtainable particularly through apprenticeships.

Work-based learning

What is work-based learning?

It is widely being acknowledged that work-based learning (WBL) strategies are a vital part of the ongoing and future development of the existing workforce. For example, in Europe the *Developing European Work Based Learning Approaches and Methods* (DEWBLAM) project[5] intended to develop a Europe-wide network of models and approaches to WBL within a European consortium of establishments, with the aim of allowing access to Higher Education qualifications for those adults currently in employment, through accreditation of prior and experiential learning.

Defining work-based learning

A broad definition of WBL is offered in *Work-based learning: A New Higher Education* [6] where the authors expand upon their definition to include meeting the requirements of learners and the contribution that this learning will have in the development of the organisation in the long term:[6]

> *"Work-based learning is the term being used to describe a class of university programmes that bring together universities and work organizations to create new learning opportunities in workplaces."*[6]

Whereas Gray identified three key elements to work-based learning to which all learners and employees can relate:

> *"A definition for the higher education level could involve any of the following work-based learning types: learning through work, learning for work and learning at work."* [7]

A further definition of work-based learning was provided by Sodiechowska and Miasch:

> *".. where students are full-time employees whose programme of study is embedded in the workplace and is designed to meet the learning needs of the employees and the aims of the organisation."*[8]

With respect to pedagogy, the practice of work-based learning can be considered to be the continued lifelong learning adults undertake throughout their lives, following education;[9] and in an educational environment. Work-based learning is a widely utilised tool employed by both HEIs and businesses to educate and develop their students or work-force in all three elements outlined above.[7]

There are many traditional WBL pathways involved throughout the education system, as well as in higher education institutions and businesses, as there are many means by which the student is engaged and assessed. Using the definition above, the following collection of approaches was compiled to illustrate the three types of learning.

Learning for work

Learning for work can involve the high-school student embarking on a two-week work-experience placement, whereby they would be involved, albeit very superficially, in the processes of the workplace, reporting on how they developed over their time.

A further example is the long-established sandwich-course observed in HE, with students spending a year within industry carrying out a more significant role within their company (for example in science-based industries an involvement in new product or existing product development), applying their theoretical knowledge in a working environment while being assessed as part of their degree course.

Teacher training courses such as the Post-Graduate Certificate of Education (PGCE) or Graduate Teacher Programme (GTP) routes which involve professional development of a learner with a means of training specifically for a certain job are also learning for work. Teacher training courses are available as purely work-based programmes, as is the case for the GTP or School-Centred Initial Teacher Training (SCITT) courses. The PGCE route offers work placements to assist in the learning for work, as well as combining the principles of pedagogy and classroom management through educational institutions, with subject specific work. All routes require each learner to collate a portfolio of evidence throughout their time within the workplace.

Learning at work

A commonplace example of learning at work is the similarly well-established on-site company training schemes and programmes which can provide a means of upskilling the existing workforce without the need for lengthy periods of time away from work, taught by an experienced senior technical expert employee or an external consultant from a specialist company. In general, these courses are not often formally assessed or given accreditation.

An example of an off-site training scheme is the Introduction to Aerosol Technology,[10] designed and run by the British Aerosol Manufacturers' Association (BAMA) to train and educate industries and employees on aerosol technologies without accreditation. This course provides a good example of prior learning through which accreditation could be awarded.

Learning through work
There are examples whereby completion of on-site training courses are formally assessed and accredited (these are examples of learning through work) as well as accredited day-release programmes through further and higher education institutions.

Approaches to work-based learning
There are many recognised courses throughout the UK which involve aspects of WBL and there are several universities with established WBL departments, with courses that can cater specifically for the individual as well as for their industry.

A recent paper by Lineham and Sheridan[11] delves quite extensively into workplace learning courses offered within Irish third-level colleges (UK – HE equivalence), to deliver new provisions for workplace learning programmes. Lineham and Sheridan surveyed seven HEIs for a total of 433 courses, of which 221 were designed by the institution alone, 47 as part of a collaboration between the institution and industry and only 10 designed by industry.[11]

It was found that learners using a work-based approach learn from their community of practice in their workplace as well as from their work-based learning peers at the university.[12]

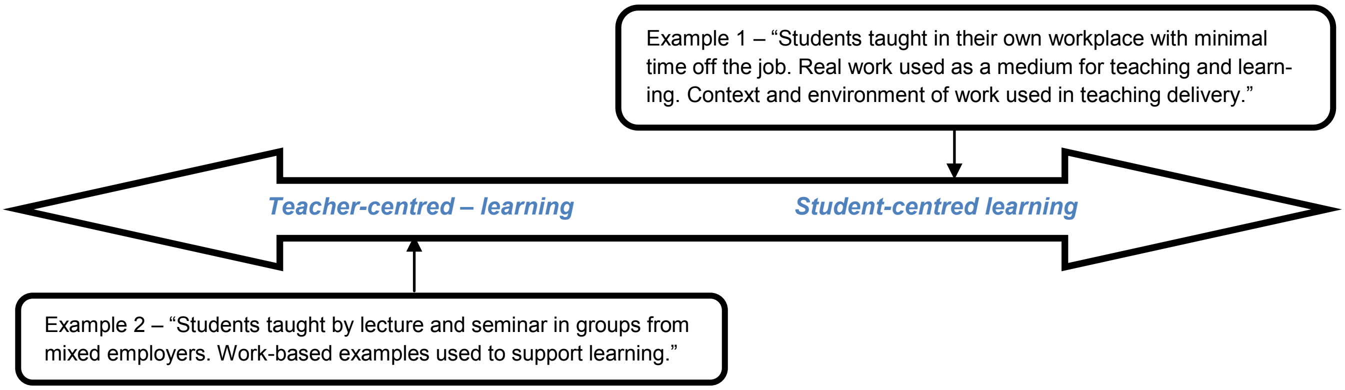
A study by Rhodes and Shiel[13] aimed to discover how work-based projects promote learning for the worker and their organisation. The research outlines through case studies how work-based projects have been utilised successfully by Northumbria University. The same review involves an in-depth look at the WBL courses that are running at Northumbria University where they highlighted principles which are based on those described by Boud:[6]

- A partnership between organisation and university to foster learning.
- Learners are employed/in a contractual relationship with the external organisation.
- The programme followed derives the needs of the workplace and the learning: work is the curriculum.
- Learners engage in a process of recognition of current competencies prior to negotiation of a programme of study.
- A significant element of the programme is through learning projects undertaken in the workplace.
- The University assesses the learning outcomes against a trans-disciplinary framework of standards and levels.

These points can be further reinforced by Bragg and Hamm, who identified a set of criteria for the success of WBL courses:[14]

- Strong Programme leadership.
- Exclusive connections between the programme and its environment (niche market).
- Frequent and effective communications with local employers.
- Beliefs about programme excellence.
- Effective school-based learning component.
- Adequate financial support.
- Innovative programme and pedagogical features.

The Higher Education Academy (HEA) Centre for Education in the Built Environment (CEBE) has released a series of guides under the title *'Employer Engagement'*, sharing guidelines and case studies for the involvement of employers in the design of courses. Figure 2 shows the continuum of ways in which WBL can be delivered.[15] Examples 1 and 2 show two variations in the work-based theme, with the emphasis changing from *teacher-centred learning* (example 2) to *student centred-learning* (example 1); both examples allow for the delivery of courses by blended learning. In the guidelines set out by CEBE, example 1 is of a tutor travelling to various employer establishments delivering content by a face-to-face means, but this could readily be adapted for distance learning.



Example 1 – "Students taught in their own workplace with minimal time off the job. Real work used as a medium for teaching and learning. Context and environment of work used in teaching delivery."

Example 2 – "Students taught by lecture and seminar in groups from mixed employers. Work-based examples used to support learning."

Figure 2: The continuum outlining the two extremities of work-based learning. Figure and annotations reproduced from Williams and Thurairajah.[15,16]

Why conduct work-based learning as either part of, or most of a course?

Most literature on the subject advocates an individualised approach for the learner whilst maintaining contact between academy and employer to assist in development of the learning plan and also satisfying the requirements of the employer; the employer involved should have a lot more input into the design and outcomes of their learners' course structures.[12]

The Learn Direct agency allows for further education and training for the existing workforce, with courses designed around the learners' requirements to fit in around their work-life with their 'Learning through Work' programmes designed specifically for such needs. Several courses run in partnership with the University of Derby.

With respect to the relation of work-based learning to organisations and employers, a quote from Clarke and Copeland states that:

> *'Work based learning is commonly taken to refer to structured learning opportunities which derive from, or which are focused on, the work role of individuals within organisations.'*[17]

The definition above provides a foundation for the new learning being based on requirements of the workplace, through collaboration between universities and work organisations, whilst incorporating underpinning knowledge and focusing these into a real world, work-related problem.[17] This allows for the development of a combination of the relevant foundation of science knowledge complemented by the learning opportunities available through the workplace.

Different models of work-based learning

How are the WBL aspects of a programme approached and delivered?

Several different courses and HEIs will be reviewed, determining whether there are any common aspects which can be built upon.

Brennan and Little define one way of constructing work-based learning courses:

> *'Curriculum controlled by higher education institution, content designed with employer – learner primarily full-time employee.'* [18]

The courses are designed with input from employers, with the framework arising from the pre-established subject discipline structure, with credits gained from modules within the course and also from accreditation of prior learning; which involves the assessment of learning gathered from work itself. Foundation Degree Forward (fdf) has published a series of detailed guides on their website (available online: <www.fdf.ac.uk/>) relating to all aspects of structuring a work-based learning course as well as engaging with employers. Two specific guides *(Work-based Access to Higher education [Course Development Checklist] and Work-based Access to Higher Education [Guidelines])* relate to the development of foundation degree courses that include work-based learning. The second guide highlights the need for the effective development of work-based learning and work-related skills:[19]

Work-based learning skills:

- Develop solutions to workplace problems drawing on theory and practice.
- Exploit the workplace as a learning resource.
- Manage oneself (and others).
- Reflect on what has been learnt in and from the workplace.
- Transfer existing knowledge, capabilities and competences to new or different contexts.

Work-related skills:

- Action planning.
- Contribute to meetings.
- Entrepreneurship.
- Goal setting.
- Negotiating.
- Networking.
- Project management.
- Self-appraisal.
- Team working.
- Using, and acting as, a consultant.

The two lists describe different sets of skills: the work-related skills describe transferable skills which are both desirable and advantageous for all employees, whereas work-based learning skills involve the learner drawing upon subject knowledge and theory, combined with their experience, to utilise the workplace in personal development. During course development, care should be taken to include the introduction and development of all the aforementioned skills within work-based learning modules, whether they are theory or skills based.

In the view of these sectors, how relevant is this form of learning?

A paper by Foundation Degree Forward examines in depth the need for developing higher skills in the work force and outlines significant positives in the successful implementation of foundation degrees.[20] Publishing benefits to employer, student and HE establishment it also defines a list of key potential perceived benefits to entice employers toward collaboration with universities to train their workforce:[20, 21]

- Better quality recruits.
- Flexible entry requirements.
- Flexible, tailored to your needs.
- Improved workforce performance and productivity.
- Increased employee motivation – higher staff retention.
- Meets skills shortages – grow your own workforce.
- Work-based learning – little time off the job, minimal disruption.
- Projects directly related to your business.
- You [the employer] are closely involved in the delivery.
- Potential to accredit company training programmes.
- Extremely good value compared to private sector training.
- Direct links to further qualifications and continuing professional development.

This list is by no means definitive. However it does provide an enticing spectrum of positive aspects for employers tempted to develop their workforce with work-based learning courses.

Implementation of Work-Based Learning
Lineham and Sheridan summarise key points for both employers and HEIs when considering the implementation of work-based learning modules and courses:[11]

HEIs:

- Ensure that recognition of prior learning is an integral component.
- Establish strong industry partnerships.
- Involve the employer in the development of the programme; especially when designing work-based projects and assignments.
- Develop customised programmes; allows for the expectations and needs of both employee and employer to be met.

Employers:

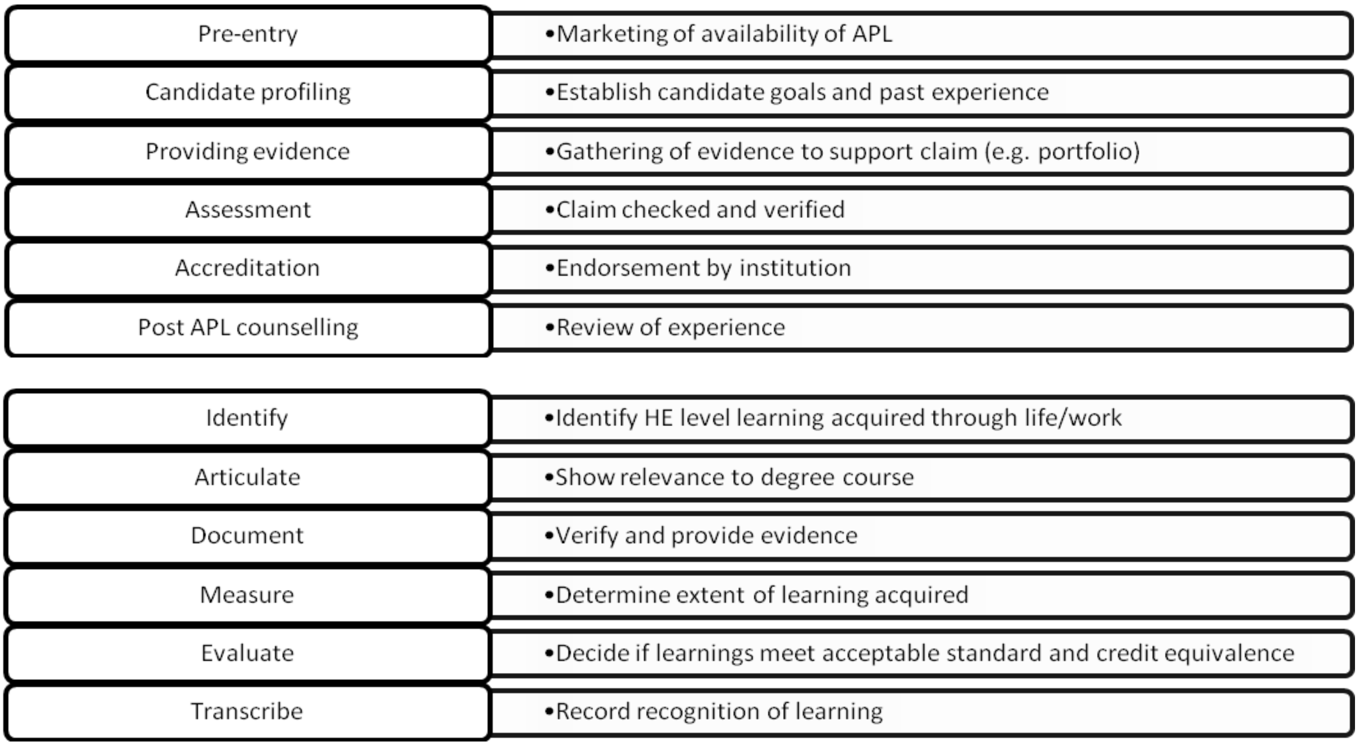
- Encourage employees to engage in skills development.
- Allocate workplace mentor to assist the learner.
- Encourage employee responsibility toward their personal professional development.
- Develop work-based projects and assignments with sense of purpose.

These short checklists provide a foundation through which institutions and employers can abide by in an attempt to coordinate with one another during the development of specialised courses and modules.

Accreditation of prior and experiential learning
Even though the continual learning at and through work is considered learning from a theoretical perspective, it is often overlooked because of its informal nature.[9] Boud and Middleton believe that a recognition of this learning would allow for an enhancement in the work and the quality of working life.[9] For adults re-entering education there is often a wealth of prior experience they can reflect upon and it is becoming more accepted that this experience requires acknowledgement. Hence, a demand has arisen for Accreditation of Prior Learning (APL) for previously assessed learning and Accreditation of Prior Experiential Learning (APEL) in which the knowledge is gained by experience and presented for accreditation.

Systems of APL are established worldwide, with unique acronymic titles depending on the country (Figure 3.) It is widely being acknowledged that such recognition of learning steers higher education toward the industrial and business world.[22] However it should not be used or marketed as a fast-route to a qualification. A survey of 433 courses at seven higher education colleges in Ireland showed that 264 out of 433 courses gave credit and recognition for prior learning, a total of 61%.[11]

There are distinctions between APL and APEL. As mentioned APL involves organised learning through which assessment or certification has taken place. The learning through APEL is related to skills, learning and knowledge gathered through experiences in the learner's work, or life, which involves no certification. Both systems gather evidence relating to the learning as opposed to the experience.[23]



Pre-entry	•Marketing of availability of APL
Candidate profiling	•Establish candidate goals and past experience
Providing evidence	•Gathering of evidence to support claim (e.g. portfolio)
Assessment	•Claim checked and verified
Accreditation	•Endorsement by institution
Post APL counselling	•Review of experience

Identify	•Identify HE level learning acquired through life/work
Articulate	•Show relevance to degree course
Document	•Verify and provide evidence
Measure	•Determine extent of learning acquired
Evaluate	•Decide if learnings meet acceptable standard and credit equivalence
Transcribe	•Record recognition of learning

Figure 3: UK and American models (respectively) for the accreditation of prior learning.[23]

The most common method by which to assess and accredit prior learning is by the employee/learner providing an in depth portfolio of evidence through which they demonstrate developed skills and knowledge gained. This process may be easier for prior learning, due to the increased formal nature of certified training courses.

The steps required in the development of a portfolio can be based on the both the UK and American APL models as depicted in Figure 3.[23]

The book 'Good Practice in the Accreditation of Prior Learning'[23] by Nyatanga gives an extensive overview into good practice of the assessment of prior and experiential learning.

Perceived Problems
Developing work-based learning for incorporation into an academic qualification will not be without issues, below is a selection of potential issues that may arise for each partner.

What issues may arise from this collaboration from the HE point of view?

- Potential shift from traditional, teaching methods, including the incorporation of a larger proportion of blended learning or wholly work-based modules than is generally common.
- Due to the work-based aspects, the quality of student experience could differ between workplace establishments, arising from variables that are not within the control of the HEI.
- The increased involvement of the employer in designing the courses could lead the HEI to perceive a reduction in control over the subject content and its quality.
- The flexible nature of the course can lead to individual learning contracts for different students. Thus flexible learning outcomes must be negotiated. This also relates to the inconsistency of student experience.
- Issues may arise over the identity of the assessor of the work-based learning modules and projects; if supervisors or mentors are provided in the workplace they may be involved in the assessment, or the employer may encourage independent assessors for sections of the course which they helped to develop.
- Support for students in the workplace, or lack thereof; workplace supervisors may not be able to dedicate the time the learner needs, this may impact on course completion and attainment.
- All courses are modular but providers may not have the administrative and financial infrastructure to allow involvement by module rather than by programme.

What issues may arise from this collaboration from the employer point of view?

- Issues may arise through perceived irrelevancies of some content in relation to specific industries, potentially arising from a lack of industrial input into the course structure or the specialist modules.
- The fast upgrading of technologies throughout all industries, coupled with a slow throughput of employees completing the course, may result in technical skills superseded upon graduation.
- Employers reluctant to release students for long periods of time. This can impinge on day-release or block learning as well as the work-based elements.
- Time and money may be required to support the work-based learning courses and modules within the workplace. Employers may mistakenly see these as 'resource free'.
- The balance between job-specific learning and obtaining a broader science education which may equip students for employment in another sector.

What issues may arise from this collaboration from the student point of view?

- Work-based learning modules could increase the learner's workload too much both in and outside the workplace.
- Learners may find that not obtaining their desired levels of support from both higher education and employers may pose a problem, as well as not knowing who to seek advice from.
- Too little collaboration between higher education establishment and employer; neither establishment sure who is the main contact for assistance with work-based learning modules.
- Module outlines and learning outcomes may be too diffuse if they are flexible enough for all students.
- Ensuring the students feel as though they are part of a community of learners.
- Inadequate focus on individualised learning outcome or study plan.
- Perceived irrelevance of certain topics over which they may have no control.
- The balance between job-specific learning and obtaining a broader science education which may equip them for employment in another sector.

The list of anticipated issues outlined above will not be exhaustive. Other potential problems may arise during the implementation of work-based learning and attempts should be made to tackle any issues which may arise to the satisfaction of all groups.

Conclusions

Work-based learning

Although there are many ways to describe and define work-based learning, the definition provided by Gray[7] provides three key umbrella categories under which can be encompassed the many models of work-based learning:

> *'A definition for the higher education level could involve any of the following work-based learning types; learning through work, learning for work and learning at work.'* [7]

The methods by which work-based learning courses can be developed are discussed in the literature, each definition or set of considerations building upon and reinforcing others. There is no rigid formula for designing work-based modules or resources. Merril's First Principles of Instruction provide a set of guidelines which lay the foundations for successful module development:[24]

- Learners are engaged in real-work problems.
- Existing knowledge is activated as a foundation for new knowledge.
- New knowledge is demonstrated to the learner.
- New knowledge is applied by the learner.
- New knowledge is integrated into the learner's world.

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Even though the continual learning at and through work is considered learning from a theoretical perspective, it is often overlooked because of its informal nature.

Diagnostic tests for the physical sciences: A brief review

Simon Bates* and
Ross Galloway
Physics Education
Research
School of Physics and
Astronomy
University of Edinburgh
Edinburgh
EH9 3JZ
***s.p.bates@ed.ac.uk**

Abstract
We present a review of diagnostic testing in the physical sciences. We cover the motivation for using such instruments and their historical development via a case study of probably the most cited and influential test instrument and application: the Force Concept Inventory, developed in the early 1990s by Hestenes and co-workers, and its use to quantify learning gains from different instructional methodologies by Richard Hake. We then present an overview of the process of creation and validation of such instruments, and highlight the results from studies that have made use of some of the many instruments available in the literature. We conclude with a short summary of our own recent work to develop a diagnostic test of data handling skills of physical science undergraduates.

1. Introduction and background

The last twenty years or so have seen considerable effort directed towards the development, validation and application of diagnostic tests in the physical sciences: standardised testing instruments designed to yield a robust, reliable and quantitative measure of student understanding on a particular topic or subject area. They usually take the form of multiple-choice questions (MCQs)[1,2] designed to test conceptual understanding as opposed to bald factual recall. Many of the tests originate from the Physics Education Research effort in the US, but the principles (and in some cases, the concepts they examine) are relevant more broadly across other science disciplines, especially chemistry.

The aim of this review is to present a brief overview of some of the tests that exist within the literature and have been developed and deployed to test attributes from broad ‘scientific thinking’ ability to conceptual understanding of specific areas of physical science.

A standardised, expertly-validated diagnostic instrument that is capable of yielding deep insights into the conceptual understanding (or otherwise!) of students at a particular stage in their studies holds an obvious appeal. The motivation for their use is succinctly embodied in a quote from the late David Ausubel:

> *“If I had to reduce all of educational psychology to just one principle, I would say this: The most important single factor influencing learning is what the learner already knows. Ascertain this and teach him accordingly.”* [3]

This is one of the main use scenarios for such instruments: the assessment of knowledge and understanding, often prior to commencing further study. This is the ethos behind the Open University ‘Are you ready for….?’ student self-assessments as course precursors[4]. Of equal validity is to look at ‘residual’ understanding long after explicit teaching, to differentiate real conceptual understanding, committed to long term memory as opposed to short term recall[5]. Another widespread use of such instruments is both pre- and post-instruction (often with the same test, possibly an isomorphic one that tackles the same concepts with different questions). The most widely-cited example of this is Richard Hake’s 1998 study[6] of more than 6000 students’ conceptual understanding of classical mechanics, using the Force Concept Inventory (FCI) devised by Halloun and Hestenes[7], which is covered in more detail in the following section.

The aim of this review is to present a brief overview of some of the tests that exist within the literature and have been developed and deployed to test attributes from broad ‘scientific thinking’ ability to conceptual understanding of specific areas of physical science. In addition, we will highlight certain areas of application of these instruments and the findings that they have yielded. We cannot be completely comprehensive in the space available, so a ‘broad brush’ approach is necessarily adopted. We hope the review will be of value to those colleagues dipping their toes into this arena for the first time, as well as more experienced staff who want a more detailed account of aspects of instrument creation and validation. The paper is organised as follows: the next section presents a case study of one particular test and its most-cited application: Hake’s study of conceptual understanding of mechanics using the FCI[6]. This is a seminal study that set the standard to which many, if not all, subsequent investigations have aspired. We then change tack slightly and consider the process of devising, validating and testing an instrument. Once again, we make use of a particular instrument to exemplify the procedure: the Basic Electricity and Magnetism Assessment, by Beichner and co-workers. Devising and validating an instrument is a time-consuming process, and many instruments have already reached this level of maturity and can be used by staff 'off the shelf'. The third section presents an overview of some of the available instruments and their applications (with links to others). Finally, we conclude with details of some of our own work to devise and validate a diagnostic instrument to test data handling skills of physical science undergraduates.

2. A case study: the Force Concept Inventory

The development of the FCI can be traced back to the Mechanics Diagnostic Test, first published in 1985, based on the dissertation research of Ibrahim Halloun[7]. It comprises MCQs covering conceptual topics in Newtonian mechanics, a subject all Physics students entering University will have had considerable exposure to, and in which will have solved a large number of 'problems'[9]. To some staff, the test items look simple and they deliver it to students confident of high scores, yet are usually surprised by the results. The most well-cited example is Eric Mazur's experience at Harvard, where it was noted that students could solve complex quantitative problems in mechanics, yet fail to correctly answer some of the (supposedly easier) conceptual questions on the FCI. This experience led Mazur to develop the instructional methodology of Peer Instruction[10] (the book of the same name includes a slightly revised version of the test), now widely adopted as a tool for interactive engagement and enhanced conceptual understanding. This methodology, plus the widespread introduction of an effective mediating technology (in the form electronic voting system handsets in lectures), illustrates just how far the FCI ripples have spread.

The FCI describes six 'conceptual dimensions' (kinematics, Newton's three laws, kinds of forces and superposition of forces) from which a taxonomy of student misconceptions (or 'alternate conceptions') has been derived. A much more detailed analysis of these dimensions is presented in the original references and elsewhere[11]. The key research findings that followed from implementation of the test by the authors suggested significance for undergraduate teaching and learning that went far beyond the content topic of Newtonian mechanics. There appeared to be little correlation between FCI scores and mathematical ability or socioeconomic level, and scores obtained prior to teaching were uniformly low. There appeared to be virtually no correlation between FCI test scores after teaching and teacher competence.

Many of these findings were convincingly reconfirmed and extended by Richard Hake's study of over 6000 students' results from taking the FCI prior to and after courses in classical mechanics (often called a 'pre- / post-' testing methodology). Hake set out to try and understand and quantify the effects of different types of two broad categories of instruction on conceptual understanding. The first of these categories was the 'traditional' instruction methods, characterised by largely didactic lectures requiring little student involvement, recipe-based laboratories and algorithmic problems for assessment. The second methodology Hake termed 'interactive engagement' (IE), a broadly defined umbrella term which is characterised by engagement of "*students in heads-on (always) and hands-on (usually) activities which yield immediate feedback through discussion with peers and/or instructors*"[6].

The results are remarkable: Figure 1 shows a summary of all data collected, comprising a total of 6542 students (2048 enrolled in 14 courses characterised as 'traditional' delivery, the remainder in 48 IE-type courses across a range of types of educational institution in the US). The figure plots class average pre-test score on the abscissa ('<pretest>') against percentage gain from the post-test on the ordinate. Each data point represents a given class / cohort and, reassuringly, all

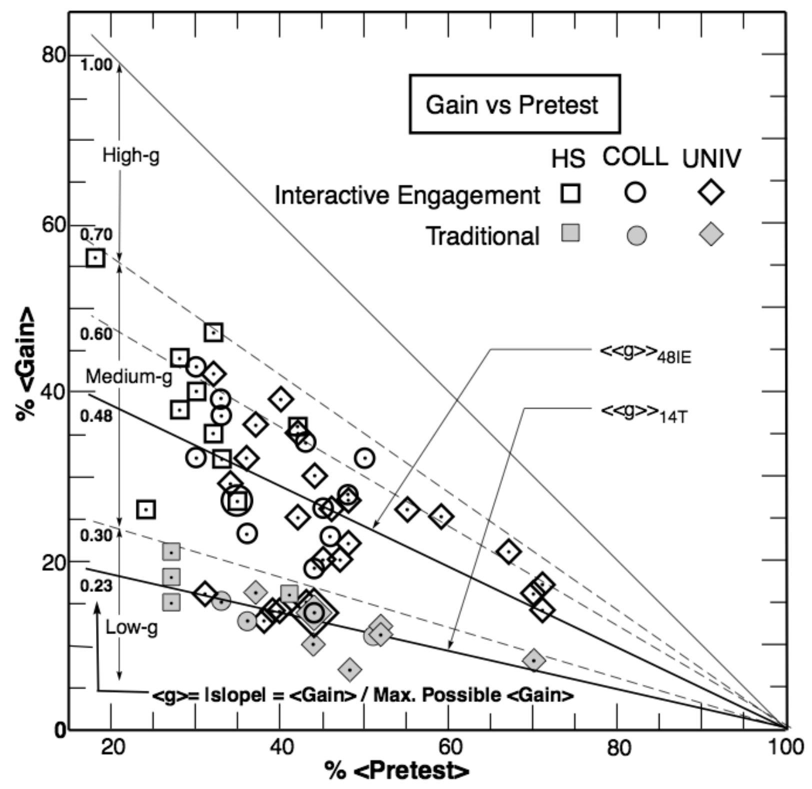


Figure 1: Post-test improvement as a function of pre-test score for a sample of 6542 students taking the Force Concept Inventory test of conceptual understanding in classical mechanics. Reproduced from reference 6.

classes show a positive percentage gain, indicating average performance improved post-instruction. A key quantity used to characterise the learning gains between pre- and post-instruction testing is the cohort-averaged normalised gain, *<g>*[6,12,13], calculated as:

$$< g >= \frac{< S_f > - < S_i >}{100 - < S_i >}$$

Where $<S_f>$ and $<S_i>$ are the post and pre class averages as percentages, respectively. Hake further characterised courses on the basis of these average normalised gains, where 'high-g' courses have (*<g>) >* 0.7 (though none of his data fell in this range); 'medium-g' where 0.7 > *(<g>*) > 0.3 and 'low-g' where *(<g>)* < 0.3. Most strikingly, all the traditional courses fell within the lowest of the three bands and most of the IE courses in the medium-g region, albeit with a broader spread. The mean values of the mean normalised gains for a particular type of instruction, $<<g>>_{48IE}$ and $<<g>>_{14T}$, as indicated on Figure 1, differed by a factor of 2. In other words, the IE courses were, on average, about twice as effective in enhancing conceptual understanding of the material as traditional courses. These gains, as Hake remarks in the original paper, offer strong evidence of one route to a solution to Bloom's '2 sigma' problem[14], the challenge to find instructional methodologies for group instruction that are as effective as individual tutoring. A closer inspection of the raw data is provided by Hake's companion papers from around the same time[15].

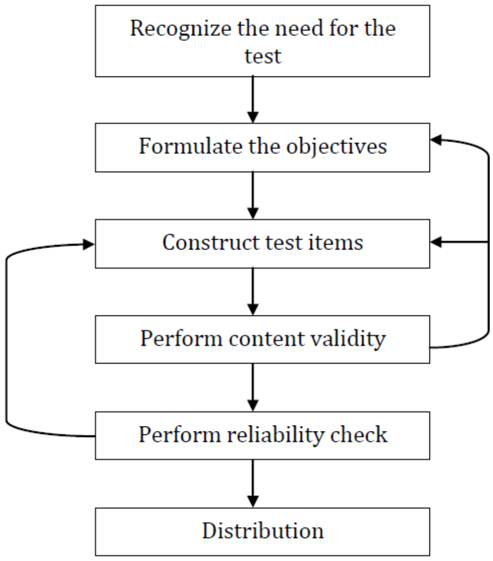


Figure 2: Flowchart depicting stages in creation and validation of a diagnostic instrument. Reproduced from reference 24.

Hake's study sparked extensive and widespread debate: critiques and responses to critiques abound in the literature. The interested reader is directed towards a few springboard papers[11,16]: there are many others. Scrutiny of these reveals subtleties and complexities: some IE courses achieve *(<g>) <0.3;* there is often a very large spread in *g* values for students on a given course; the fact that traditional courses in the survey produced low *<g>* values does not rule out the fact that some traditionally delivered courses may yield medium-*g* scores. Furthermore, the FCI is a particular type of assessment: Mahajan has observed that even students who score very well on the pre-test can have significant difficulties answering free response problems of a conceptual nature or that require estimation skills[17]. However, laying this debate to one side, it is abundantly clear that this paper has had an enormous and lasting effect. Its impact has been felt both within the physical sciences and across many other disciplines and its findings have been used as the basis for a great deal of curriculum change and reform. At the time of writing, it has been cited 343 times.

Our own experience in Physics and Astronomy at Edinburgh with the FCI stretches back a mere 6 years, influenced by Hake's guidelines for administering the test[18]. Since then, we have administered it consistently pre- and post- instruction. We have done this both as a measure of student conceptual understanding in the topic area at the entry and exit points of the course, but also as a measure of effectiveness of the teaching on the course as we have progressively incorporated IE elements more consistently. These have included studio based teaching approaches[19], electronic voting systems[20] and elements of Peer Instruction[10]. In terms of the students' understanding, our results show many similarities with previously published studies: on entry, average conceptual understanding of the cohort is significantly below the 60% level, identified by Hestenes[7] as the 'entry threshold'. Below this threshold, student understanding of the concepts is deemed to be insufficient for effective problem solving. In terms of measuring the effectiveness of the instruction, we have seen *<g>* rise from 0.3 to consistently around or above 0.5, with a substantial fraction (but by no means all) of the cohort attaining the 'mastery threshold' of 85% on post-instruction testing. What is striking is that the performance on many of the questions, in terms of not only percentage of students choosing the correct answers, but those who choose particular distracters, is almost completely invariant over time. Some questions have a large and consistent fraction of the cohort choosing the same wrong answer year after year: we call these 'banana-skin' questions, as successive year of students seem to slip up on them in the pre-test. The construction of the questions is such that one is able to directly ascertain the world-view that students are operating within, for example the pre-Newtonian conception that 'motion must imply a force'.

Before we conclude this section on the FCI, we should also point out some of its close relatives. The closest of these is the Mechanics Baseline Test (MBT)[21], which focuses more on processes rather than concepts. Both the FCI and MBT have been further developed by one of the original authors (Halloun) in work to devise basic inventories of concepts and processes (IBC-Mechanics and IBP-Mechanics, respectively)[21]. Other instruments include the Force and Motion Conceptual Evaluation, described along with the effects of research-based active learning strategies to improve conceptual understanding[23].

3. Creation and validation of diagnostic test instruments

Generating a diagnostic test which is sufficiently robust as to provide an effective measure of student performance is necessarily an involved task. Here we are able to give only a brief overview; for the interested reader, Engelhardt gives a very detailed and readable account of the entire test creation process from start to finish[24]. In essence, the process involves multiple stages, many of which may feature multiple iterations, and which can occupy many months to years. Beichner[25] has succinctly encapsulated the process in a flowchart, shown in Figure 2.

As this figure shows, creation of a diagnostic test instrument involves much more than just writing the test questions. The starting point should always be the identification of a specific area which requires diagnostic investigation: ‘chemistry’ is likely to be too broad, whereas ‘spectroscopic notation in quantum mechanics’ is probably too narrow. Frequently, diagnostic tests are structured to cover areas which would naturally fall within a single ‘lecture course’ unit in the higher education setting. Before embarking further on test creation, at this stage it is worth checking the literature to make sure a suitable instrument does not already exist: diagnostic testing in the physical sciences is a rapidly growing field. (A non-exhaustive summary of some existing instruments is given in section 4 of this review.)

Having identified the desired field for the instrument, the next requirement is to establish the learning objectives it is intended to assess. These should be framed in terms of student competency (i.e. “Students should be able to…”), and are often focussed on areas where instructors find that traditionally there are widespread difficulties or alternate conceptions. It is important not to be too ambitious here: Engelhardt reports recommendations of 5 to as many as 20 questions per objective, and suggests a minimum of 3 questions per objective for ‘low-stakes’ tests such as diagnostic instruments[24]. Thus, to prevent the test becoming unmanageably long, there are a practical maximum number of objectives, probably at most ten.

To mitigate the chances of wasted effort at the question-writing stage, at this point it may be desirable to commence *validity checking*. This is one of the verification elements of the process, which involves a panel of subject experts (usually university faculty, preferably independent). Their task is to address the validity of the instrument, in terms of *face validity* (i.e. does the diagnostic actually assess the skills it intends to assess) and *content validity* (i.e. does the diagnostic feature all the relevant elements of the topic area while excluding unrelated material). The suite of test objectives may be revised in light of the input from the expert panel.

The next stage is to write candidate test questions which address all the desired objectives. It is worthwhile to generate more than the minimum number needed for each objective, as some may need to be discarded later in the process due to reliability problems or to provide a balanced test. In selecting distracters, commonly-observed student misconceptions should be included. It may be useful to trial the questions in a free-response format (i.e. without multiple answer choices) with a small group of students; their answers can then be collated and any frequently-occurring errors or misconceptions adopted as distracters. In constructing the answer options, it is important to avoid what we have dubbed ‘the Sesame Street effect’ (“One of these things is not like the others”): none of the answers should stand out noticeably from the others due to length, style, or for language reasons. (One way to test for this is to give a trial set of students *only* the answer options, i.e. without the question, and check if any answers are unreasonably favoured.)

When a suitable bank of candidate questions has been generated, these can be assembled into an appropriately balanced prototype test, again with validity input from the expert panel. Questions and answers should be revised if necessary to enhance clarity and remove sources of ambiguity. Further trials with students, followed up with supporting interviews, are useful at this stage to make sure that students are interpreting the questions and answers in the manner intended by the setters (i.e. that the test has face validity).

The validated prototype test should now be ready for large-scale trials and verification of its *reliability*. The notion of reliability is quite distinct from validity: a reliable test is one which will give a consistent measure of students’ competency in the relevant topics, and which will successfully discriminate between students with high and low ability. In essence, we seek to ensure that a student’s test score is determined primarily by their actual facility in the targeted objectives, and not by some artefact of the test instrument, random chance, or some other external factor. Reliability verification is achieved by a statistical evaluation of the test responses of a large number of trial students. These should be drawn from as wide a sample as possible of the intended target population, i.e. from different classes, disciplines, institutions, years of study, and so on as appropriate. (Clearly, recruitment of colleagues from other departments/institutions for this trial phase is likely to be required, and should be set in motion early in proceedings.)

When the trial diagnostic instrument responses have been collated, the instrument reliability can be evaluated using a standard battery of statistical tests. In their description of the reliability verification for the Brief Electricity and Magnetism Assessment (BEMA), Ding et al. give a concise and lucid account of a set of five such appropriate statistical tests[8], which have become widely used for diagnostic test evaluation. We will not repeat their detailed treatment here, but qualitatively describe the statistical tests and refer the interested reader to their paper for mathematical details. The five reliability tests may be divided into two broad categories: those which focus on individual test items (but which nevertheless should also be examined from the perspective of the whole test), and those which assess the whole instrument as a unit. The former consist of the item *difficulty index* and *discrimination index* and the *point biserial coefficient*, whereas the latter are *Ferguson’s delta* and the *reliability index*.

For each test item, the difficulty index is simply the ratio of the number of students who got the question correct to the total number of students who attempted the question. (Clearly, the more students who successfully complete the question, the higher the value of the difficulty index: for this reason, many suggest that it should more properly be called an ‘easiness index’.) For a maximally discriminating diagnostic, a majority of questions with a difficulty index of about 0.5 is preferable, though in practice this is clearly challenging to achieve and questions with difficulty indices in the range 0.3-0.9 are regarded as acceptable.

The discrimination index measures the extent to which a particular question successfully delineates between students with a firm grasp of the tested concepts and those with weaker knowledge. Questions with a high discrimination index strongly indicate whether a student getting them right is likely to do well overall. Conversely, any question with a negative discrimination index is more likely to be done correctly by the weaker rather than the stronger students; such a question is dysfunctional and should be amended or discarded. In general, a discrimination index of 0.3 or higher is desirable. The discrimination index can be calculated in two ways, either by dividing the trial cohort into two halves (with higher and lower overall scores) or by comparing the highest and lowest quartiles of the cohort. The second approach is more robust since with a normally-distributed cohort there will be a large number of students straddling the upper-half/lower-half boundary, but it does neglect half of the student responses so may be less desirable in cases where there is a limited volume of trial data.

The point biserial coefficient is a related concept to the discrimination index, and measures how strongly correlated the score of a single item is with overall scores on the complete test. Items with a high point biserial coefficient are consistent in performance with the remainder of the instrument. Consequently, questions with a low (or negative) coefficient feature student performance on a particular item which is not consistent with their performance on the test as a whole: such questions should therefore be considered for revision. A minimum value of 0.2 for the point biserial coefficient is the usual criterion.

The preceding three statistical tests are all applied to the individual questions making up the diagnostic instrument. Ideally, all questions should pass all the tests. However, a few outliers can be acceptable (particularly if there are compelling reasons for their presence, e.g. scene-setting questions or related, multi-part questions), provided that the values of these test statistics when averaged over the whole instrument lie within the recommended ranges.

In addition to these item-by-item statistics there are, as previously mentioned, two whole-test statistics to apply. Ferguson's delta is a test of discrimination, and measures how widely the scores of the trial student cohort are distributed over the possible range of test scores. An effectively discriminating diagnostic should have a large distinction between the scores of the stronger and the weaker students, and hence a broad range of overall scores, and consequently a large value of delta. Ferguson's delta values of 0.9 or above are generally considered acceptable.

The reliability index seeks to measure the repeatability, or self -consistency, of the test. Ideally, a reliable test given to the same student twice in quick succession should yield identical (or, at least, very similar) results. Clearly, actually doing so in practice is not feasible, not least of all because the student will remember the questions and their answers from the first iteration. The usual solution to this problem is to make use of a split-halves technique, in which the student's responses are divided into two halves, equivalent to them having completed two shorter tests in parallel: correlation between their scores on these half-tests can then be investigated. Clearly, this correlation will depend somewhat on exactly how the instrument is divided up. To address this, we may use Kuder-Richardson reliability formula 20 (KR-20), which averages over all possible combinations of half-tests. (For dichotomously scored tests such as those using MCQs, KR-20 is also exactly equivalent to Cronbach's alpha[26], another widely-used statistic.)

A related formula is Kuder-Richardson 21 (KR-21), which is simpler to calculate than KR-20 but makes the rather rigid assumption that all the test questions are of the same difficulty. KR-21 is reported in the BEMA reliability study and is also used elsewhere, e.g. in Wuttiprom *et al.*'s reliability study of the Quantum Physics Conceptual Survey[28]. However, in situations where this assumption is violated (which will almost always be the case with diagnostic tests) KR-21 will give only a lower bound on the true reliability[27], and may seriously underestimate the actual test reliability[29]. Since computer-based data processing techniques have become ubiquitous in the period since the introduction of the Kuder-Richardson formulae, there is now little additional burden in calculating KR-20 or Cronbach's alpha in preference to KR-21. For measuring the ability of groups of students (whole classes, etc.), the usual criterion is a value of the reliability index of 0.7 or higher.

In adopting split-halves measures such as these, there is an implicit assumption that all the test questions *should* be correlated with each other. This will be true if all test items are measuring a single 'construct' (which will indeed be the case for many diagnostic instruments), but if the diagnostic test in question is addressing more than one different (but presumably related) constructs then this assumption may not be valid. Thus, reliability indices such as these should be interpreted with caution.

It should be noted that the validity and reliability verification procedures evaluate the diagnostic instrument as a whole: for this reason, it is generally considered inadvisable to employ (or draw conclusions from) a limited subset of the test. If this is done, it should be done with care and with an eye to its limitations, as individual questions lack the robustness of the whole instrument and a restricted suite drawn from a larger test may not necessarily be reliable even if the whole instrument has satisfactory reliability.

Having evaluated the prototype diagnostic instrument using the statistical tests, any problematic items should be revised (or discarded if necessary). If the reasons for the dysfunctional nature of the questions are not clear, further triangulation via student interviews may be necessary, and if the modifications to the test have been substantial, further rounds of validation, trial deployment and reliability verification may be required. When a valid, reliable diagnostic instrument has been finalised, it can then be made available for widespread deployment. It is generally recommended that tests *not* be made freely accessible, either by publication or on the web, since their value will be very quickly compromised if students are able to see the content before testing. A common approach is to password-protect tests on the web, making the password available to instructors on request.

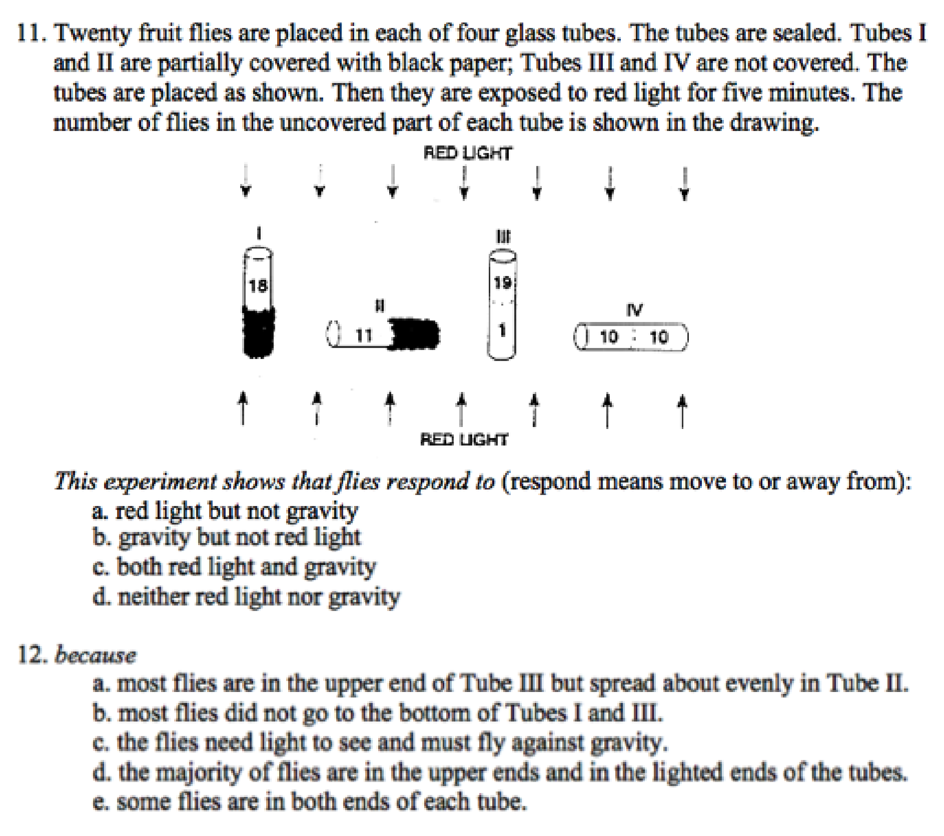
4. A brief survey of other tests in the literature

A plethora of other instruments have been developed and in this section we will give a brief tour through some of them. Links to many others can be found elsewhere[30]. We do not aim for a comprehensive list, but instead highlight certain families of instrument that have been created and validated and have subsequently been widely applied. Omissions are not through any lack of worthiness but principally due to lack of space.

Our first family tree to examine is the set of instruments that deal with the assessment of student expectations and beliefs about their subject (this area has been recently reviewed in a previous volume of this journal[31]). Elby has argued that ways of thinking about the subject that mirror those of expert practitioners – an ‘epistemological sophistication’ as he puts it - are extremely valuable, correlating with academic performance and conceptual understanding and supporting good study habits and metacognitive practices[32]. Such instruments - that aim to assess student attitudes and epistemologies - have a history of development back to William Perry's early work and have been active areas of development in the physical sciences almost as far back as the FCI (see, for example, Ref 33.) They include the Epistemological Beliefs Assessment for Physical Science (EBAPS)[34]; the Maryland Physics Expectation Survey (MPEX)[35], the Views About Science Survey (VASS)[36] and the more recent Colorado Learning Attitudes about Science Survey (CLASS)[37]. Our own investigations with the CLASS instrument have produced some interesting findings about the development of expert-like views as students proceed through their degree programme[38]. Similar findings have been reported from a comparable study at UCSD[39].

Another important family are the diagnostic tests that have been developed within the UK and deployed to provide quantitative evidence of the ‘maths problem’: the serious decline in mastery of the skills needed for mathematically based HE programmes. The key report on this, although now a decade old, is ‘Measuring the Mathematics Problem’[40]. The serious (and rather bleak) picture painted at the time that report was written has improved somewhat over the last decade but many of the same challenges still remain for those teaching in introductory courses in mathematically-based disciplines. Several institutions have decades’ worth of data on this topic but unfortunately rather little of it has found its way into journal or conference papers.

These sorts of assessment instruments add an important alternative perspective by not focusing on specific content knowledge. Related to this are assessment instruments that aim to appraise general attributes fostered and developed by a degree in the physical sciences. One of the most ubiquitous of such ‘graduate attributes’ in any science degree is the development of scientific reasoning and thinking skills. The Lawson Classroom Test of Scientific Thinking (LCTST)[41] was developed in the late 1970s and probes probabilistic thinking, identification of variables, proportional thinking and deductive reasoning via a series of 24 paired MCQ questions. Studies have found a strong positive correlation between students’ normalised gains on the FCI and scores on the Lawson test[42]. A more recent study by Bao *et al.* has compared the scientific reasoning ability of post K-12 (final year) high school students in China and the USA and found broadly similar distributions of scores[43]. However, the same study showed that this similarity is starkly different to the same groups’ performance on the FCI and BEMA instruments. Here, content knowledge and reasoning skills diverge, with the Chinese K-12 students significantly outperforming those from the USA.



11. Twenty fruit flies are placed in each of four glass tubes. The tubes are sealed. Tubes I and II are partially covered with black paper; Tubes III and IV are not covered. The tubes are placed as shown. Then they are exposed to red light for five minutes. The number of flies in the uncovered part of each tube is shown in the drawing.

This experiment shows that flies respond to (respond means move to or away from):
a. red light but not gravity
b. gravity but not red light
c. both red light and gravity
d. neither red light nor gravity

12. *because*
a. most flies are in the upper end of Tube III but spread about evenly in Tube II.
b. most flies did not go to the bottom of Tubes I and III.
c. the flies need light to see and must fly against gravity.
d. the majority of flies are in the upper ends and in the lighted ends of the tubes.
e. some flies are in both ends of each tube.

Figure 3: Sample question pair from the Lawson Classroom Test of Scientific Thinking. Reproduced from reference 42.

An example of a question from the Lawson test, reproduced from Coletta’s paper[42], is shown in Figure 3 and illustrates the ‘paired’ nature of the questions on the test. As well as asking ‘what’, the second question of the pair asks for a ‘why?’ It is perfectly possible to have students reason what the correct answer is to the former, but choose one of the incorrect responses to the latter. In the case of this particular question pair, several of the ‘why?’ statements are valid, but do not fully specify the correct reasoning. These sorts of two-tier questions in diagnostic instruments have been widely developed by David Treagust, looking at conceptual understanding in the field of chemistry (see for example[44,45]).

Our own studies in which we have used (parts of) the Lawson test, including the question pair illustrated in Figure 3, have revealed some interesting differences between student cohorts in physics on either side of the school-university transition. Whilst the percentages of each group that get the first part of the question pair correct show no statistically significant difference, around twice as many end-of-first-year undergraduate students choose the correct what-why pair of answers compared to students on the brink of entering university. This is statistically significant for the size of cohort groups we investigated ($N = 80$, 100, respectively).

In terms of challenging topics in a physical sciences degree programme, few can match quantum mechanics for its conceptual difficulty, counter-intuitiveness and a lack of real-world concrete experience. There has been much previous work in this area, including our own studies reported in a previous volume of New Directions[46]. The University of Colorado PER group have developed the Quantum Mechanical Conceptual Survey (QMCS), drawing on earlier work to develop a similar instrument. The test was devised using a two-tier free response approach, where an initial pilot version of the test asked students to identify 'what', followed by a free-text response area where they were asked to given a short reason 'why' they chose this. A detailed account of the construction and deployment of a test of conceptual understanding of introductory quantum mechanical concepts has been described by Wuttiprom *et al.*[28] This study covers not only details of the design and validation of the instrument, but assesses student performance and improvement after teaching on different types of questions (interpretive and non-interpretive).

It is no real surprise that these and other studies find compelling evidence of widely held alternative conceptions by students in the topic area of quantum mechanics, some of which persist after instruction. One of the most commonly-held alternate conceptions is to be found in the topic of quantum tunnelling. Students often remain convinced (even after instruction) that particles involved in tunnelling must lose energy, indicating a classical mental model of the process. This has been confirmed by our own investigation[46], the Colorado group[48] and a separate study from the University of Maine[49]. The latter study conducted a multi-year investigation using surveys, exams and interviews, and concluded that '*the response that 'particle energy is lost in tunneling' is prevalent across all our studies*'. This particular topic is one where visualisation is key to understanding: several groups have reported effective use of simulations in supporting and improving students' conceptual understanding of these topics[50,51,52]. Other approaches have also been described, such as vicarious learning through student-tutor discussions[53].

One final topic area in which we highlight instrument development is that of astronomy. Bardar *et al.* have reported the construction and validation process, together with field trials, of the Light and Spectroscopy Concept Inventory (LSCI)[54]. In this volume, Balfour and Kohnle present a fuller summary of available diagnostic tests in this area, together with results from their own instruments[55].

5. A case study: the Edinburgh Data Handling Diagnostic Instrument

To conclude our review, we illustrate some of the preceding points by way of a brief case study of one of our own diagnostic tests, the Edinburgh Data Handling Diagnostic (DHD). A full account of the development and validation of this instrument, along with its initial findings, will be given in a forthcoming publication[56].

The initial motivation for the creation of this instrument originated with a small-scale trial of a short (10 question) pre-prototype test of laboratory data analysis skills developed by a team at the University of British Columbia (UBC). Results from this trial were not fully conclusive (not least of all because it proved to be too difficult for undergraduate-level students), but nevertheless there was a strong suggestion that our undergraduate students were not developing the mastery of data handling skills that we might expect from the four or five years of a physical science degree.

Quantitative data handling skills, i.e. the ability to assess the quality of measured values, and process, display, interpret, and draw valid conclusions from them, constitute one of the most valued aspects of science degrees. Not only are they of key importance within the science disciplines themselves, but are also identified as being of essential utility by a wide variety of employers (see for example[57]).

However, these skills often form part of the so-called 'implicit curriculum' (see for example Atkinson's commentary[58]). The implicit curriculum is that set of learning outcomes which we all 'know' or 'expect' that out students will have acquired by the time they graduate, but which may not be explicitly taught or specifically assessed. In the case of practical data analysis skills, many degrees will feature specific tuition of the basics of data processing (means, standard deviations, etc.) in early years of the programme, but more advanced topics (non-linear model fitting, analysis statistics, etc.) are expected to be 'absorbed' as a side-effect of tackling in-depth experimental projects. Similarly, learning in the laboratory is often assessed by means of a standard 'lab report', which conflates many relevant but disparate elements, such as experimental competence, standards of record keeping, data processing, and clarity of expression. De-convolving a student's ability in one defined element of the experimental process – such as data handling skills – from a composite measure such as this is not always practical or reliable.

In response to this identified need and clearly delineated area of interest, we set out to develop a diagnostic instrument which would be tailored to the appropriate curriculum content and set at a level suitable for evaluating the skills of physical science students at various points in their degree course. In consultation with colleagues with responsibility for laboratory and data analysis instruction at various levels (and who formed part of our 'panel of experts'), we identified relevant topics for inclusion, incorporating such areas as accuracy & precision, functional forms, line fitting and quantitative error analysis.

The development team then generated a large bank of candidate questions, assembled a prototype instrument, and iterated it through multiple versions with validation input from both the expert panel and some trial students. When an instrument with appropriate balance had been produced – and in which we could be confident there were no obvious sources of confusion or ambiguity – we proceeded to the large-scale trial phase of the development process. This involved trial deployment of the prototype 23-item instrument to over 1200 students in ten institutions across the UK and Ireland. The students were drawn from all educational levels (Scottish first year to final year Honours) and from both physics and chemistry departments. (This trial cohort was fairly large – many diagnostic instruments are reliability-tested with cohorts of a few hundred.)

Responses from the trial students were analysed en masse in order to assess the reliability of the instrument, using the statistical tests outlined in section 3. The diagnostic was found to perform satisfactorily. Four items required minor revision in light of their statistical performance and on feedback from trial students. (One of these was the first question, which proved statistically problematic since it was substantially too easy; however, it was retained as-is since it served an important purpose in scene-setting and as a confidence-builder, a factor which was rated as highly valuable in trial student feedback, particularly in light of the excessively difficult UBC pre-prototype.)

Satisfied that our diagnostic instrument was performing well, we were then able to investigate overall student performance on the test. Figure 4 shows an example of the response profile from a single test question. As may be seen, only a minority of students choose the correct answer (B). Of those answering incorrectly, the vast majority choose the same wrong answer (C). This is the hallmark of a classic misconception: if students have not been instructed on a topic or simply don't know how to do it (or are guessing), then the incorrect answers will be fairly evenly distributed amongst all the distracters (and indeed such answer profiles are seen for many of the DHD questions). A profile such as that seen in Figure 4 indicates something different: students do *think* they know how to do something, but are consistently doing it incorrectly (in this case confusing the standard error on the mean with the standard deviation). Response profiles such as this will either confirm previously-known alternate conceptions or highlight areas in which they also exist and to which more instruction should be focussed.

Comparison of the mean test scores between different classes was also informative. Our early suspicions about the development of data handling skills were confirmed: between the first and second years of our own degree programme there was a significant increase in ability, but thereafter (from second to fifth year) the mean test scores stagnated, with no statistically significant changes. A similar picture is seen nationally: for those institutions for which we have longitudinal data (i.e. test scores from more than a single year group), in only one instance was there a significant improvement in a later year of study (and again this was between a first and second year class).

You want to measure how long seals can stay under water by measuring the time between a dive and a resurface with a stopwatch. After watching a seal dive three times you have measurements of 13 minutes, 7 minutes and 10 minutes. What do you determine as the best estimate and standard error of these measurements?

Tip: In this case the standard deviation is found from: $\sigma = \sqrt{\frac{1}{N-1}\Sigma(x_{obs} - x_{ave})^2}$

A 10.0 ± 1.0 minutes

B 10.0 ± 1.7 minutes

C 10.0 ± 3.0 minutes

D 10.0 ± 5.2 minutes

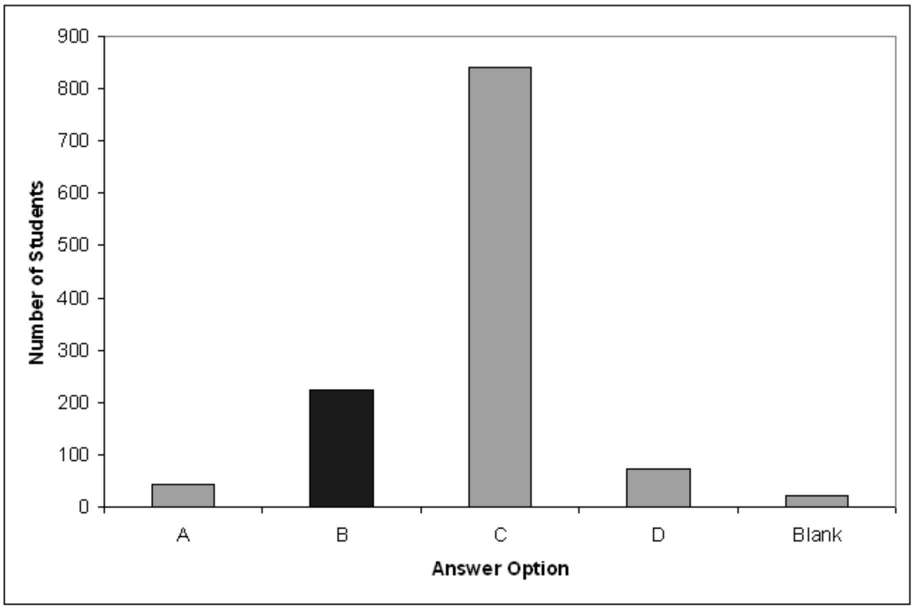


Figure 4: Sample question and student response profile (N ~1200) for one of the items in the Edinburgh Data Handling Diagnostic instrument. Item B is the correct answer.

In fact, the national picture is surprisingly uniform across all disciplines, institutions, and years of study: the variance of the mean scores of all the classes is less than all of the individual within-class variances, indicating that there is a relatively broad spread of individual student ability in data handling, but that on average most classes perform similarly, irrespective of discipline, location, or number of years of instruction. (Question-to-question success rates also show a striking correspondence, suggesting that the topics that the students do know are also fairly uniform.)

> ...a properly validated and robust diagnostic instrument ... affords an extremely powerful means to confirm the effectiveness of our teaching or to provide evidence-based guidance on which areas should be targeted for attention

The final phase of our project to develop the Data Handling Diagnostic is the generation of supporting learning resources, to be made available on-line. Students taking the test can be directed to these resources, which will provide additional instruction, explanation and practice for those areas in which they performed poorly. Follow-up steps such as these are a vital component of the diagnostic testing process: creation and deployment of a diagnostic instrument is only the first step, and must be followed with an analysis of class-aggregated and individual performance and such intervention as is found to be required (from extra supporting resources, through additional classes, to curriculum re-design if necessary).

As we have seen, as well as providing direct and useful feedback to students, a properly validated and robust diagnostic instrument (whether taken from the already wide-ranging literature or home-grown) affords an extremely powerful means to confirm the effectiveness of our teaching or to provide evidence-based guidance on which areas should be targeted for attention. Thus, diagnostic tests constitute one of the most valuable elements in the toolbox of the evidence-based educator.

Acknowledgements

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...diagnostic tests constitute one of the most valuable elements in the toolbox of the evidence-based educator.

Cognitive psychology and problem solving in the physical sciences

David Sands* and
Tina Overton
Department of Physical Sciences
University of Hull
Hull
HU6 7RX
***d.sands@hull.ac.uk**

Abstract
This paper provides and introduction to the literature on cognitive psychology and problem solving in physical sciences. We consider the working memory and its three different components, two of which hold and record information and are controlled by an executive that controls attention. Working memory alone cannot explain problem solving ability and we review the influence of schemata, the construction of mental models, visual reasoning and the cognitive style of field dependence.

Introduction

The ability to solve problems is widely recognised as an important outcome of undergraduate programmes. For example, in 2008 alone there were over 160 papers published in over 100 different journals which covered topics as diverse as child development, psychology, cognition, computers, neurosciences, mathematics and education[1]. The breadth is quite staggering, but we are interested mainly in problems in chemistry and physics. Intuitively we feel that problem solving in these areas is likely to be different from problem solving in, say, mathematics or medicine. Is it, though? Or is it just that the content is different but the techniques are similar? Specifying exactly what it is we do when solving problems is difficult enough, but defining exactly what we should be teaching and how seems nigh on impossible.

The first question that inevitably arises is, what do we mean by problem solving? Hayes wrote in 1980[2]: '*Whenever there is a gap between where you are now and where you want to be, and you don't know how to find a way to cross that gap, you have a problem*.' A similar view was expressed by Wheatley[3]: '*Problem solving is what you do when you don't know what to do.*' Pithy, but seemingly not too helpful. However, they express the essential difficulty: if you're at a loss, how do you get started? Perhaps specific help can be offered in specific circumstances, but it would be better if we could identify the essential elements of a problem solving strategy. As we will show, knowledge is important, but knowledge alone is not enough. Can we identify what else is needed and change the way we teach to cultivate problem solving abilities? This paper will attempt to answer these questions by drawing on the literature from cognitive psychology and both physics and chemistry education research to lay down some general principles of problem solving.

As we will show, knowledge is important, but knowledge alone is not enough. Can we identify what else is needed and change the way we teach to cultivate problem solving abilities?

Expert-Novice studies

Much of the early literature on problem solving were concerned with general processes and rules for reasoning and problem solving '... that might be acquired as transferable habits of thinking'[4]. The content of such studies were abstract problems, or perhaps puzzles, that had little direct connection with the domains of knowledge with which real-life problem solvers were familiar and in which they operated. It was not until the late 1970s that the artificial intelligence (AI) community began to construct computer programmes of problem solving and the importance of domain-specific knowledge, and in particular the organising principles behind the knowledge structures of experts, was recognised. Physics was identified as an established problem-solving discipline and provided the context in which many of the early expert-novice studies were undertaken.

Two papers stand out from that time by Larkin *et al*[5] and by Chi *et al*[6]. Larkin *et al* were concerned to produce computer programmes that replicated human thinking and described a few examples, at the heart of which are production rules. These are specific algorithms that generate actions from given conditions: 'if *x* then *y*'. This paper is remarkable for its early recognition of all the important features of problem solving that have dominated the literature since, including in particular working memory capacity and the use of representations, both internal and external. Working memory capacity is essentially how much information can be held in the head at any one time. Larkin *et al* described expert chess players who can memorise with remarkable accuracy the positions of some 25 or so chess pieces on a board after looking at them for only a few seconds. Novices, on the other hand, can remember only a few pieces, but experts perform in much the same way as novices if the pieces are placed randomly. Experts are familiar with many different patterns of play and clearly recognise and recall those patterns, thereby reducing the load on working memory. Experts in physics employ similar strategies, working forward from the givens to the solutions on simple kinematics problems. Novices, or students, tend to work backwards and according to Larkin et al this is a more efficient search strategy. Clearly experts are not searching; they are recognising patterns and working with them.

Chi *et al* discuss many of the same things, but they were concerned to look also at how knowledge is structured. Rather than solving problems, they asked experts and novices to characterise a set of end-of-chapter problems according to common features. Experts characterised the problems according to principles or laws involved in their solution, whereas students characterised them according to common surface features. In Glaser's words[4]; "… [*the*] *knowledge of novices is organised around the literal objects explicitly given in a problem statement. Experts' knowledge, on the other hand, is organized around principles and abstractions that subsume these objects.*" Access and use of knowledge is "*a major component of thinking*" according to Glaser[4], but there is one aspect of thinking that is not really addressed in any of these papers: that is the use of qualitative reasoning. Much is made of content knowledge: concepts, laws, facts, etc. and the procedural and strategic knowledge of how, where and when to use it. But the problems in these studies are quantitative, so the methods used to solve the problem are also quantitative. However, according to di Sessa[7], "*qualitative controls quantitative*". In other words, it is much easier to arrive at a quantitative solution if first there is a qualitative understanding. Equations might symbolise concepts or laws but those symbols must be connected to "*richly elaborated mental constructs*" which are qualitative in nature. It is these qualitative relationships that allow us to plan and execute a problem-solving strategy.

Experts spend a great deal more time than do novices on understanding the problem, and an essential part of that understanding is drawing a diagram.

Representations

A representation of a problem is an essential component of the mental constructs to which di Sessa refers. Experts spend a great deal more time than do novices on understanding the problem, and an essential part of that understanding is drawing a diagram. Glaser[4] calls a representation constructed in order to understand a problem a '*cognitive structure*'. That is to say, the construction of a representation is part of our thinking about a problem, from understanding through to the formulation of a solution. There are two kinds of representation of particular interest: diagrams and mental images. In Nersessian's view[8], these two constitute a coupled system. That is to say, we use diagrams and mental images as the basis of a form of qualitative reasoning whish Nersessian calls 'model-based reasoning'.

It comes as something of a surprise to many science educators to find that diagrammatic representation and reasoning has been a topic of study for many years within the AI community. There is too much work to quote here, so we will restrict ourselves to a few illustrative examples. Of particular relevance is the work of Suwa and Tversky[9], who, studying the way that designers use diagrams, concluded that diagrams contribute to the dynamic construction of ideas. In particular, diagrams free working memory by putting down on paper ideas and concepts that might otherwise have to be held in the head. Diagrams also cue retrieval from long term memory through the recognition of particular structures or patterns, allow perceptual judgements about spatial relations, and, most perhaps most important of all, allow the generation of new ideas.

Within the physical sciences education research literature there is also extensive evidence for the use of diagrams and mental representations both to understand a problem and to formulate a solution. One of the criticisms often levelled at early expert-novice studies is that the problems do not represent much of a challenge to experts who, by and large, are familiar with the material. Singh[10] conducted a study in which he presented experts in physics with a problem to which they did not know the solution. He observed that diagrams were often constructed, but in addition experts use other techniques to develop an answer, including consideration of limiting cases. In order to do this it is necessary to create and run a mental model. This is Nersessian's model-based reasoning. Within Chemistry Bodner's work stands out[11], as does the work of Stieff and Raje[12]. The latter presented experts with problems in organic chemistry from finals papers from a range of universities. The aim of their paper was ostensibly to show that experts use techniques other than visualisation. The technique used most was recall of either the problem or the solution, which of course obviates the need to visualise or draw a diagram. The next most common techniques were either visualisation or the use of a diagram.

Spatial ability: the role of working memory

The ability to manipulate mental images in the manner just described varies from person to person and is closely related to working memory[13]. Working memory capacity has already been mentioned, and the concept is fairly well known within science education, but capacity is only one aspect. According to Baddely[14], the originator of the concept, the term is taken '*to apply to a limited capacity system that is capable of storing and manipulating information and that is assumed to be an integral part of the human memory system*'. The concept of working memory is an extension of the earlier psychological concept of short term memory which was seen essentially as a temporary repository of information before it entered long term memory. Working memory, on the other hand, is not a unitary system and also has a '*functional role in other cognitive tasks such as learning reasoning and comprehension*'[14].

Understanding exactly what the different components of working memory do and how they relate to each other is still an ongoing question for psychologists. It is even more difficult for non-psychologists interested in how it affects performance in science learning to understand the concept. Essentially working memory is seen as a tripartite system: two slave functions which hold and record information controlled by an executive that controls attention, how it may be switched from one focus to another, the activation of long term memory, and possibly also the processing of information. The slave functions are quite distinct, with one, the phonological loop, holding acoustic or speech-based information and the other, the visuo-spatial sketch pad, holding spatial and visual information. Despite being perceived visually, written words are still controlled by the phonological loop.

The phonological loop is the best understood component of working memory, but for our purposes it is the least interesting. In Baddeley's view[14], this system probably evolved as a crucial component of language acquisition, so, beyond determining memory capacity, it is not directly involved in problem solving. Memory capacity, important as it is, is only one aspect of working memory. It is measured by speech-based information so it is connected to the phonological loop, but it is commonly supposed that there is a similar capacity for spatial or visual information. However, the visuo-spatial sketch pad is not nearly as well understood. For example, the capacity for speech-based information arises because the memory refreshes itself automatically. If refreshing is prevented, say by a distraction, the information is lost after even just a couple of seconds. In a long sequence of data, therefore, the last information is processed after the first information has disappeared from memory. All this is well known and well understood within psychology, but the visuo-spatial sketch pad is much more complex and its characteristics correspondingly harder to measure. In addition, some of its functions, especially those related to imagery, rely heavily on the central executive, which is understood even less.

Psychologists investigate the relationship between these different components through interference tests. That is, propositional reasoning is assumed to occur through the phonological loop, so if a subject is made to undertake a simple spatial secondary task it is possible to see to what extent the spatial task interferes with the primary[15]. If there is no interference the systems are assumed to be separate. The picture that emerges from the literature is that propositional reasoning often involves a spatial component. Complex propositions might, for example, invoke imagistic strategies such as the mental construction of Venn diagrams. It is also clear that spatial reasoning relies heavily on the central executive and that a limited capacity in the central executive can affect the ability to reason spatially and propositionally[16,17]. This is the basis for individual differences in spatial ability, but the implications for problem solving in the physical sciences will not be clear until the concept of field dependence-independence (FDI) has been described.

Field dependence-independence

FDI was initially used to describe the ability to perceive upright in a darkened room where the only visible objects, an illuminated square frame and a rod, may be oriented independently at an arbitrary angle[18]. Some subjects perceive upright to correspond to the orientation of the frame while others are able to define upright correctly regardless of what they see. People who take their cue from the visual field are said to be field dependent. It quickly emerged that field dependence defined in this way correlated with a range of other characteristics, most notably the inability to disembed important information from a perceptual field and the inability to order information. The consequences can be quite profound. First, in relation to disembedding, FD subjects often struggle to decide what is important or not in a problem statement. Second, as described by Witkin, learned material often lacks an inherent structure and, whereas field independent students are able to re-order material to aid their own learning, field dependent students struggle. Not surprisingly, a study of Spanish school children revealed a significant achievement gap across all subjects which is not accounted for by differences in general intelligence[19]. There are other studies that show directly, and quite emphatically, how, for field dependent students, learning in science can depend on the way material is presented and structured[20-22].

These two effects are related to the central executive. Describing the role of working memory in the construction of mental models, García-Madruga states that one of the functions of the central executive is to discard irrelevant information[16]. Ordering information clearly places a high load on the working memory. First, several concepts have to be held in the mind at once, but in addition there has to be a fair amount of reasoning about the concepts which is likely to be more demanding than simple propositional reasoning. Concepts have be understood not only in themselves, but also in their relationship to each other. There might even be a spatial element in as much as the concepts of before or after, first or last, following, etc. might well imply spatial relations and invoke spatial imagery. The central executive is likely to be heavily loaded during such a task and individuals with a low capacity will struggle. Rittschof[23] summarises much of the psychological research which links field dependence to the central executive.

Problem solving: how can it be taught?

The preceding has laid down some of the essential ideas in cognitive psychology that relate to problem solving in the sciences. Necessarily the ideas are brief and the reader is referred to the literature for a deeper understanding. What is clear, though, is that problem solving is a complex activity and the idea that we might teach problem solving as a technique in the same way that we might teach other skills like computing does not stand up. Rather, it appears to be something that ought to be cultivated over a long time. The first requirement is for students to build up a body of knowledge, but often we want to set problems as a way of developing knowledge. This is a contradiction and probably explains why many problems are algorithmic in nature. Students simply do not have the knowledge, not to mention other skills, to cope with more complex, open-ended problems. Moreover, in trying to build up this knowledge, we run into the problem of field dependence.

The construct originally described by Witkin is likely to be binary; either one can perceive upright independently of the visual field or one can not. However, field dependence today is often measured using a spatial reasoning test involving hidden figures and a broad spectrum of abilities is often measured, including field neutrality. The terms field dependence and independence should therefore be interpreted as tendencies rather than absolutes. That said, we have no real idea of the distribution of these tendencies among physical science students in UK universities. It is a common experience, however, that abilities vary greatly and perhaps more so now that higher education is more inclusive. If we accept that some of these students tend to field dependence we must recognise the possibility that conventional lectures will leave many of them floundering. Field dependent students appear to be very inefficient at making their own notes[24]. As they can neither discard irrelevant information nor impose order on perceived material they produce notes that are wordy, lack coherence, and appear to be hard to learn from. However, if they are given an outline which provides an external structure they can learn just as well as field independent students whose notes, by contrast, tend to be in outline form, with headings, subheadings and a great deal of order to the information.

Modelling is one form of problem solving. It often employs the sort of qualitative reasoning that we have argued is an essential component of scientific thought.

The body of knowledge should, if possible, include schemata. A schema may be considered to be a mental model around which information is organised. For example, the concept of an elastic collision implies hard spheres as well as the conservation of both momentum and energy. Thus, a schema helps to reduce the load on the working memory by allowing access to a series of associations held in long term memory. Schema are best developed by students themselves working cooperatively in a constructivist environment such as the modelling approach advocated by Hestenes[25]. Modelling is one form of problem solving. It often employs the sort of qualitative reasoning that we have argued is an essential component of scientific thought. As we have argued, such reasoning is not just propositional but may be spatial or diagrammatic, which brings us nicely to the subject of spatial abilities and whether they can be improved.

Spatial ability is very closely linked to field dependence and to the central executive in working memory. Spatial abilities therefore vary among individuals and ultimately might be limited by biology, but even if the capacity in the central executive or the visuo-spatial sketch pad is fixed there might be reason to suppose that strategies can be developed to compensate. Baddeley[14], for example, describes patients with severe impairments to some of the functions of working memory who nonetheless cope well. The use of diagrams is likely to form part of that strategy. We have described how diagrams are used to understand problems and also to develop solutions, but crucially they reduce the load on working memory. Depending on the nature of the problem and on the individual, iconic mental models might be developed and manipulated, but if the mental models become too complicated it is necessary to free up working memory by setting some of the information down on paper. Once on paper spatial relations might be more easily perceived and investigated through the medium of the diagram.

Diagrams are important for another, perhaps unexpected, reason. Sorby[26] reports that one of the best ways of developing spatial abilities is old-fashioned sketching. Perception appears to be very important for developing spatial skills. Holding and manipulating physical models, for example rotating them, also appears to work. Although these methods have been investigated in the context of engineering education, and in fact there is interest around the world[27,28] in improving spatial abilities in engineering students, this is a technique that is immediately applicable to organic and molecular chemistry. It might be thought that working with 3-D computer graphics will help, but in fact it does not. It seems that there has to be some spatial reasoning associated with the task: imagery, mental rotation, mental extrapolation, etc. This is why sketching is so useful: it requires spatial reasoning to identify relationship as well as important components, which is especially interesting in light of the work by Mohler[29]. Mohler investigated practical differences between high and low spatial ability students by analysing their performance in a spatial task involving complicated diagrams. Even high spatial ability students can experience cognitive overload; '…*I screw stuff up because when you're looking at everything, … it's easy to get real messed up*'. The difference is that students with high spatial ability recognise it and work on smaller portions of the diagram whereas those with low spatial ability do not. Mohler asks whether this skill can be taught, and as yet there is no answer. Perhaps it is a manifestation of the central executive's inability to discriminate and discard irrelevant information, but if it can be taught, perhaps sketching might be one way. In constructing a sketch it is necessary to make a choice about what is important and what is not in order to put something down on paper. Activities that encourage the construction of diagrams in problem solving do more than simply provide a mechanism for reasoning about the problem.

Conclusion

The present work has considered the cognitive psychology of problem solving from early expert-novice studies through to later studies on spatial reasoning and the cognitive style of field dependence. We have shown that qualitative reasoning about problems precedes quantitative reasoning and is an essential aspect of scientific inquiry. We have also discussed at length spatial abilities and their role in problem solving, particularly in constructing mental models and diagrams. It is clear that students of low spatial ability are to some extent disadvantaged in a conventional academic environment, but designing activities that will allow field independent students to flourish while at the same time providing the kind of support that will benefit field dependent students is by no means easy. According to Rittshof, "*studies from several decades past emphasise the ways that field dependent learners benefit from external types of information structuring and motivation, while field independent learners benefit from the opportunity to use their own structuring of information and motivation as they construct knowledge*". Serving both sets of students at the same time poses a tremendous challenge, one that perhaps has only been appreciated within the field of cognitive psychology. However, by looking at that literature as well as that from education research we can at last begin to appreciate what we should be aiming for. We have suggested how spatial skills might be cultivated, but there is a lack of practical knowledge about the best way forward.

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Testing conceptual understanding in introductory astronomy

Jordan Balfour and
Antje Kohnle*
School of Physics and
Astronomy
University of St Andrews
St Andrews
KY16 9SS
***ak81@st-andrews.ac.uk**

Abstract

Understanding students' prior beliefs about the nature of the Universe is a first step towards improving astronomy instruction. This article describes results from two diagnostic surveys testing understanding of astronomy concepts given to first, second and third-year St Andrews students taking astronomy and astrophysics modules.
We highlight results pertaining to the phases of the Moon, the cause of the seasons, planet temperatures and properties of comets, and discuss possible underlying reasons for student difficulties. We find that some misconceptions remain at higher levels, and that new knowledge may be incorporated into prior beliefs without a substantial conceptual change.

Introduction and Background

Pre-existing student beliefs can strongly influence the development of new knowledge[1]. Knowing these pre-instructional beliefs that are common amongst students can allow the tailoring of instruction to promote substantial conceptual change. If these pre-instructional beliefs are inconsistent with current scientific understanding, they are often called misconceptions, and this term will be used in what follows. The importance of conceptual understanding for problem-solving has been demonstrated, in particular for problems requiring a transfer of knowledge to new contexts[2]. Standardised, validated multiple-choice diagnostic instruments to test conceptual understanding exist in many areas of physics, and also increasingly for astronomy and astrophysics (see also the article by S P Bates and R K Galloway in this volume). These instruments use incorrect choices (so-called distractors) that can elucidate common misconceptions. Examples for astronomy include the Astronomy Diagnostic Test[3], the Astronomy and Space Science Concept Inventory[4], the Light and Spectroscopy Concept Inventory[5], the Lunar Phases Concept Inventory[6] and the Star Properties Concept Inventory[7]. However, most of these astronomy inventories were created for School level or introductory university astronomy courses for non-science majors.

The importance of conceptual understanding for problem-solving has been demonstrated, in particular for problems requiring a transfer of knowledge to new contexts

This work investigates understanding of astronomy concepts for physics and astrophysics students at the University of St Andrews. We describe the development of two surveys, one administered to level 1 (first-year) students in an introductory astronomy and astrophysics course, the other given to level 1, 2 and 3 (first, second and third year) students enrolled in astronomy and astrophysics modules. We describe selected results from these surveys, their implications and possible future work.

Methodology

In 2008/09 and 2009/10, students completed a diagnostic survey (called Solar System survey in what follows) covering topics from the Solar System part of the level 1 AS1001 course in the first and the last lecture of this course (pre- and post-test design). The survey consisted of nine multiple-choice questions on planet temperatures, phases of celestial objects, cause of the seasons, properties of comets, common features of satellites, and common properties of planets. Students were asked to choose one or more answers. An additional question asked about prior astronomy school courses. To analyse the survey results, we determined moments of the distribution of total scores and gains and normalised gains for each question and averaged over the survey[8].
The Solar System survey covered only one part of the AS1001 course, and students rated only their overall confidence, so that it was not possible to determine students' confidence in particular incorrect choices. This led us to develop a conceptual survey covering all parts of the AS1001 course, including 11 questions on the Solar System, 6 questions on stars and elementary astrophysics and 5 questions on galaxies and cosmology. The survey (called Astronomy Conceptual Survey, ACS, in what follows) was developed using known misconceptions from the literature and discussions with course lecturers and tutors. The survey was validated by trialling it with postgraduate astronomy

students and staff. The survey was administered via WebCT (a virtual learning environment) as an anonymous survey to level 1, 2 and 3 students taking astronomy modules and to higher-level astronomy students on paper. Students were asked to choose one or more answers for each question, and to rate their certainty for each question.

To analyse the results, we determined moments of the distribution of total scores, performed t-tests to test for a significant difference in means between levels, and calculated effect sizes (defined as the difference in means divided by the average standard deviation) for significant differences. Due to small numbers, we grouped data from different levels where the distribution of responses was not significantly different. We determined discriminatory power of individual questions using the item difficulty index, item discrimination index and point biserial coefficient, and whole test reliability using the Kuder-Richardson reliability index and Ferguson's delta[9], and found the values of these indicators to be satisfactory. Of particular interest were those questions that were answered with a high degree of certainty but a low percentage of correct answers.

Student Survey outcomes

For the Solar System survey, in 2008/09, 59 students took the pre- and 48 students took the post-test. In 2009/10, the numbers were 53 (pre-test) and 41 (post-test).

For the ACS, 22 of 49 (45%) level 1 students, 17 of 22 (77%) level 2 students and 21 of 28 (75%) students in levels 3 and above completed the survey. Of those students at level 1 that completed the survey, 5 were astrophysics students, 15 are physics students and 2 are studying for other science degrees. At levels 2 and above, all students are studying for an astrophysics degree. The mean total score for the ACS (out of 22) was 12.9 for level 1 students, 13.4 for level 2 students and 15.6 for higher level students. The increase from level 1 to level 2 was not significant at the 95% confidence level, but the increases from level 2 to 3 (t-test, p=0.044, effect size = 0.70), and level 1 to 3 (t-test, p=0.013, effect size = 0.81) were significant.

Phases of the Moon

Question 6 of the Solar System survey was as follows:

> *What causes the phases of the Moon?*
> *A) Earth's shadow covering part of the Moon*
> *B) The Moon's direction relative to the Sun as seen from Earth*

It is easy to see that A) cannot be correct[10], as a gibbous Moon cannot be the result of Earth's shadow, and Sun and Moon would need to be on essentially opposite sides of the Earth all the time excepting for Full Moon, i.e., the Moon could not be in stable orbit around the Earth.

Figure 1 shows the results for this question both for the Solar System survey and the ACS. It is noticeable that a large number of students chose A) in the pre-test, namely 27 of 59 (46%) in 2008/09 and 25 of 53 (47%) in 2009/10. In the post-test, the fraction of students choosing the correct answer B) increased to 83% in 2008/09 and 88% in 2009/10, but in 2008/09 the fraction of students choosing the incorrect answer A) did not decrease accordingly: while one student chose both answers in the pre-test, seven students chose both answers in the post-test. In 2009/10, 4 of 41 students chose both answers in the post-test. Although these are small student numbers, these results may show that instruction does not necessarily lead to the revision of prior beliefs, but instead may lead to an inconsistent set of ideas. It would seem that misconceptions need to be explicitly challenged in order for students to

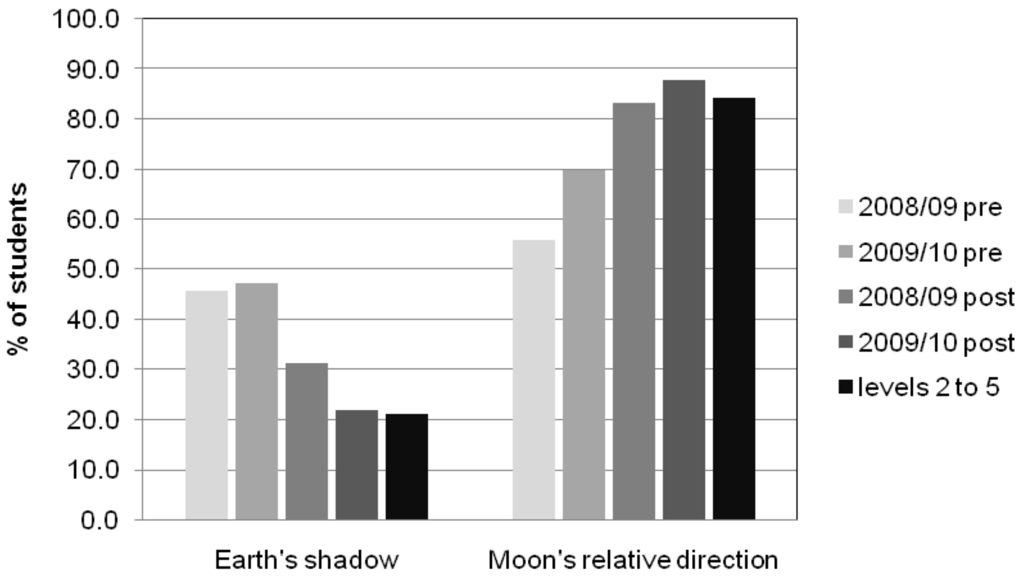

Figure 1: The figure shows the responses to the question "What causes the phases of the Moon?" (see text for full details of choices) for level 1 introductory astronomy students pre- and post-instruction for two different years, as well as for astrophysics students in levels 2 to 5 from a survey conducted in Spring 2010. The level 1 course is taken by physics, astrophysics and science students, whereas the level 2 and above courses are only taken by astrophysics students. The total student numbers surveyed range from 38 (levels 2 and above) to 59 (2008/09 pre).

overcome them, in particular when these prior beliefs are deep-rooted in everyday experience. The ACS contained a slightly revised version of the above question (including an additional choice C), allowing comparisons with astrophysics students in levels 2 and above (see Figure 1). 21% (8 of 38) of higher-level students stated choice A is correct, two students in this group stated that both A) and B) are correct. All these students were certain of their answer, excepting one student who stated “somewhat certain”.

Cause of the seasons

Question 1 of the ACS was as follows:

> *Which of the following predominantly causes the seasons on Earth?*
>
> > *A) The changing distance from the Earth to the Sun*
> > *B) The tilt of the Earth’s axis causing one hemisphere to be closer to the Sun than the other*
> > *C) The tilt of the Earth’s axis inducing changes in sunlight intensity and day length*

While there is a difference in temperatures due to the axis tilt (choice B), it is exceedingly small (0.02 K), so cannot be the cause of the seasons. Figure 2 shows the results. No students chose response A), which is not shown in the figure. Results were similar for level 1, 2 and 3 students, leading us to sum the data for all levels. No student chose “not at all confident” as confidence rating. 37% of students chose B). The confidence of students choosing B) was quite high, but lower than for the correct response C).

These results coincide with the results from the AS1001 exam in 2010: almost all students were able to calculate correctly the difference in equilibrium temperatures at Earth’s perihelion and aphelion (the points nearest and furthest away from the Sun on its elliptical orbit), 4K for a difference in distance of 5 million km. In contradiction to this, 9 of 46 students (19.6%) stated in the exam that the seasons are caused by the hemispheres alternately being closer to the Sun, with all but one of these students getting full marks or almost full marks on the previous calculation.

How can one explain these results? Comins[10] argues that over-generalisation of a general principle based on our everyday experience may be an underlying cause: in this case, the principle would be that the closer we are to a heat source, the more heat we feel. This would agree with the level 1 results that pre-instruction, 54% of students state that Mercury is the hottest planet, not Venus.

When asked about common properties of all known Solar System satellites, post-instruction 32% of level 1 to 3 students combined (81 students in total) state ‘they are smaller than the smallest planet’ (Ganymede is larger than Mercury), 20% state ‘they are practically spherical’ (e.g., Mars’ satellites aren’t), and 9% state ‘they have no atmosphere’ (Titan does). Here, the underlying cause may be the overgeneralisation of the properties of our Moon. Another underlying principle may be the belief in permanence of celestial objects: In a question on comet properties, pre-instruction only 31% of level 1 students agreed with the statement “Comets disintegrate after 100 to 200 passages close to the Sun” (2008/09 and 2009/10 data combined). Post-instruction, this number rose to 79%.

Discussion and outlook

Our results show that some misconceptions in astronomy persist to higher levels, and are not easily corrected. They also illustrate the importance of stressing conceptual understanding in astronomy instruction, and getting students to relate results of calculations to astronomy concepts.

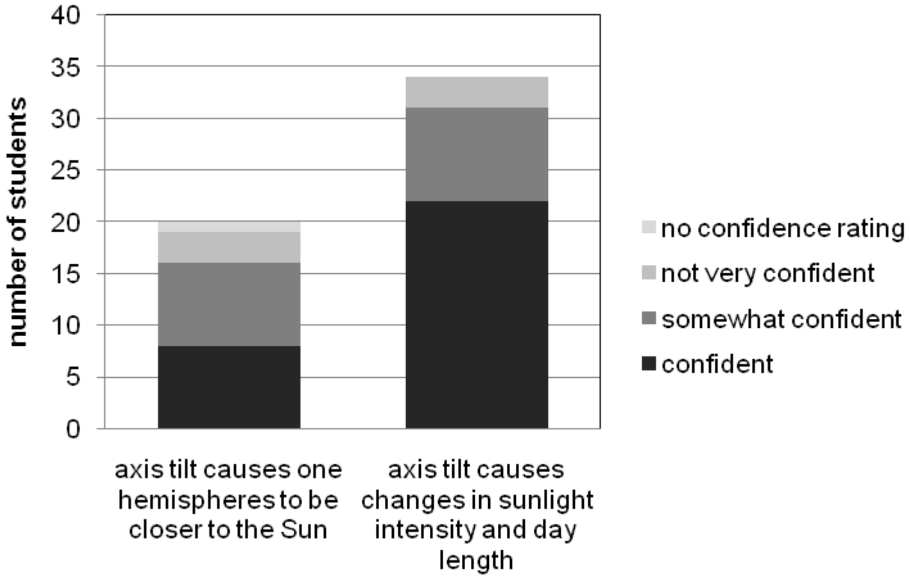

Figure 2: The figure shows the responses and confidence ratings to the question “Which of the following predominantly causes the seasons on Earth?” (see text for full details of choices) for students taking astronomy modules in levels 1 to 3. The data include 22 level 1, 17 level 2 and 15 level 3 students.

We found that the distribution of responses to the ACS questions was similar across the levels, and that the increase in average score with increasing level was only modest. This may be due to the fact that higher-level astronomy courses do not stress the concepts tested in the ACS in detail.

Limitations of this work are relatively small student numbers, lack of free text explanations of reasoning or student interviews to uncover underlying reasons for incorrect choices, and the fact that this investigation was only carried out at a single institution. Knowing students' astronomy misconceptions can only be a first step in the ultimate aim of helping students to come to a correct understanding of the nature of the Universe. Future work includes extending this study to other institutions, gaining more insight into underlying reasons for misconceptions in astronomy, and developing and evaluating course material to target specific misconceptions.

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> It would seem that misconceptions need to be explicitly challenged in order for students to overcome them, in particular when these prior beliefs are deep-rooted in everyday experience.

Closing the feedback loop for clicker questions

Simon Bates* and
Keith Brunton
School of Physics and
Astronomy
University of Edinburgh
Edinburgh
EH9 3JZ
***s.p.bates@ed.ac.uk**

Abstract

We describe the output from a recently-funded JISC Learning and Teaching Innovation Grant: Electronic Voting Analysis and Feedback for all (EVAF4All). We have created a web-based software tool (EVAF) that allows electronic voting system data captured at the point of delivery in lectures, to be fed back to students, thus providing valuable formative feedback of their progress over what can be a large number of such questions. In institutions where 'loanership' models of handset distribution are used (typically, when students keep the same handset for a whole course or year) this is particularly powerful as it can supply students with their own data as well as the aggregate data from the rest of the cohort. Academic staff can use the tool to evaluate the effectiveness of their clicker questions as an aide to course monitoring or development processes. We briefly cover the technical aspects of the system we have built and also present a case study of its use in an introductory Physics course taught at the University of Edinburgh.

EVS background and motivation

The use of electronic voting systems (EVS) in taught classes, as an aid to interactive engagement and rapid feedback to students is now well-established within many disciplines in Higher Education. Comprehensive resources provide detailed information on the technology, pedagogy and various use scenarios of these handsets[1-3]. In the UK, the original JISCmail mailing list for EVS adopters has broadened and expanded to an online community exploring all forms of classroom technology to engage students[4]. Textbook publishers now routinely provide extensive electronic bundles of ‘concept tests’ with new titles or revised editions, a name for EVS questions coined in Eric Mazur’s 1997 seminal text on peer instruction[5].

We have created a web-based software tool (EVAF) that allows electronic voting system data captured at the point of delivery in lectures, to be fed back to students, thus providing valuable formative feedback of their progress over what can be a large number of such questions.

We have been using EVS in introductory Physics courses in Edinburgh for the past 6 years, developing our questions and methodology of use during this time. The technique has been widely adopted throughout Schools in Science and Engineering and deployment of handsets to practically all first year students is organised by our library. Students receive a handset at the start of the Semester and retain this for the duration of their course, returning it at the end of the Semester or academic year to the library, just as they would with borrowed textbooks. This mapping, matching a given student to a particular handset, is a key feature that we have exploited in the design of the online system described in this communication.

Our motivation for this project was to try and make use of the huge amount of data that was collected at the point of question delivery, usually in lectures, over a given course. In our first year Physics course we typically pose between 50 and 80 questions during the Semester-long programme of 30 lectures. In a class of 300 students, this represents an enormous volume of data that usually languishes on the laptops of the various staff who lecture on the course. This data would have value to both students and staff if it could be presented in a readily-digestible format, without unreasonable effort by busy academic staff. The data could provide students with detailed personalised feedback on their own performance on the range of EVS questions, together with the aggregate whole-class data. Staff would be able to use anonymous aggregated class data for question development, course monitoring and review. EVS software provided by handset vendors certainly does permit *some* of this functionality, but it tends to be focussed on staff evaluation of questions rather than provision of feedback to students. Whilst some of this software does integrate with ‘gradebook’ functionality in major Virtual Learning Environment (VLE) systems the maintenance of class lists and rosters within the EVS software is by-hand and time consuming for large classes.

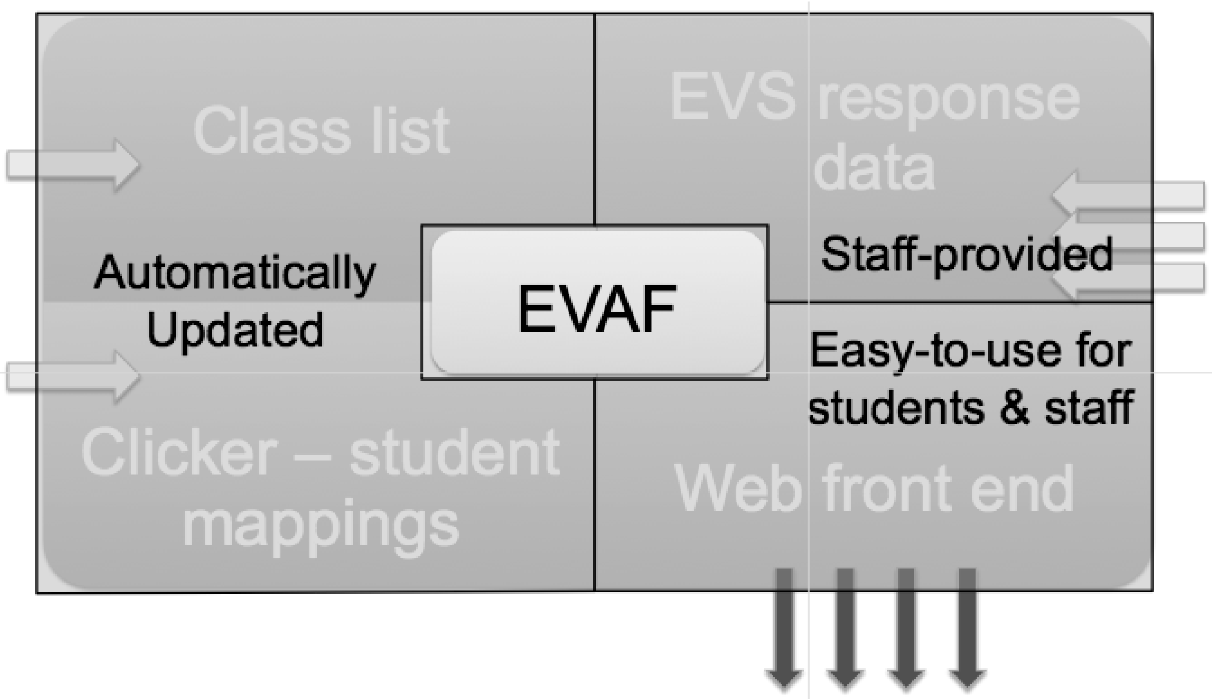


Figure 1: Schematic map of components and functionality in the EVAF software system.

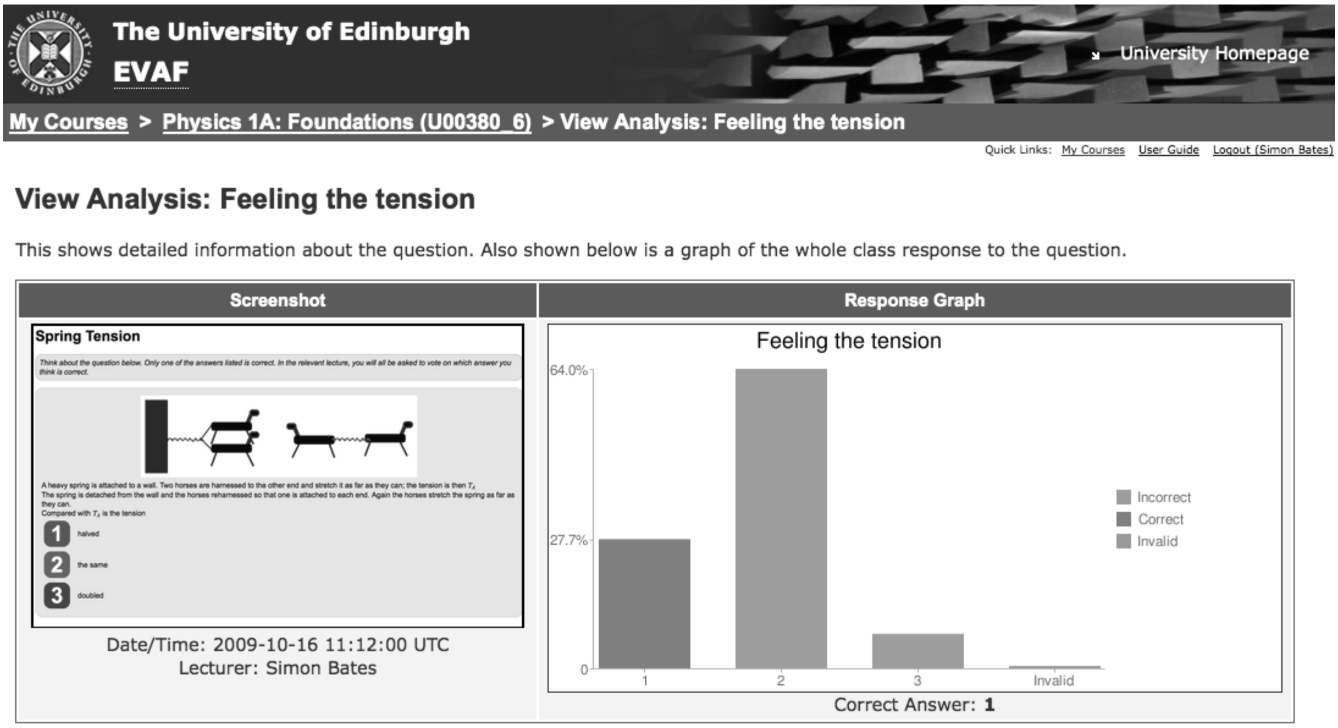
We bid to the JISC 'Learning and Teaching Innovation Grant' scheme in 2008[6], to build an online system to make it easy to return this data to staff and students which was capable of working at other institutions by interfacing with their authentication systems and VLEs. The project was funded and ran for one year during 2009. This communication presents a brief overview of the system architecture and how it has been used in our first year Physics course in the 2009-10 academic session. Much more detailed documentation and access to the software developed during the project is available from the project homepage[7].

Architecture of the system
There are three components to the EVAF software: the most visible front-end software functionality, the 'connector' functionality and deployment/configuration aspects that allow the software to be installed and integrated to another institution. Here, we focus on the first two of these and Figure 1 schematically illustrates these components in the software. EVAF necessarily requires other behind-the-scenes information sources besides the voting data uploads: this is illustrated on the two left hand blocks of Figure 1. The class list of students on a particular course and clicker-student mappings form the basis of the information needed to identify individual students on a course with a given handset. These can be automatically updated from the VLE and loanership scheme records, respectively, or can be managed via manual uploading of .csv files. An automated feed of class list data is particularly useful at the start of large courses, as there is inevitably traffic into and out of the course after it has commenced. Within the year's duration of the project, we successfully implemented connectivity modules to one of the main EVS software export formats (e-Instruction) and the WebCT VLE platform. The system's modular software design is such that it can be extended to interact with different VLEs (though this is problematic for some VLEs) and import EVS data from different software. Additionally, EVAF has the capacity to use local authentication mechanisms for login of staff and students.

The other main data ingredient needed by EVAF is illustrated in the upper left hand block of Figure 1: the EVS response data provided by staff after collection during teaching sessions. It is a simple form-based upload screen, with the system trying to 'guess' sensible values for various fields based on what is read in from the files. It was neither practical nor desirable to try and automate this step completely; some staff even within a given course may prefer to use their own laptop or the lecture theatre fixed PC to collect data. To build in a specific data upload location would have been overly prescriptive here.

The most important part of the system is the web interface through which students and staff of an institution can review questions posed and votes that were cast during lectures using EVS. Staff across multiple courses can upload their saved voting data so that students can view, analyse and reflect on how they voted in lecture in the context of the rest of the class. Staff can view aggregated data, review efficacy of questions and add screenshots or comments to questions. EVAF has granular use and course management allowing staff to work in teams and encouraging colleagues to share findings and good practice. Context sensitive help is also provided, tailored according to role (student, staff, administrator etc).

Figure 2 shows the staff view of a typical question stored within EVAF. The screenshot on the left is a clickable link which expands to provide the viewer with a clear view of the question that was posed. (For staff who utilise EVS software



View Analysis: Feeling the tension

This shows detailed information about the question. Also shown below is a graph of the whole class response to the question.

Spring Tension

Think about the question below. Only one of the answers listed is correct. In the relevant lecture, you will all be asked to vote on which answer you think is correct.

A heavy spring is attached to a wall. Two horses are harnessed to the other end and stretch it as far as they can; the tension is then T_A
The spring is detached from the wall and the horses reharnessed so that one is attached to each end. Again the horses stretch the spring as far as they can.
Compared with T_A is the tension

1 halved
2 the same
3 doubled

Date/Time: 2009-10-16 11:12:00 UTC
Lecturer: Simon Bates

Correct Answer: **1**

Figure 2: Screenshot of the staff view of an EVS question and response set stored within EVAF.

integrated with PowerPoint, these question screenshots are captured automatically at the point of question delivery). The right hand panel shows the whole class response data. The student view of this page is similar, with the addition of an arrow to indicate the response chosen by that particular student (together with a tick or cross if it is correct or incorrect).

Other useful features of the software include a full-text search facility, a ‘leaderboard’ option to show the clicker ids (not student ids!) of those with the most questions correct and a question filter feature. This last option comprises built-in filters for questions which are deemed ‘easy’ (>75% of the class answering correctly), ‘hard’ (<40% correct) and ‘tricky’ (most popular answer is not correct). Rather than present endless screenshots, we have prepared a short screencast that highlights many of the features of the system[9].
EVAF is written primarily in the Ruby language and the popular Ruby-on-Rails platform[8] which allowed for the agile development of features and functionality. The EVAF front-end does not require the use of any browser plugins. Other technologies used include SQL, XML (Web Services) and some freely available software & JavaScript APIs for components such as graphs (Google Chart API) and image manipulation (ImageMagick). Relevant Web standards have been kept in mind during development.

Implementation and use in Physics 1A
'Physics 1A: Foundations' is a first-year first-Semester course in classical Physics, taken by approximately 300 undergraduate students each year. It is compulsory for all students reading towards Physics degrees (these typically comprise half the cohort) and also available as an elective option for students on other degree programmes (chiefly, but not exclusively science degrees). The course enrols students with a wide range of previous study of the subject, ranging from one year's study post Standard Grade (Scottish Higher) to A-levels and an increasing number of International Baccalaureate (IB) candidates. This range of diverse background (in terms of both aptitude and prior study) coupled with the nature of the material (familiar, yet often counter-intuitive aspects of Newtonian mechanics) makes for its own particular set of challenges instructing a very heterogeneous class cohort.

The course has a long history of a blended learning approach, with an e-learning component designed to supplement (not supplant) the face to face teaching activities, which goes back over a decade. The course has been using the pedagogy associated with EVS handsets for approximately the same length of time. Initially, these questions were introduced and voted on with coloured cards with the switch to voting handsets taking place 6 years ago. There are three lecturers teaching on the course, aided by workshop demonstrators, technical and administrative support staff.

EVAF was not introduced to the students until around week 4 of an 11 week teaching semester. This is the first semester of (most) students' first year at University and there is plenty of information that students are bombarded with at the start of the course (and doubtless in other courses they are taking too). Experience shows that things have settled down after approximately 3 weeks of the course, and additionally a useful number of EVS questions have already been covered in lectures. At the end of the 3rd week of lectures, EVAF is shown to the students at the start of a lecture as 'the place where all the clicker data goes' and students are shown how to access the tool from the course homepage on the VLE. At the start of the 4th week of lectures, the course lecturer demonstrates how to view real data captured in the previous lecture and explains the sorts of things that students can do with it.

The tool is linked not only from the course homepage on the VLE, but also linked through the online content sections that are the EVS questions. (It is possible to link *directly* to individual question datasets in EVAF, however the option we have used is to include a 'top level' link to the course page for EVAF that can then be drilled down into individual questions). Course staff have already made use of EVAF to evaluate student performance on various questions, with a view to development of future questions or replacement of questions.

Google analytics was used to track site visitors to EVAF from the Physics 1A course. There were 650 visits to the site during the course, averaging between 10 and 35 visits most weekdays. Usage tended to tail off towards the end of the course, but persisted beyond the cessation of teaching and into the examination period in December. Visitors spent on average a few minutes on the site during each visit and approximately half the traffic on the site was returning visitors. One aspect that seemed to capture the imagination of the students was the introduction of a 'leaderboard' feature on the site: there was a competition run with a small prize for the student who answered the highest percentage of correct answers. This was clearly quite motivating for the stronger students in the class. The commenting functionality of the site (where students could comment on particular questions) rather like a discussion board thread was not used.

In the light of this modest but encouraging uptake, the course team are considering future plans for the use of the system in the course next year. At present, EVS questions are used in a single mode of delivery: asking questions in lectures. We are experimenting with and considering other methods of use, such as building 'consolidation' or review exercises on the EVS questions into the tutorial workshop sessions for the course, and also the use of student generated content (EVS questions) within the course.

Acknowledgements
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Recording of lectures

Graham Wightman
School of Contemporary Sciences
University of Abertay
Dundee
DD1 1HG
g.wightman@abertay.ac.uk

Abstract
In recent years there has been an increase in the number of students wanting to record lectures. Two factors have contributed to this. Firstly, there is wide availability of compact, solid state recorders, and recorders are often incorporated into other goods (MP3 players, mobile phones, cameras, laptops). Secondly, within many universities facilities have been provided by student support services for students with a special need to record lectures.

However, the recording of lectures presents a number of issues related to ownership, data protection, potential misuse, and the pedagogic issue of ensuring equal treatment for all students. University recording policies address some of these issues, but the individual academic also needs to reflect on the consequences for their teaching.

A trial has been carried out offering streamed recordings of lectures, and the merits of streaming and downloading are discussed. A survey was made on the usage by students and their reasons for accessing the recordings, and these are reported. There have been a number of advantages to students as well as to the lecturer which have required relatively little extra burden on the lecturer. One important initial conclusion appears to be the need to incorporate recordings as part of the teaching material in the initial pedagogic design rather than an addition. For some students the recordings have proved a valuable additional resource and feedback from students has been positive.

Audio recording of lectures by students or staff is increasing, and the availability of facilities for recording and of portable audio equipment for playback can make this an attractive prospect.

Introduction

Audio recording of lectures by students or staff is increasing, and the availability of facilities for recording and of portable audio equipment for playback can make this an attractive prospect. There are, however, a number of considerations that need to be addressed before embarking on an exercise to make lectures available in audio format. This paper discusses some of these and presents some evidence of their benefit to students. The role of recording can be extended to video recording, preparation of support materials for tutorials or revision and verbal feedback. However, this discussion focuses on recording live lectures since audio recording require little additional input from staff yet provide a useful extra resource for students.

Issues for Consideration

The recording of lectures presents some serious ethical and legal issues. The intention in allowing special-need students to record lectures is to provide lecture material in a form that is a reasonable adjustment (SENDA 2001)[1]. However, in doing so it could be argued that we are disadvantaging students without a special need, since they have only a single opportunity to hear the lecture. This issue is not unique to recording, and is a pedagogic issue that has to be addressed with care. Making a recording that is available to all students can benefit certain learning styles as well as those with disabilities. In fact the Higher Education Academy (HEA)[2] recommends audio recording as a tool to aid international students. A web search will show other examples of students wanting to record lectures[3], or of manufacturers advocating their product for this purpose[4].

From the point of view of the academic (and of the university) there is the question of copyright of material. Academic contracts usually clarify ownership of materials produced for teaching purpose. However, in the case of recordings of a live lecture the issue may be complicated by the ownership of the original live ‘performance’ and ownership of the ‘recording’. With current computing and internet facilities, it is very easy for recorded lecture material to be copied and made widely available. From a technical point of view, a student could even record the whole of their degree course and publish it and the institution or academic would then have to pursue action for any consequential loss. In these circumstances ownership of the recording may depend on whether the recording was made with or without permission, and what permissions were given for use of the recording. Most institutions now have a recording policy clarifying these issues and the main power is as a deterrent against misuse, but the onus would be on the institution or the academic to take action on any infringement.

Data protection is another aspect of recording. Again, contracts for staff will clarify what an institution expects from their employees, but students are in a different position. Whilst students normally sign a global waiver of some of their data protection rights (e.g. to allow for publication of graduation results) this waiver may not cover their rights if asking a question in class, and distribution of a recording where the voice of a student is also recorded might contravene this aspect of the law. Recording policies usually require a class to be informed when a recording is being made, but this could mean that the student's only option is not to ask the question unless the academic pauses the recording.

From an academic's point of view there may be a fear of the lecturer being replaced by a recording. On the other hand, offering additional resources can enhance a lecturer's reputation as a good teacher. A second concern in making recordings available is that it might mean a drop in class attendance. However, a counter-argument could be made that properly integrating recordings into the pedagogic design might improve engagement and hence increase attendance. Studies that have been carried out with video recordings of lectures (e.g. [5-7]) suggest that the effect on attendance is small, and similar results were observed in this present study.

A final aspect of recordings is their use, or misuse, for purposes not originally intended. Comments made by a lecturer could be taken out of context and broadcast maliciously (for example, a comment originally intended to provoke a student response). Video clips of school teachers have been circulated on You-Tube and other similar sites, and in May 2008 there was concern over a lecturer recorded advising students to fill in a questionnaire in order (allegedly) to bias the result. No-one would condone inappropriate action by staff, but should an audio recording originally made for one purpose be used as a tool to bring about disciplinary or legal action, particularly if the recording itself was made illicitly? There is clearly an ethical issue in the use of a recording and whilst the Data Protection Act may give some protection to staff, there is a possible grey area.

In summary, the issues that need to be addressed before considering recording lectures are:

- Equal treatment of all students.
- Ownership and copyright of content.
- Staff perceptions.
- Data protection for students.
- Misuse of recordings, or phrases taken out of context.

Recording Policies

In view of these concerns many institutions have a recording policy and some examples can be found in the references [8-10]. These may allow any student to make recordings, but are more frequently concerned with special-needs students. Permission is usually granted for personal use within a limited time frame, provided prior agreement is obtained from all present (both staff and students). However, special-needs students can usually obtain a permission that overrules the need to obtain prior agreement, provided that everyone present is informed that a recording is being made. The onus is normally on the academic to inform the class that a recording is being made, but this can present confidentiality issues with the disability, if not correctly handled.

A policy makes clear to students the limits of acceptable behaviour. However, its main strength is as a deterrent against misuse by making it clear what action could be taken if a breach is incurred. In practice, applying these sanctions after serious misuse would probably be ineffective.

A Trial in Recording Lectures

Although I had tried experimenting with a tape recording of lectures in the late 90's, my experience of recordings by students began in sessions 2006-7 and 2007-8 when a small number of students with dyslexia asked to make recordings. In 2006-7 one person asked to record a single lecture, but in 2007-8 three students asked about recording a lecture series, and initially this meant three separate recorders being worn or placed on the desk. Subsequently two of these students decided to record from their own desk. During this lecture series it became unclear whether other students were taking advantage of recording and were also using other recording devices without permission. The class were reminded of the university recording policy, but it still remained unclear whether recordings were being made.

The current generation of students has grown up in an environment where recording is not seen as particularly immoral, and CDs are copied and files downloaded with little concern over copyright.

One alternative is to produce a single official recording. Abertay's Information Services were keen to support and encourage academic staff to use technology in support of teaching, so a trial of audio recording was carried out.

Initial Objectives and Potential Pitfalls

There were several reasons why I thought audio recordings of live lectures might offer potential benefits:

- An official recording allows some control in the use of the product rather than students producing their own (multiple) versions.
- There is value in **all** students having the opportunity to listen again for revision purposes.
- Sometimes students miss a lecture for valid reasons, and a recording could be beneficial in catching up on missed material.
- Recording might allow supplements to lectures, for example: provision of study material to cover the absence of the lecturer, and additional explanations if the original lecture required it.

I did, however, have some reservations:

- Would recordings increase the workload, or conversely would they reduce the need for academic staff?
- Ownership of the recording if students were able to download the sound file.
- Would the availability of recordings deter student attendance?

It soon became apparent that a recording is not a substitute for the original. There is a debate in the literature[5-7] on the value of recordings for students (mainly referring to audio-visual recording), but there appears to be consensus that recordings are not an adequate replacement for personal tuition. The audio recording is primarily a medium for transferring information but the majority of students still need to reflect on this information and will require additional support in order to convert it into knowledge that they can apply.

The issue of the additional workload proved to be a pleasant surprise and little extra time was involved. Initially Information Services provided support to download, edit and stream the files. Later on downloading and any editing were done by the lecturer. After careful consideration it was decided that ownership and availability would best be controlled by allowing the recordings to be accessed only as streamed files.

The decision to use streamed files rather than downloadable files raises a major consideration over access, since it restricts student ability to listen to the recording at a pc. A podcast in MP3 or WAV format, on the other hand, could be listened to anywhere. Streaming therefore gives some control over use and ownership of the recording (whilst a secondary recording could still be made from a streamed file by a student, it is more difficult and lower quality). However, there is also an important educational benefit: to listen to a streamed recording the student has to make a deliberate effort and set aside time and is therefore more likely to concentrate on the content. With a podcast the student may have the recording on in the background whilst undertaking other activities (multitasking) and not fully concentrate on the lecture. It also means that if a student misses a lecture they still have to set aside an hour to make it up - a recording is not an easy option to replace attendance at the lecture.

Practical Aspects
An Olympus digital voice recorder with clip-on microphone was used and provided adequate recordings on the low quality setting. The unit was portable and simple to use and the only requirement was remembering to switch on and off! This particular recorder did, however, require special software to download files. The class was warned at the start of each lecture that recording was about to begin. One benefit of a clip-on microphone is that it will not easily pick up student questions, thus minimising data protection issues. However, it does mean that it is necessary to repeat the question for the benefit of listeners to the recording

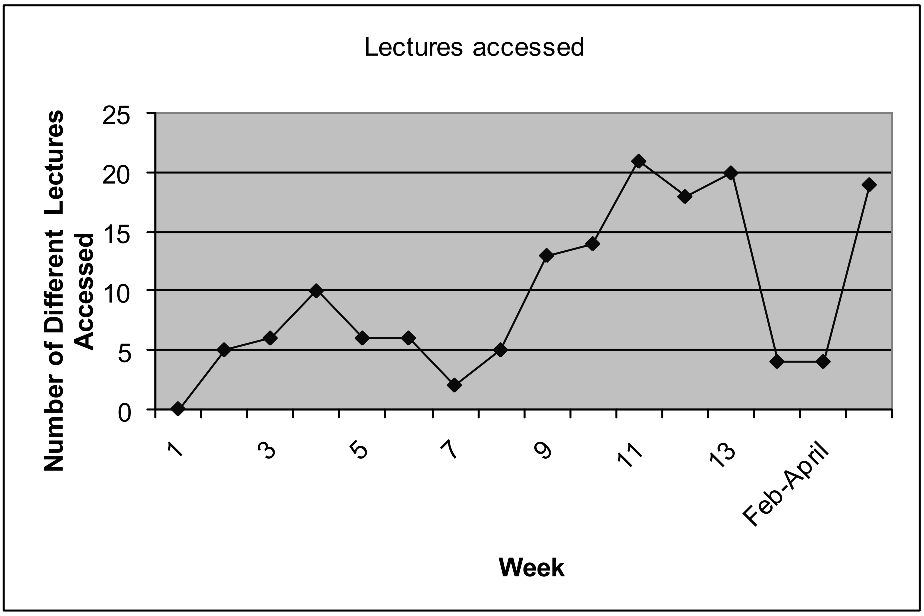

Figure 1: Accessions to the recording each week, Year 2 module.(Delay in streaming occurred weeks 5-7. Exam is week 13 and resit exam in August).

Editing was done using Audacity open-source freeware. Limited editing only was carried out to tidy up the start and finish, and to remove silences when students are writing. Some students, however, said they preferred the periods of silence to allow them time to consider what they had heard and to relate it to the PowerPoint slide, suggesting that for some students synthesis was taking place during their listening as they integrated information. Occasionally an irrelevant aside has been removed, but the editing was not essential and raw recordings have been made available. Summary notes could be scripted and recorded for revision purposes, but would take more time to prepare and is another area for future investigation. Recording live lectures minimises the input required and retains the naturalness of personal tuition.

Streamed recordings can be accessed at any point in the recording so a student can select part of a lecture if they wish. One minor limitation of streamed recordings is the inability to vary the speed. Audio files can often be speeded up electronically by software that compresses the sound into shorter intervals, thus avoiding any change in pitch. This was briefly investigated, but my personal perception was that, whilst listening to speeded up versions of lectures did reduce the listening time it became difficult to assimilate the information once the speed was increased by 50%, and this would reduce an hour's lecture by only 20 minutes. Whilst this might be attractive for revision purposes, it is an area that would need further investigation.

When streaming files, consideration needs to be given to the distribution platform. Initially access was via hyperlinks but this presented problems for some students depending on their browser settings. The use of WebCT or Blackboard as a platform overcame this problem and gave the facility to see how frequently the files were used.

Perceived Benefits

The first benefit was actually an unexpected one. Listening to myself on a recording I became aware of mannerisms that the students were only too aware of! It has required a conscious effort to try and improve my delivery style, and this has been beneficial.

Students have used the recordings. Initially numbers were not high, but those who accessed the files were positive about the benefits, and the trial was continued and extended.

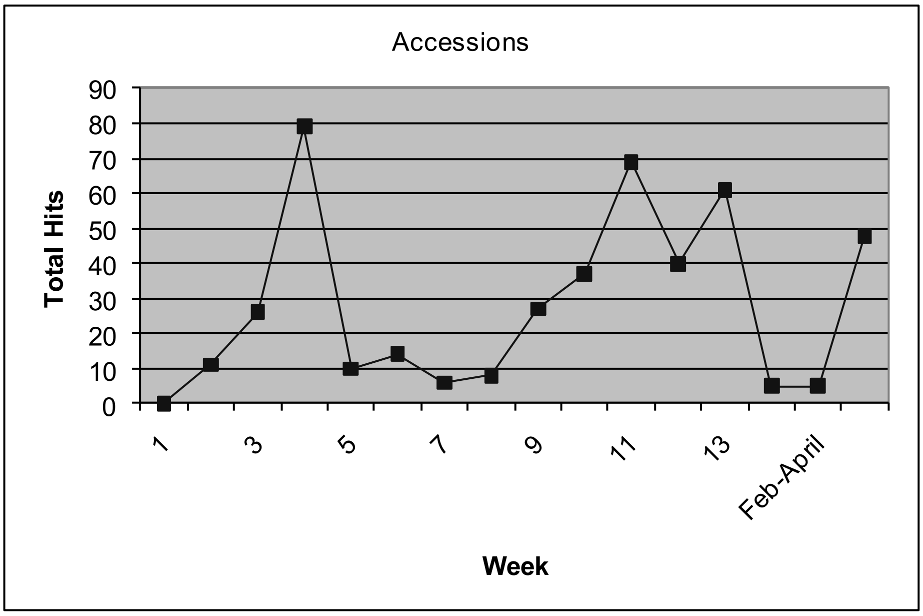

Figure 2: Range of lectures accessed each week.

Observations on student use are discussed in more detail in the next section.

The library of recordings is a resource that students can be referred to if they require additional help.

The recordings have been used by absent students as well as students with disabilities, and a range of students have accessed them for revision purposes.

The recording can be used to check exactly what was said on a particular topic, by both staff and by students. This has been beneficial when students have sought verbal clarification of assessments.

The ability to edit the files before transmission is a benefit where an area is lacking in clarity, or something was said that could be misunderstood. So far the only limited editing has been necessary. The delivery of one lecture had to be truncated, and it was possible to record a summary of additional points that had not been covered.

Usage

Initially the trial was limited to one part of a module, and access to the recordings was on request and was therefore not straight forward. Despite this, 20% of the cohort persevered, and their anecdotal evidence on the benefits was encouraging.

In the extended trial all lectures were made available covering part of a first year module, the whole of a second year module, and parts of a third and a fourth year module. In all cases access was through WebCT and recordings were usually available within a week, although for one three week period there was a delay in availability and this had an effect on usage. It needs to be recognised that accessing the link does not necessarily mean the whole, or even part, of the lecture was listened to. However, students repeatedly accessed the files, suggesting they were listening to them.

Level 4 students barely referred to the recordings until they started revision for exams (4 hits during the lecture period, with an additional 30 hits prior to exams, from a cohort of 30 out of a sequence of 7 lectures). This trend was also reflected in their use of other on-line support material. A similar effect was observed on two third year modules taught by multiple staff (23 hits during lectures with 17 further hits during revision for a cohort of 44 and 12 lectures, and 10 hits during lectures and 68 during revision for a cohort of 44 and 14 lectures). In both cases students accessed pre-lab PowerPoint presentations and material in support of coursework (50% hit rate). This suggests that access through technology is not the limiting factor, but their perception of the benefit of the recordings may be. Use for revision purposes does seem to be attractive. The first year module again is part of a multiple-taught module and 113 hits were made from a cohort of 82 students and 7 lectures. (In this module there was no examination so no differentiation in use has been made).

Table 1: Ratio of total hits to cohort numbers and lecture numbers.

Cohort	Total Hits	Number of Lectures	Number in cohort	Ratio
Year 4	34	7	30	16.2%
Year 3	40	12	44	7.5%
Year 3	78	14	44	12.6%
Year 2	449	31	62	23.4%
Year 1	113	7	82	19.7%

The second year module was taught by a single lecturer. Out of a cohort of 62, and 31 lectures a total of 449 hits were made. 8 recordings received over 10 hits during the first 6 weeks, with two recordings (the introduction to the module and a lab feedback/prelab tutorial) receiving 28 and 32 hits. However, usage declined during the 3 week period when there was a delay in uploading recordings, as seen in Figure 1. Figure 2 shows that about 66% of the recordings were being accessed in the three week period prior to the exam and the period prior to the resit. 16 students had over 10 hits each (and 3 students had over 30 hits) whilst 21 students had no hit or a single hit. Students with multiple hits are more likely to have listened to at least part of the recording whereas a single hit may mean only one item was of interest, or it may mean the student listened but decided the resource was not helpful to them. An analysis of hits and absences also showed that students were using this as a resource to make good missed lectures. The use of recordings was plotted against attendance and against module grade and these graphs showed that use was made both by students who attended regularly and students with poor attendance. Similarly some students who obtained good grades made extensive use of this additional resource and some weaker students also appreciated the additional support. Likewise, there was a spread of non-users across all attendees and all abilities. It therefore appears that the resource is of potential benefit to all students and it is a personal choice whether to use it.

I had wondered whether first and second year students may be more inclined to use additional web-based support resources than later year students: level 3 and level 4 students should be accessing their own support resources and consequently may prefer to look at other sources rather than listening again to the lecture. The ratio (hits/(students x lectures)) is shown in Table 1. This ratio indicates the uptake and if every student accessed each lecture once, it would give a value of 100%. However, the ratio does not take into account multiple uses by the same student, nor does it differentiate use during revision periods. Table 1 does show a higher ratio for year 1 and 2. The level 2 cohort had the highest ratio (23.4%) and in this module WebCT was used extensively as a source of support material and students had to download and submit practical worksheets each week, and it is thought that this integration and familiarity has increased the use of recordings. The decline in usage due to the three week delay in uploading recordings (Figure 1) may also add support for familiarity of access being important, but further work is needed to confirm this.

Student Feedback

Initial feedback from students was via verbal comments and was always positive. However, students may be less likely to comment adversely to a member of staff so two surveys were carried out. One cohort had a WebCT quiz that contributed part of their assessment portfolio and survey questions were appended to this to ensure a high response rate. Another cohort undertook a paper survey of the module which included questions about the recordings. Table 2 shows numeric data

Table 2: Survey results Year 2.

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
Having recordings of lectures available is useful?	13	23	11	2	1
Streamed files were more useful than MP3 files because it made me set aside time to listen?	1	5	29	12	3
I did not use the recordings because they were streamed but I would have done if they had been available for download?	6	8	28	7	1
I accessed recordings	>10 times: 3	5-10 times: 7	2-5 times: 21	Once: 9	No access: 10

Table 3: Students' comments.

What did you use recordings for? (WebCT survey)

Checking on something that I didn't hear in the class
Taking additional notes, going over something I didn't understand in class
Missed lecture catch up, when the sheets were unclear you could hear Dr W explaining it
I haven't used them yet but I will during my revision
To check a missing piece of information
Recapping the lecture, remind myself what some of the slide diagrams meant
For additional material which was not in lecture notes, to recap on what was said, sometimes its easier to understand the lecture notes

Were the recordings a helpful resource? (Paper survey)

I didn't use them but I like that they were there and you can use them to supplement your learning
Yes, they help explain parts of the notes that were more complicated
Very useful. Only problem I encountered was that outside the university it wasn't easy to access them
Very useful. More lecturers should do this
Definitely – anything extra is helpful
The recordings were helpful, but not a substitute for the actual lectures
I found them extremely helpful as I could listen to them in my own time and play back the important parts
I was at the lectures so didn't see a need to use them but I knew they were there if I needed to go over any lectures again

on student attitudes, whilst Table 3 presents some of their comments. Over 70% agreed the recordings were useful and only 6% disagreed. Two opposing questions on the use of podcasts or streamed files suggest a slight preference for podcast, with 55-60% being neutral. There were no negative comments apart from some students saying they had not needed to use them, and a comment about accessibility off-site.

Conclusions and Future Work

The study shows that students will use audio recordings of live lectures and they find them to be beneficial. Data shows that uptake is typically 10-20% of the potential student-listenings (number of students times number of recordings), with a higher uptake in earlier years and when recordings are integrated into a supportive platform. Although this may seem a low return, very little effort was required to achieve this. Furthermore, not every student will want to listen to every recording.

There are issues to be considered with respect to recordings but a single source recording has benefits for control of distribution and editing. There are merits and disadvantages to both streaming and to podcasts, and whilst there is a slight preference for podcasts, there appears to be no strong preference amongst students thus allowing the lecturer freedom to choose what they consider most appropriate. Recording live lectures can require little additional effort by the academic.

Audio recording can find wider application, for example preparation of pre-lab materials, tutorial preparation, revision aids, and verbal feedback. These will require additional input compared with a live lecture, and therefore a prior evaluation should be made of alternatives such as video recording. However, audio recording has potential due to the ease of distribution and accessibility.

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There are merits and disadvantages to both streaming and to podcasts, and whilst there is a slight preference for podcasts, there appears to be no strong preference amongst students thus allowing the lecturer freedom to choose what they consider most appropriate.

Towards sustainable public engagement (outreach)

Timothy G Harrison and
Dudley E Shallcross*
Bristol ChemLabS
School of Chemistry
Bristol University
BS8 1TS
***d.e.shallcross@bris.ac.uk**

Abstract

There are myriad benefits to science departments that have a public engagement in science portfolio in addition to any recruitment of new undergraduates. These benefits are discussed in this paper and include: improving congruence between A level and first year undergraduate courses, training in science communication and the breaking down of barriers between the public and universities. All activity requires investment of personnel and incurs a financial cost. Small scale activities may be able to absorb this cost, but ultimately as the portfolio grows this will become an increasing drain on resources. Bristol ChemLabS Outreach has, from the very start, set out to be fully sustainable financially and in terms of personnel. A very important component is the full support of the senior management team. In this paper we discuss how we have achieved this.

Introduction

There are many studies that demonstrate the importance of public engagement in science to schools and adults[1,2,3,4] highlighting the importance of breaking down barriers between scientists and the public and promoting positive attitudes[5]even increasing them[6] . These activities can also impart the latest information accurately and not via a third party, allowing the public to ask questions. Such activities may have a positive impact on students' achievements in science[7,8,9].The engagement with science can of course take a whole manner of forms, from one extreme, for example reading books to a full-blown hands-on event. It is also a good opportunity for scientists to become aware of general misconceptions in understanding that may be present and to refine their communication skills[10]. Recruitment is often cited as an important reason for conducting outreach (to schools at least) but there are many other benefits that far outweigh an increase in applications[11,12,13,14].

With the endorsement of the senior management team... it was agreed that Outreach to schools in particular was something that a Chemistry Department such as Bristol's should be doing to raise the profile of Chemistry regardless of its short and long term impact on its own recruitment.

Outreach is at the core of the Bristol ChemLabS project (starting in 2005) and has carried on from a successful program that had been in place for five years previously. With the endorsement of the senior management team in the School of Chemistry at Bristol in 2000 it was agreed that outreach to schools in particular was something that a Chemistry Department such as Bristol's should be doing to raise the profile of chemistry regardless of its short and long term impact on its own recruitment. Indeed, in 2000 the School of Chemistry was already receiving as many applications from students in the local area that one would predict as a maximum based on A level grades and progression rates for A level chemists to a degree in chemistry (about 10%). During the previous five years a network of chemistry teachers had been built up called CHeMneT (<www.chemlabs.bris.ac.uk/outreach/chemnet/> April 2010) who advised the Schools' Liaison Officer on what events and activities to run and when to run them and, provided feedback on ways to improve these events. A key aspect of the outreach activity once the CETL was established was the appointment of a full-time School Teacher Fellow (STF) to work alongside the School's Liaison Officer (now called the Outreach Director). The role and impact of the STF are detailed in previous papers[11,15]. The impact of the STF has been enormous[10,12,16,17,18,19] and the School of Chemistry now engages directly with over 30,000 people a year. The CETL funding is a finite sum of money for five years. How can we sustain such an activity beyond the life of the CETL? In the rest of this paper we outline some of the perceived barriers to outreach from both a University and School perspective and offer solutions to both, as well as suggesting how to make the operation sustainable in the long term, both in terms of personnel and finances, whether there is a full-time school teacher fellow or not.

Current barriers to outreach: a University perspective

- A major barrier is the Senior Management Teams' (SMT) perception of the value of the activity. Many view such activities as an added extra and not part of the 'core business' of the department.
- Promotion is often cited as a reason for not engaging in outreach in many departments. Institutes' promotion and academic progression in general is linked to research activity and teaching; rarely is it linked specifically to public engagement. Therefore, not only is outreach a distraction from research and career progression; it is also often viewed as a distraction for postgraduates and postdoctoral researchers.
- The cost in terms of technical and secretarial staff as well as postgraduate and postdoctoral students can mount up and there is the risk of equipment breakages and general wear and tear. Raising funds for outreach activities can be difficult, especially raising small amounts of money.
- There is a latent fear that once the doors are opened to schools the department will be overwhelmed with requests from them.
- Not knowing what will go down well with schools is a barrier; it is terrible to put on an event that is inappropriate.
- To alleviate the previous problem it is advisable to make contact with school teachers, but this can be difficult. Phoning teachers is a lottery; several days can go by before one hits that perfect time when they are free to answer a call. E-mailing is also a lottery unless one has the relevant teacher's correct, frequently used, e-mail address. Contacting a head of science or headteacher either in writing, by phone or e-mail may appear to be a black hole as well. Once one contacts the teacher, finding a suitable event and pitching it at the right level takes time and effort.
- There appear to be no obvious benefits to 'local' outreach in terms of recruitment or research, apart from a little PR and perhaps a press cutting or two.
- Some believe there is no market for these interactions and therefore it is not worth engaging in them.

Current barriers to outreach: a School perspective

- Costs can be a barrier to many activities. These costs may include the cost of substitute (cover) teachers, travel and the charge for the event itself. Curiously, the cost of organising the event or, indeed, the 'overtime' costs of the teachers that may work outside of their normal hours are never calculated.
- The cramped curriculum demands may limit the outreach opportunity to one per school year per subject, if at all (unless it is for sports, drama or music).
- The difficulty of contacting a University. Many university websites are intractable. A teacher looking for outreach events or simply the name of the correct person to contact about such matters, may spend a long time trawling through a website and still come up empty handed. Such information should be made highly visible on the front page of any department website.
- Given the huge volume of paperwork such as health and safety (possibly including the requesting of risk assessments), contacting parents/carers, obtaining payments and permission slips, altering school meal numbers, hiring coaches or minibuses required for an event, whether on site or at a university or other venue, the organising teacher must be sure that this time and trouble would be well worth it.
- This leads directly to timing. The advertising period for an event is usually too short. Schools need to have plenty of time to organise the relevant paperwork and to communicate with families and other colleagues. Therefore, it is preferable to give a term's notice i.e. 6-8 weeks.
- Distances to travel can be a barrier. Some areas of the UK are not located conveniently close to a university that either has a chemistry (or relevant science) department or a department that is engaged in outreach activities.
- Headteacher's or Senior Leadership Team's (SLTs) value of such events may not be the same as the subject teacher or coordinator. This may be because they have no understanding of the educational value to students because they are not science trained themselves.

Solutions to these barriers

University

First it should be noted that the UK Higher Education Funding Councils, RCUK and the Wellcome Trust have established Beacons for Public Engagement in the last two years (see <www.rcuk.ac.uk/sis/beacons.htm>, 2008). RCUK are keen that public engagement and research go hand in hand, so it may well be a more telling factor in obtaining research grants in the future, rather than the standard paragraph on dissemination that appears in most proposals today. Indeed, impact plans are now common requirements for RCUK grants and some element of public engagement is expected. In the USA, dissemination to the public is a non-negligible component for obtaining grants. Therefore, demonstration of outreach may become a necessary part of a research grant, where it will then most certainly become part of any SMT's agenda.

Second, we have noted in previous papers the many benefits of outreach activities to a science department (see previous references in this paper) in terms of establishing links with secondary school teachers and their input into teaching, particularly in first year courses. Teachers can advise on a wide range of issues, such as laboratory skills and the general congruence between A level and the first year of a degree[20]. The benefits to lecturers, postgraduates and postdoctoral researchers have also been discussed and will not be repeated in detail here. Leshner[21] emphasises the very real need to train postgraduates and postdoctoral researchers in science communication.

The issue of promotion is a difficult one. At Bristol University and in other institutes a variety of career pathways has been established that recognises the importance of research, teaching and public engagement. However, the authors have found themselves invited to a variety of countries to present outreach activities and to train others to do the same. On many occasions these outreach activities are based at local Universities and in every instance we have been invited to give research lectures. Following on from these lectures we have been invited to present plenary or keynote lectures at conferences. In several instances important research collaborations have been established on the back of public engagement, an unforeseen and positive impact of public engagement. In the UK it has brought us into contact with a completely different set of academics and here too synergies in research have emerged (in particular cross disciplinary) that would never have occurred through regular research links. Hence, in our experience public engagement has enhanced research activity in ways that could not have been envisaged and that alone can feed back into promotion whatever progression scheme is operated by that institute. In our particular area of research, atmospheric science, working with schools to obtain measurement data has been a particular bonus for both sides.

We will cover the issue of cost for both parties under sustainability. In our experience school teachers are overwhelmed themselves and very wary of bothering academics. Therefore, in the ten years that we have been running an outreach program we have never been overwhelmed in the way many colleagues fear.

It can be hard establishing links with secondary school teachers but this is the key to a successful school outreach program. Working in partnership with school teachers to develop activities is clearly the most sensible way of avoiding a poor engagement activity. Our advice would be to not try telephoning teachers at school. The best ways to establish links are usually face to face. Here are some suggestions:

> Once you have established a few links, either visit the teachers or invite them to your institute for a discussion on possible events and their timings.

- Present yourself at local and national teachers' conferences, for example, local ASE events.
- Link up with your local Science Learning Centre and either ask for a message to be posted to their portal, which will automatically be sent to their school teacher network, or carry out an event at the SLC.
- Science advisors for local authorities are a useful source of information as are local SETPoints, now called STEMPoints.
- Closer to home one can ask all members of your department or faculty to find out the names and contact details of their children's science teachers. Your departmental admission officer will of course have information on schools in the region, but may not have named teachers. Or you can contact your institute's widening participation officer or Undergraduate Ambassador Scheme co-ordinator[22].
- You can try a cold letter drop but don't expect a high hit rate and, particularly for independent schools, it may be worth searching websites.

Once you have established a few links, either visit the teachers or invite them to your institute for a discussion on possible events and their timings. Make this meeting after school hours and if possible reimburse travel costs. It would then be sensible to establish a teaching advisory board (Shallcross et al., 2010) that would meet 2 times a year, involving these teachers and a few academics, to plan outreach activities for the next 3-6 months and also to discuss undergraduate teaching modules in the department with these teachers.

If the Bristol ChemLabS experience is a general one, having established a local network of teachers and outreach activities, it will not be long before outreach activity spreads well beyond your local region[17], particularly if you establish links with the Science Learning Centre networks. The difficulty in establishing contacts with secondary schools may be perceived as an indicator that there is no market: nothing could be further from the truth.

UK Schools

With the freeing up of curriculum time in Key Stage 3 (KS3) and the requirement at KS4 and post 16 to incorporate 'How Science Works' in the latest science GCSE and A levels there is a very strong driver to override the excuse of a cramped curriculum, even with the 'rarely cover' policy. This policy was put in place in 2009 to ensure that teachers 'rarely cover' the classes of colleagues who are absent. However, if the activity has been booked in advance, as suggested, this should include provision for teacher cover and will not be affected by this new policy. It should be noted that this policy was not designed to prevent outside activities but to ensure that teachers are not overloaded with additional teaching; therefore the need for good planning and preparation is essential.

In today's litigious society, properly completed paperwork cannot be avoided. All this takes time and that is why at least a term's notice is required. Risk assessments should be readily available from the University to aid the teacher. It should be normal practice to work through risk assessments with the teacher. This will help to shape the activity.

Distances are a major hindrance to some engagement activities. If the distance is too far for the students to come to the HEI for a day's event it is possible to (a) take a version of the event to the school or (b) provide several overnight events e.g. a summer school or chemistry camp that individual students can access. Taking outreach to the school is a little more limiting in that there is less of a 'wow' factor than a student entering a science department and being able to use the undergraduate teaching labs or sit in a lecture theatre.

Preferably, this engagement uses some postgraduate chemists, not just the academics. The distances can of course be shortened for many if more university science departments provide more outreach opportunities. Experience at Bristol tells us that schools will travel in excess of 2 hours in each direction for the opportunity to engage.

The reluctance of some Headteachers to allow outreach is also a difficult problem. However, if the activities at neighbouring schools are a success then that is the best recommendation. If time permits, discussion with the Headteacher can be a very positive action.

Sustainability

It goes without saying that sustainability involves both people and finances. The key message is do not overload staff or students. Postgraduate students are a vital part of our Outreach Portfolio, particularly in laboratory practical sessions at the University and hands-on science workshops. These students receive training from our local STEMPoint and become Science Ambassadors. We provide additional specific training for the various activities and each Ambassador is paid for all the outreach they do for us. Although there is an initial investment in time, the energy, enthusiasm and new ideas that these students provide, as well as being excellent role models means that academics and technicians need not be doing everything. Schools in particular would prefer to have one event done well than five mediocre ones, and so it is vital to ensure that activity does not outstrip resource. The School of Chemistry appointed a Schools' Liaison Officer in 2000 and that was their administrative job. They did not have additional jobs to do; full support from the SMT is essential.

> It has been our experience that having a range of new people coming into the department has had unforeseen benefits. Many new groups, such as local interest groups now engage with us.

There will of course be major projects from time to time funding outreach such as the Royal Society of Chemistry led Chemistry the Next Generation (C:NTG; <www.rsc.org/pdf/education/aimhigher.pdf> April 2010) and Chemistry for our Future (CFOF)[23], both projects being funded by HEFCE. However, in both cases not all regions in England were supported (including Bristol) with funding and in any case what happens when this money runs out? Does all the outreach come to a halt? There are a number of funders one can apply to e.g. Wellcome Trust, AstraZeneca Science Teaching Trust, local sections of the Royal Society of Chemistry, local sections of the Institute of Physics, and other learned societies. It may also be possible to obtain seed corn funding from within the University (even in the present climate). There are EU calls that may be appropriate for groups that have already established a portfolio of activities.

Outreach provision costs money and time and under full economic costs it is a lot of money. There is no easy solution; it takes time to establish a broad portfolio of income streams. It is instructive to carry out a full economic cost for each activity. You may not charge that amount but you will know what a break-even cost is.

We all know that grant applications take time to write and are not always successful, so how can we make the activity sustainable in the long term? Should charges be made to schools in the first place? It is our standard working practice to charge schools at least a token charge for an event. This has significantly reduced the 'no show' or last minute cancellations. Headteachers, in circumstances where there is a high staff absence would prefer to cancel a free event whereas they think twice about cancelling an event that incurs costs. There is also a higher expectation that an event that costs money has more value than one that is 'free' despite the costs to the provider being the same. Even with a reserve list of schools/students wishing to take part in an activity cancellations usually mean that resources are wasted. Schools pay for a variety of activities, or charge the parents, particularly in areas such as music and drama, so why not science? Having established the quality of the event, charging is possible and leads to financial sustainability, independent of grants.

For schools, there are funding streams for sections of the school community using a crude assessment based on individuals or whole school type and performance that can aid them with internal costs, such as teachers cover. Other sources of funding do exist for schools that will help them to cover the costs of the activity provided. We have constructed a list of potential funders to which schools can apply to obtain funds to engage with university science departments (see <www.chemlabs.bris.ac.uk/outreach/resources/Sources_of_funding.pdf>; April 2010).

There are a range of funds that the school itself can apply for, such as the Royal Society Partnership grant scheme, and we have found considerable success aiding schools in applications to these and other groups. Grants are also available from within the education authorities and child services and from within the schools themselves (gifted and talented, enrichment). Once again, working with schools on developing bids for funding can be extremely successful. Since charging for events we have seen the number of applicants increase not decrease and this has been maintained even in the recent economic downturn. Once a portfolio has been established then one can think about the international dimension and running summer schools for students from overseas.

In the School of Chemistry at Bristol University all RCUK grant applicants are asked to add some of the STFs time onto their grant (up to 5%), just as you would add technician time or computer support time. In this way new grants are supported by public engagement activities and they in turn support on-going outreach. Following extensive discussions with our alumni office, they started to discuss sponsoring our activities with alumni. We now receive donations from alumni specifically to support outreach and this is a growing component of our funding stream. It is great to have alumni come back to the department and want to support the work that goes on to promote science. We have also been fortunate to develop commercial software that also brings in an income stream to support outreach[12].

The general public are very interested in science and we have found that taster days are very popular (garden chemistry, chemistry of food, etc.) and can fill in slots when teaching laboratories are not being used. They can be fun to devise and once trialled and modified are a great way develop relations with the local community. It has been our experience that having a range of new people coming into the department has had unforeseen benefits. Many new groups, such as local interest groups now engage with us. Some have led to additional funding streams, some to useful contacts for new projects but, above all, we have engaged with some enthusiastic and interesting people.

Currently, grants make up less than 20% of our budget for outreach, with the rest coming from direct income from events (~60%), alumni (~10%) and software sales (~10%). Our aim in the next two years is to be independent of grants and to use them to stimulate new project areas only. It is perfectly possible to operate a sustainable outreach activity by charging for events, without driving schools and the general public away. We do have an obligation to communicate with the public and so some activities will of course be free of charge, but a balanced portfolio will include these.

Summary

There are many barriers to engaging in outreach to schools and the public and there is a very real cost in terms of resources and people's time. However, it is perfectly possible to overcome these barriers and to establish a sustainable activity. The most important points are to have a supportive senior management team within your department, to set realistic targets for events, to cost all activities so that you know how much each element costs, and to not be afraid to levy a charge for activities. The long term benefits of a successful public engagement programme are substantial for teaching and research, for training of postgraduates, for raising the profile of the department and institute and bringing a department into contact with a new set of people. In many cases these new people have themselves been extremely beneficial to the department in terms of advice and support.

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> It is great to have alumni come back to the department and want to support the work that goes on to promote science.

First year mechanics taught through modelling in VPython

David Sands
Department of Physical Sciences
University of Hull
Hull
HU6 7RX
d.sands@hull.ac.uk

Abstract

This paper describes a development project carried out in 2008/9 aimed at developing model-based learning in mechanics for a first year physics module. Based on the work in the literature, VPython, the visual extension to the Python programming language, was chosen as the vehicle for developing the models. VPython is ideally suited to modelling mechanics for various reasons, including a class of variables called vectors which have all the properties of vectors in mathematics, the ease with which basic models in VPython can be constructed, and the instant feedback on the operation of the models afforded by their visual nature. Thus the emphasis is much more on the physics and the modelling rather than computation. It is shown how an analysis of students' understanding has revealed that Newton's third law of motion causes difficulties, leading to a greater emphasis on this concept in the modelling for 2009/10. In addition, a greater attention was given to the methods and techniques of modelling, especially spatial reasoning. The evidence for student reasoning in this way is presented.

Introduction

This paper describes the implementation and subsequent development of a first year course in mechanics based around modelling in VPython, the visual extension of the Python programming language. Developed with the help of development project funding from the UK Physical Sciences Centre, the aim was to design an alternative form of instruction which helped overcome the deficiencies in entry-level maths knowledge. It is widely recognised, for example, that, compared with a generation ago, the entry level knowledge of physics undergraduates has declined markedly due to changes in the teaching of both physics and maths in schools. Many students now lack in-depth knowledge of either differential calculus or Newtonian mechanics. In consequence, lectures on topics which draw heavily on mathematical principles, such as electricity and magnetism or mechanics, are hard to follow and hard to grasp. Moreover, even if mathematical knowledge and skills are taught alongside the physics, students are unlikely to be fluent and may find it difficult to transfer this knowledge from the mathematical domain to the physical context. Therefore the aim of this approach is to concentrate on physics concepts themselves through the construction of computer models.

> *Many students now lack in-depth knowledge of either differential calculus or Newtonian mechanics. In consequence, lectures on topics which draw heavily on mathematical principles, such as electricity and magnetism or mechanics, are hard to follow and hard to grasp.*

The methodology is based on the work of both David Hestenes[1], and Ruth Chabay and Bruce Sherwood[2]. Hestenes is a strong advocate of the power of modelling to improve student learning, having previously identified the naive views that physics students often hold about mechanics, are tested by the FCI, or Force Concept Inventory[3]. Chabay and Sherwood have long advocated a computational physics approach based on VPython. Thus Hestenes' work provides the nature and structure of a model and the importance of qualitative reasoning and Chabay and Sherwood's pioneering efforts in computational instruction provide the basis for quantitative modelling. This flow of information from the qualitative to the quantitative appears to be quite general and an important aspect of computational modelling[4].

There is another reason, however, for wanting to combine these two different approaches to modelling: practicality. This course replaced a conventional 20-lecture, mathematically based course on classical, mechanics it was expected to feed into later modules that the students take. It is not possible, therefore, to tear up the curriculum and start afresh, which precludes adopting Hestenes' approach in its entirety. Hestenes[5] advocates the construction, through group discussion, of just a few models related to motion, but in the present work the physics content is largely fixed. It is desirable, however, to move away from conventional lectures. Hestenes has shown that FCI scores correlate with functional understanding of complicated Newtonian concepts and testing of thousands of students post-learning reveals that traditional, lecture-based learning

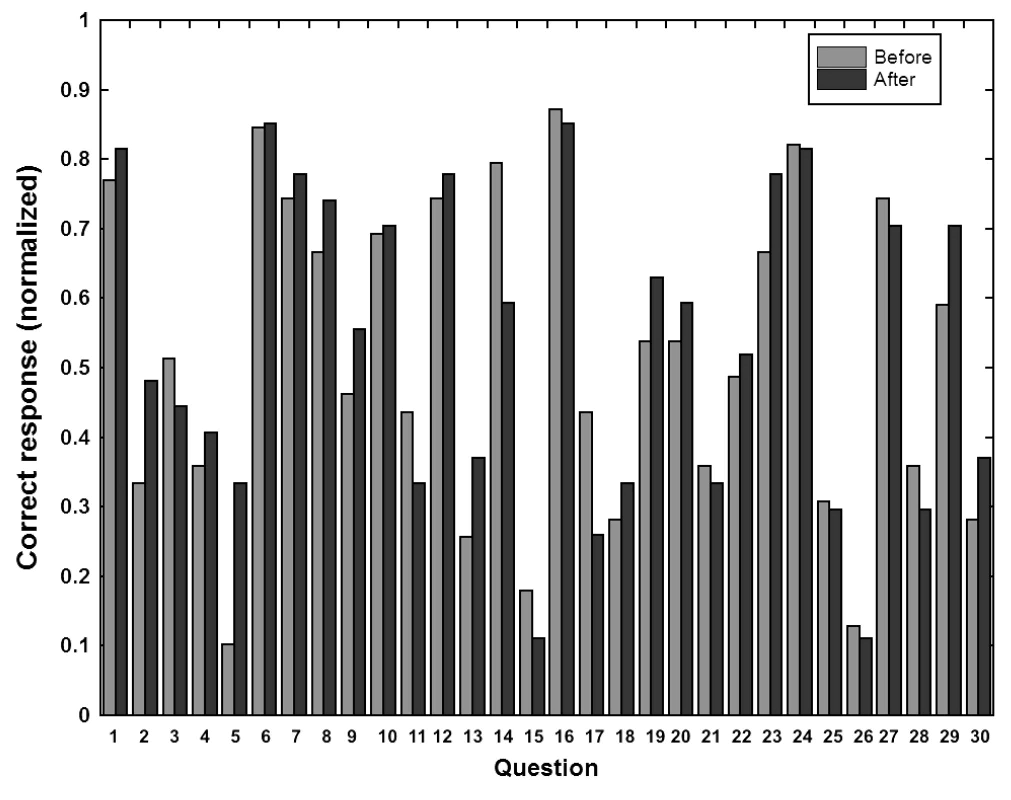


Figure 1: The percentages of correct answers broken down by question in both pre- and post-instruction FCI tests.

yields the least return[6]. Students taught using model-based learning, on the other hand, can use concepts to solve physics problems. This, then, defines the approach taken in this course material is delivered through a combination of lecture, demonstration and modelling exercises in which students reason about a problem and construct models in VPython. It will be shown in the following that whilst course content is important just as much attention has to be given to the modelling methodology and the methods and techniques of problem solving.

The Course

HEA UK Physical Sciences Centre funding was obtained to fund a student to write programmes in VPython over the summer of 2008. These were intended to serve as the basis for a series of visual demonstrations as well as providing a point of reference for students building their own models. The choice of programming language always presents a difficulty. It has been known for some time[7] that huge variations exist in aptitude and attitude towards computing. Conventional languages such as Pascal have been used in physics education[8] but extensive lines of set-up code can be required. Python, on the other hand, is rapidly becoming accepted as an easy-to-use and easy-to-read language for scientific computing[9] and VPython, the visual extension, is ideally suited to the construction of dynamical, vector-based models. Indeed, an essential element of VPython is a class of variables called vectors which have all the properties of vectors in mathematics, including *dot* and *cross* products. In addition, the visual representation, which is rotatable in all dimensions to give an accurate 3-D depiction, provides instant feedback by allowing the student to see instantly whether the physics is sensible and corresponds to experience.

The course was first delivered in 2008 to 51 students in their first year of a physics bachelor's degree over twenty conventional 50-minute lecture slots. The syllabus, exam structure and total contact time were all constrained by the existing programme specification. The delivery consisted of a mixture of demonstrations using VPython models, walk-through exercises, modelling sessions, and PowerPoint presentations to deliver some of the more formal ideas. These included motion under constant acceleration, such as ballistic trajectories, position dependent forces, such as electrostatic or gravitational attraction, and simple harmonic motion (SHM), including damping and forced harmonic motion. All four techniques were fully integrated in the delivery of a class. By way of assessment, students had to construct two models as well as sit a conventional examination in which the questions tested their knowledge of mechanics rather than Python programming. In addition, students had to construct a number of models in class and two models by way of assignment. These last two comprised exercises on ballistic motion and electrostatic forces.

The course was evaluated using the FCI both before and after instruction. A slight improvement in the post-instruction scores is evident, but the improvement is not as large as might have been hoped for. Further analysis revealed a number of possible factors, two of which stand out. First, the FCI measures understanding of Newtonian concepts and does not address learning in vectors or in SHM, both of which were important parts of the course. Second, as shown in Figure 1, the breakdown of FCI scores by question indicates that a significant prior knowledge of some Newtonian concepts already exists and in such a mixed class it is possible that the learning needs of students at both ends of the ability spectrum are not being addressed. It was decided therefore to make changes to the computational aspects of the course work for 2009 to emphasise those areas of mechanics that are clearly lacking. As indicated in Figure 1 by questions 5, 15 and 26, this involves identifying forces using Newton's third law. Two computational exercises were designed around reaction forces and a third on mutual electrostatic repulsion. The use and manipulation of vector quantities integral to these problems so in addition to the pre- and post course testing with the FCI, elements of the Vector Evaluation Test, or VET[10], were also employed.

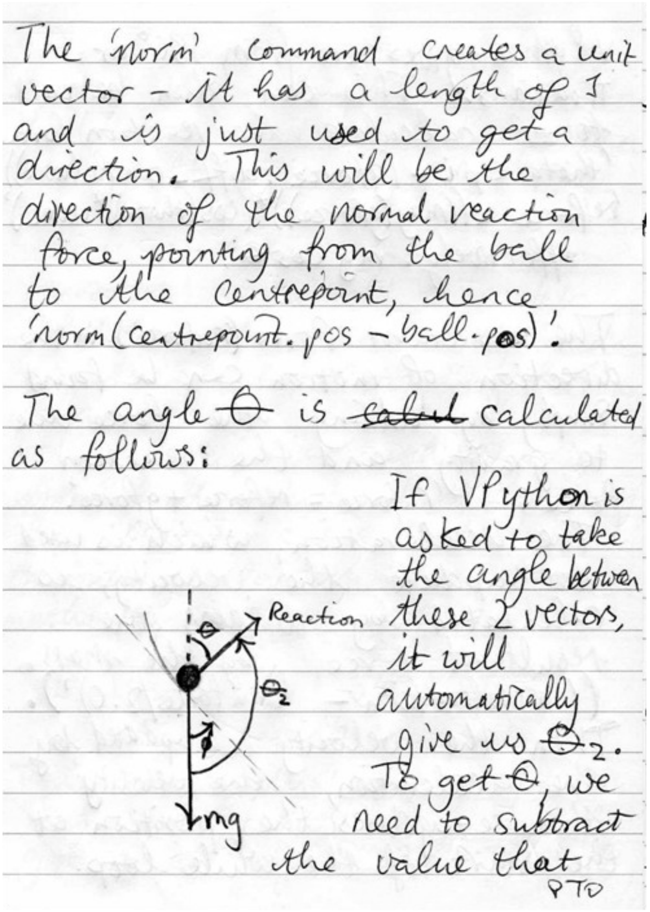
In addition to the above, the problem solving aspects of modelling have been emphasised to a much greater extent. Problem solving is an integral part of modelling, especially computational, as it is necessary first to understand a problem and its solution before constructing a computer model. However, students are neither mature problem solvers nor expert programmers and in response to some of the perceived difficulties support for both of these aspects has been enhanced in 2009/10. First, the formal time spent at the computer was increased to twenty hours and, second, the students were required to keep a diary of their modelling activities. As part of the formal instruction students are shown, by means of a walk-through exercise, how the use of diagrams can aid reasoning and lead to a solution of a problem prior to the generation of a computer model. In a paper co-authored with Tina Overton (this journal) the author has reviewed the literature on problem solving and shown the importance of spatial reasoning, especially the use of representations both to understand the problem and to reason through to a solution. The diary is therefore expected to contain problem representations, qualitative and quantitative reasoning, and information on encoding the problem in VPython.

The Outcome

The course has now run for two years and the outcomes were mainly positive in the first year with further improvements in the second. There was a small, but significant gain in FCI scores and many students like programming in VPython and commented that the course was enjoyable, though some struggled with VPython in the first year. As described above, a number of changes designed to address specific issues were made, including the design of modelling exercises that both emphasise Newton's third law and take advantage of one of the features of VPython, extended computational support through additional class hours, and a greater emphasis on the problem solving aspects of modelling through the use of a diary. In addition, the VET was used for the 2009 class to augment the pre- and post-course testing with the FCI, but at the time of writing a complete analysis of this testing is not available. However, there are indications within the modelling diaries that students have made significant gains in their understanding of vectors. By way of illustration, Figure 2 shows an extract from one of the diaries in which the problem of a mass sliding down a curved slide is addressed. Note that mention is made of a unit vector defined by differences in position (expressed in Python code), and that the diagram is clearly being used to aid the spatial reasoning about angles.

One of the interesting features of this kind of activity-based learning is that it affords an opportunity to observe a class at work in ways that other kinds of instruction do not. There are times during a computational class when students are working away without the need for help and on these occasions it is possible to watch the students at work either on their own or with another, or perhaps even explaining something to another student. A common feature observed in all these classes is the extensive use of hand gestures to depict motion, directions, or spatial relationships. The use of similar gestures using simulations of relative motion has been cited as strong evidence for spatial reasoning[11, 12]. Taken with the diaries and the fact that all but a handful of students out of a class of 60 produced at least one working programme, there is evidence of not only learning in mechanics but also the development of wider problem solving skills. This would not typically be an outcome of a conventional lecture-based course.

It seems reasonable to attribute this success to the requirement to keep a modelling diary. Chabay and Sherwood report that after ten years of activity in introductory computational physics instruction they have not achieved the full educational potential of modelling. A close examination of the work of Kohlmyer[13], a PhD student working with Chabay and Sherwood, reveals a possible reason. Although it was intended that the physics should be emphasised, in fact the emphasis was placed firmly on the computation through the use of problems that were too difficult initially and which had to be altered for subsequent students. In addition, reference to the literature on problem solving tended to concentrate on knowledge structures, by which is meant that a problem based around energy is intended to cue the use of potential energy, kinetic energy or work. It is fair to say that there is little or no reference to qualitative or spatial reasoning or the use of representations. By contrast, this feature of problem solving has been emphasised in the present work and the problems are at a level commensurate with the students' abilities and knowledge. That is not to say that some students did not encounter difficulties with programming. As described by Bishop-Clark[7], enormous personal differences in performance on computer programming tasks exist, and it is clearly an ongoing research issue to try to identify the reasons why some students struggle, but the emphasis on qualitative and spatial reasoning and the production of a diary means that students can still benefit from solving the problem even if a working computer model is not always an outcome.



The 'norm' command creates a unit vector – it has a length of 1 and is just used to get a direction. This will be the direction of the normal reaction force, pointing from the ball to the centrepoint, hence 'norm(centrepoint.pos – ball.pos)'.

The angle θ is ~~calcul~~ calculated as follows:

If VPython is asked to take the angle between these 2 vectors, it will automatically give us θ_2. To get θ, we need to subtract the value that

PTO

Figure 2: A page from a modelling diary illustrating the writer's appreciation of code, unit vectors, and the importance of a diagram (reproduced with permission).

Conclusion

A course in classical mechanics has been designed in which material is presented formally, using VPython models to demonstrate concepts, and students spend time constructing models in VPython. The reasons for choosing VPython over other languages have been discussed. The emphasis throughout has been placed on the physics and modelling rather than on the computation. The models themselves are based on Newton's third law of motion, the concept which the FCI indicates is most lacking in these students and it has been shown how students have been supported in both computation, through the provision of extra contact time, and in their modelling through the use of a diary in which students record their reasoning about the models. Finally, the evidence from both observation and from the diaries points to significant spatial reasoning by the students.

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A common feature observed in all these classes is the extensive use of hand gestures to depict motion, directions, or spatial relationships. The use of similar gestures using simulations of relative motion has been cited as strong evidence for spatial reasoning.

Easing the transition from secondary school to higher education through recognition of the skills of our students

Orla C Kelly
Faculty of Education
University of Plymouth
Drake Circus
Plymouth
PL4 8AA
orla.kelly@plymouth.ac.uk

Odilla E Finlayson
CASTeL
Dublin City University
Dublin 9
Ireland

Abstract

This short communication discusses research, which has investigated students' self-perception of their skills. This was to identify which skills they felt most and least confident in upon starting university. General and scientific and practical skills as well as skills related to improving learning were explored. The results suggested that students felt most confident in working in groups, interacting with people to obtain the necessary information and assistance, and observing chemical events and changes among others. In contrast students felt least confident in planning and presenting an oral presentation, analysing and evaluating experimental data, and using the internet and other resources to gain information. Details of how the findings were used to make effective changes to an existing module will be discussed. Furthermore, the relevance of this in terms of supporting our first year students in their transition to university-level work and subsequently planning appropriate modules will be discussed in relation to the recently published results from the UK Physical Sciences Centre Review of the Student Learning Experience in Chemistry and in light of the Department for Business Innovation and Skills Higher Ambitions and Skills for Growth papers.

Background

It is common practice to have a subject level entry requirement to university courses. In the sciences, it is typical that students have obtained at least a C grade in an appropriate science subject at A-level, as well as a particular number of 'points'. For example, at the University of Plymouth, applicants to the BSc in Environmental Science degree are required to have 240-280 points depending on subject combinations, which have to include a science subject to at least grade C. However, despite ensuring a particular academic level of our entrants to higher education, we rarely audit their skills. This may result in us placing both subject knowledge and skills demands on our students, not least mathematics demands which are recognised as causing learning difficulties for students[2]. In the worst case we may expect them to have particular skills to enable them to make progress with their subject knowledge and understanding, resulting in them making little or no progress, coupled with a feeling of frustration. This is particularly pertinent with the recent shift towards context and problem-based learning approaches to teaching the physical sciences in Higher Education[,], which demand a range of skills from the students to enable them to make progress with their task set. This study aims to: (1) provide insight on what skills our students have upon starting university, drawing from both a small scale study carried out at Dublin City University and published literature, and (2) to consider the implications for our teaching of the physical sciences in Higher Education. A brief review of the current situation of practical work at upper secondary level is needed to provide insights into the students' experiences of practical work prior to starting university.

Current A-level science curricula in the UK offer students various elements of practical work but there is limited opportunity for independent or inquiry-based practical work in the school laboratory.

Current situation of practical work at A-level and Leaving Certificate

Current A-level science curricula in the UK offer students various elements of practical work but there is limited opportunity for independent or inquiry-based practical work in the school laboratory. Furthermore, in a recent study of undergraduate students' experiences of A-level practical work , it was reported that practical work was either conducted to verify theory, or as a vehicle for assessment. Reviewing the Irish chemistry and physics curricula for Leaving Certificate (A-level equivalent)[,], there are a number of experiments that the students are required to do, but again these are in the form of verification experiments or demonstration. With a verification approach the teacher defines the topic to be investigated, relates the investigation to previous work and directs the action of the students, with the students typically following directions from a manual. It is a popular time-, resource- and cost- effective approach allowing large numbers of students to access laboratory techniques and procedures. Verification experiments are not without their critics however. Indeed there has been much

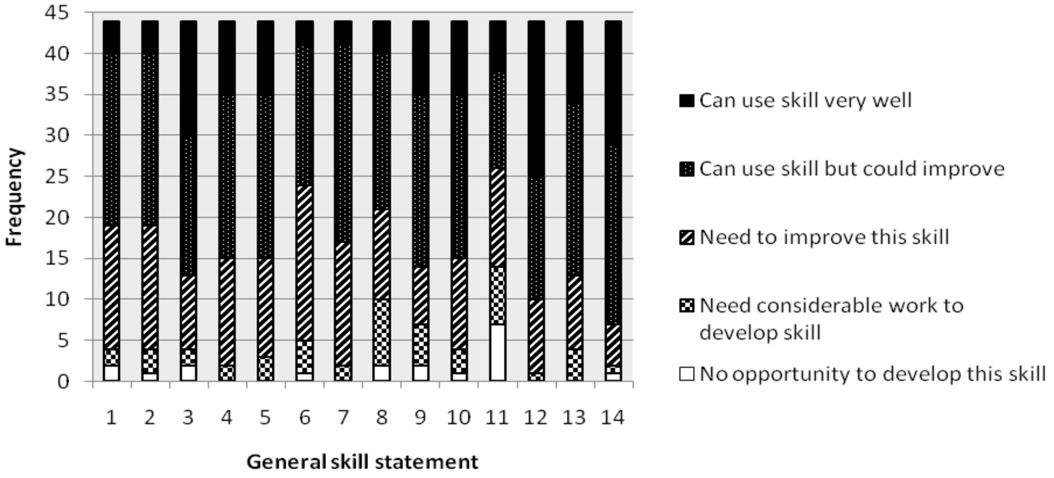

Figure 1: Bar chart of the frequencies of answers to the 14 general skills.

published on the disadvantages of these 'recipe' style laboratory experiments, not least the information overload that is placed on the students. However, evidence from the recent review of the student learning experience in chemistry in Higher Education[2], shows clearly that year 1 and 2 undergraduate students prefer this type of practical work where the expected outcome is known and the procedures are familiar. It is only in Year 4 that 40% of students report a preference for practical work where they do not know the outcome and procedures have to be devised. Does this suggest that independent practical work such as inquiry or problem-based work in Year 1, presents too big a jump considering the experiences that our students bring from secondary school? With such a perceived risk, there must be considerable advantages in these alternative approaches in order for lecturers to adopt them in the early years of their programmes.

Problem-based learning (PBL) in Higher Education

When students are immersed in a PBL environment they are working in groups on problems that demand the acquisition of new knowledge and the use of a range of skills to solve the problems. The contextual element of the problem provides relevance and motivation for the students.

> *Problem based learning (PBL) is a style of learning in which the problems act as the context and driving force for learning. All learning of new knowledge is done within the context of the problems. PBL differs from problem solving in that in PBL the problems are encountered before all the relevant knowledge has been acquired and solving problems results in the acquisition of knowledge and problem-solving skills.*

It is claimed that a PBL approach:

- produces more motivated students;
- develops a deeper understanding of the subject;
- encourages independent and collaborative learning;
- develops higher order cognitive skills;
- develops a range of skills which include problem solving, group working, critical analysis and communication.[2]

Alternative approaches to science education, such as PBL, are also in response to calls for development of transferable and employability skills. The Dearing report as far back as 1997 noted the importance of developing key skills, cognitive skills and subject specific skills in Higher Education. More recently the *Higher Ambitions* and *Skills for Growth* strategies recognise the critical role universities play in equipping people with the skills they need to prosper in a knowledge economy and, that employers in all sectors need graduates with skills for the modern world of work. In particular it is recognised that 'the needs of growing markets like bioscience and low-carbon will require new and higher level skills' (p 4) This focuses the role that we, as science educators, have in preparing our students for the future demands of our society.

Methodology

Considering the demands for 'skilled' graduates and the promised outcomes of PBL, a problem-based approach was introduced to the Year 1 chemistry laboratory module taken by students on the BSc in Science Education at Dublin City University, Ireland. The rationale for development and the students' experience of this module have been previously described'. With the concern over the experiences of our students prior to starting university it was decided to carry out a skills audit of our Year 1 students on starting their university course. Students from the 2002-2003 and 2003-2004 cohorts were asked to complete the skills survey (44 students completed the survey). This was to identify what skills students felt they were confident in using, and which skills the students had little opportunity to develop. The module would then be tailored to enable the students to develop a full range of skills.

The survey was adapted from the RSC's Undergraduate Skills Record (USR). Various skills were identified in the USR which were seen to be important for first year undergraduate students, such as to interpret laboratory measurements and observations and to use feedback to improve on future work. The skills survey asked the students to rate a series of 26 skills on the basis of their confidence in performing each. The students rated their confidence in each of the skills on a scale

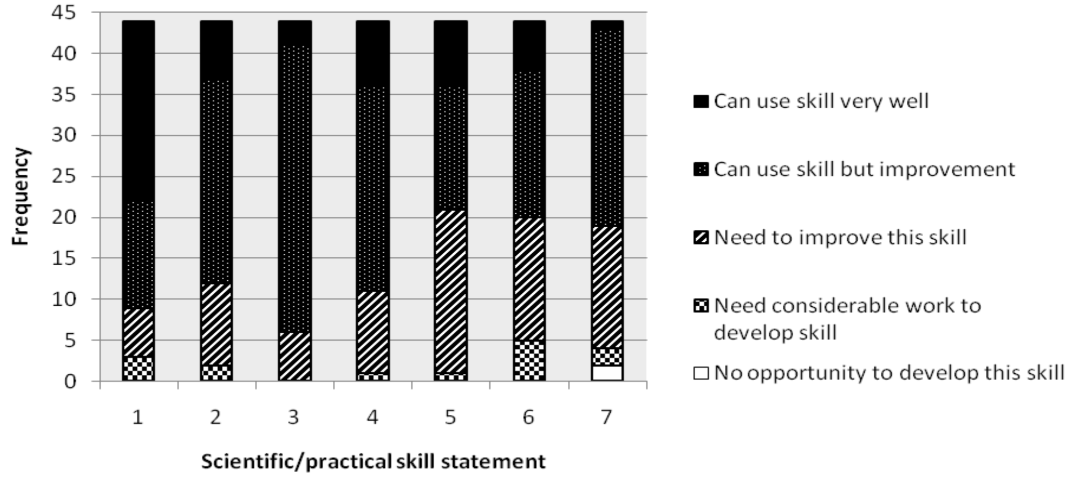

Figure 2: Bar chart of the frequency of answer to the 7 scientific/practical skills.

of 1 to 5; with 1 meaning they have had no opportunity to develop the skill to date and 5 meaning they can use the skill very well. The skills were separated into three key areas:

General skills (14 Statements);
Scientific/Practical skills (7 Statements);
Improving learning (5 Statements).

It is acknowledged and appreciated that this study was carried out in an Irish university, with students who had been through the Irish school system. However, it is hoped that the similarities between the experiences of Leaving Certificate and A-levels physical science students justify implications being drawn for the UK as well as Ireland.

Results

Figure 1 shows a bar chart of the frequencies of each answer for the general skills from the combined data for the two years. It is clear from the chart that students felt that they could apply skill 12 ‘work in groups’ and skill 14 ‘interact with people to obtain the necessary information and assistance’ with confidence. Skill 11 ‘Plan and present an oral presentation’ was identified as the skill that the students have had the least opportunity to develop and felt least confident in, with skill 6 ‘analyse and evaluate experimental data’ and skill 8 ‘interpret chemical information’ respectively scoring second and third lowest.

Figure 2 shows a bar chart of the frequencies of each answer for the scientific and practical skills. In terms of these skills, students identified skill 1 ‘maintain awareness of specific hazards relating to chemicals’ and skill 3 ‘understand the processes involved in experiments’ as their most developed in this category. Students felt least confident in skill 7 ‘select appropriate techniques and procedure’ and skill 6 ‘understand errors’ as shown in Figure 2.

Figure 3 shows a bar chart of the frequencies of each answer for the improving learning skills. Students revealed that they felt most confident in skill 2 ‘maintaining an interest in general science issues’ and least confident in skill 3 ‘using internet and other resources to gain information’ and skill 4 ‘use computers to prepare reports/presentations’.

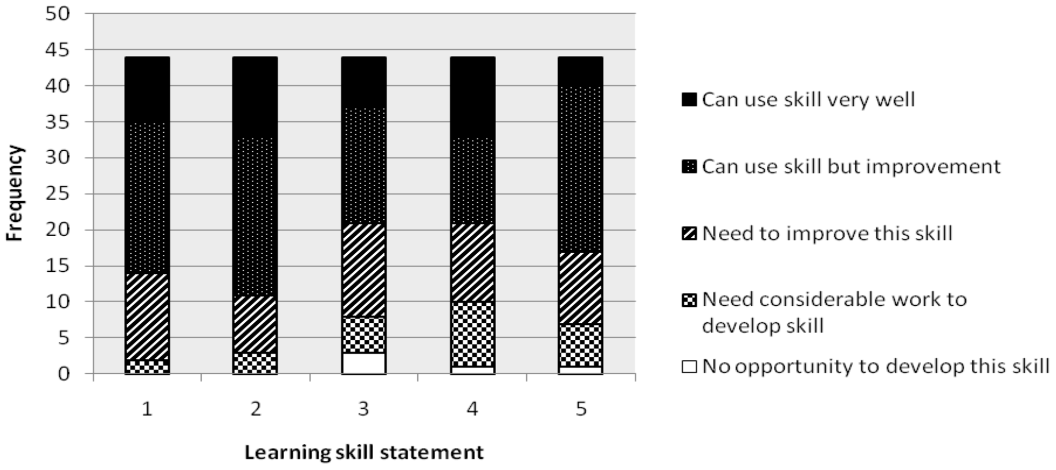

Figure 3: Description of skills to improve learning.

Description of General skills statements

My ability to…

1. Plan ahead and demonstrate good time management.
2. Plan for practical work and project work.
3. Make, organise, and store notes effectively.
4. Make the most of group work, and tutorials to support my understanding.
5. Make the most of practical work to support my understanding.
6. Analyse and evaluate experimental data.
7. Interpret laboratory measurements and observations.
8. Interpret chemical information (i.e. chemical formulas, equations etc.)
9. Maintain good laboratory notes.
10. Provide written reports on time.
11. Plan and present an oral presentation.
12. Work in groups (i.e. contributing in labs.)
13. Assume a range of roles within a group.
14. Interact with people to obtain necessary information and assistance.

Description of Scientific/Practical skills statements

My ability to…

1. Maintain awareness of the specific hazards relating to chemicals.
2. Understand the principles behind experiments.
3. Understand the processes involved in experiments.
4. Measure and observe chemical events and changes.
5. Record experimental data coherently.
6. Understand errors.
7. Select appropriate techniques and procedures for experimental work.

Description of Skills to Improve Learning

My ability to…

1. Use feedback to improve on future work.
2. Maintain an interest in general science issues.
3. Use the internet and other resources to gain information.
4. Use computers to prepare reports/presentations.
5. Apply acquired knowledge to the solution of chemistry problems.

It is worth commenting on the limitations of this skills survey. Firstly, some of the students had limited practical experience, and therefore limited understanding of the statements. Also, it is a self-perception survey and so may not reflect the actual skills of these students. Despite these, it is a useful tool to begin to appreciate the strengths and weaknesses of the cohort's skills. This small-scale study was used to inform the development of the PBL module at Dublin City University, by focusing on tasks that develop particular skills further and build students' confidence in using a range of skills. Examples include incorporating oral (PowerPoint) presentations into the laboratories, and getting students involved with the development of experiments, by researching appropriate techniques and procedures using the internet and other resources. Also, the importance of errors and evaluating experimental data was a key focus of their write-ups and their oral presentations. This was done in a gradual way, increasing the skill demand across the year-long module.

Discussion

The UK Parliamentary Standing Committee on Science and Technology states '… *school science can be so boring it puts young people off science for life. GCSE science students have to cram in so many facts that they have no time to explore interesting ideas, and slog through practical exercises which are completely pointless. This is a disaster: we need to encourage a new generation of young scientists*'[19]. This is exemplified by Abraham's research on motivation and practical work in school science which stated that 'the proportion of pupils, within each year group, who claim to like practical work in an 'absolute' sense, as against simply preferring it to writing, decreases as the pupils progress through the school. Indeed it would seem from the pupils' comments that, within their first year of secondary school, the novelty of being in a laboratory environment appears to wear off and they evidently become disillusioned by the reality of school science (p 2349-50).

This is not a situation unique to the UK. A recent review of school science education in Europe led to a number of recommendations relevant to this discussion, not least that more attempts at innovative curricula and ways of organising the teaching of science that address the issue of low student motivation are required and that the emphasis in science education should be on engaging students with science and scientific phenomena. Evidence suggests this is best achieved through opportunities for extended investigative work and 'hands-on' experimentation[22]. If things change for school level science this should mean that our future science undergraduates will enter our courses with more developed skills. However, in the mean time, it is essential that the skills level of our students is recognised on starting their university degree programme. Moreover, on recognising deficiencies in their skills, we need to give our students experience in developing these areas.

It is interesting that in the recent UK Physical Sciences Centre review[2] it was noted that chemistry teaching staff recognised that '*the weakness in problem-solving ability stems from the difference in teaching methods between schools and universities...universities expect independent learners, whereas school students are teacher-led*' (p 26), yet '*fewer departments than might be expected have a specific strategy to develop the problem-solving abilities of students*' (p 42). Careful planning and consideration are needed to develop skills from within programmes and it should not be assumed that students will naturally do this. Additionally, research by Slaughter and Bates who investigated students attitudes and beliefs found that over the course of the first year of a physics degree programme, students became 'more novice-like in' 11 areas and 'more expert in 2' (p 37). The two areas that students became more expert-like in were both issues that were specifically addressed by the course design. This supports the notion that we must actively seek to develop particular skills and embed support within our programmes and modules.

In summary, we need to continue to push for more innovative curricular in school science, which support the development of skills, acquisition of knowledge and development of understanding and to continue these innovative curricula in higher education. Furthermore, we need to be aware of the skills of our students and provide appropriate experiences for them to develop and expand their skills so they can emerge as graduates with the attributes, attitudes and skills to contribute successfully to the knowledge economy and be responsible citizens with the scientific literacy to engage with the debates that the future will bring.

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Lecture capture: Early lessons learned and experiences shared

Christopher J Andrews,
Richard C Brown,
Charles K W Harrison,
David Read* and
Peter L Roach
School of Chemistry
University of Southampton
Southampton
SO17 1BJ
***d.read@soton.ac.uk**

Abstract

Lecture capture has been on the minds of university level teachers for some time. The ability to record teaching sessions for delivery online has a number of potential impacts, not all of them positive. The technology now exists to make it feasible and relatively affordable to deliver entire lectures online. But should we do it just because we can? This article aims to share our experiences in recording a series of organic chemistry lectures, and the findings of the evaluation that followed.

The rationale behind our approach

Due to timetable constraints, we identified that it would be useful to capture our first semester organic chemistry lectures and make them available to a small group of students (5 out of c. 120) online. Organic chemistry is a very visual subject and, as such, we regarded an audio-only recording as being unfit for purpose, and some sort of video deemed essential[1,2]. The first of the two lecturers on the course in question largely used PowerPoint slides containing images, animations and videos, while the second employed more of a ‘chalk-and-talk’ approach. These differences would require us to be flexible in the way we captured and delivered the lectures to ensure that we would do each teaching style justice.

Techsmith’s Camtasia Studio[3], a relatively inexpensive form of ‘screen capture’ software, has been used previously to support the teaching of chemistry.[4] We concluded that capturing the first lecturer’s PowerPoint presentation directly as a video file would be the optimum way of getting this content into an appropriate form. Audio was recorded onto a voice recorder[5] in conjunction with a tie-clip microphone, and was then synchronised with the video using the consumer editing tool Sony Vegas.[6] Final processing was completed in Camtasia Studio, allowing the addition of captions as and when required. As this particular lecturer is very active in his delivery, we decided that it was also essential to use a camcorder to capture live video and to present this alongside the screen captured material in the video window. An additional benefit was the fact that this would allow us to capture any impromptu board work that one might expect to see in an organic chemistry lecture.

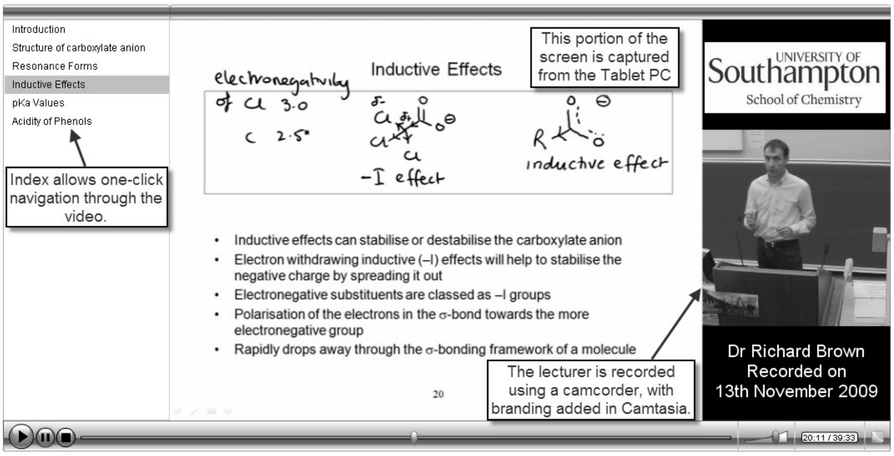
...we found that a number of students had already been recording audio of lectures for their own purposes, and these students in particular were keen to contribute to this work.

In the case of the second lecturer in the series, we decided to use a Tablet PC to annotate notes on the screen directly, rather than trying to capture extensive board work with a camcorder. Using Camtasia, we were able to capture the slides and the lecturer’s annotations in real-time as a video file, similar to the process described in another article in this issue.[7] Once again, we used a camcorder to capture video of the lecturer and to act as a backup in case there were any technical problems with the Tablet PC.

Methodology

We have extensive experience of the recording and processing of video and audio files, and we devised a step-by-step method to put together our final videos. To reduce staff input, we identified students who were able to handle the recording of the lectures, and we found that volunteers were very keen to be involved, particularly when there was a small financial reward on offer. Interestingly, we found that a number of students had already been recording audio of lectures for their own purposes, and these students in particular were keen to contribute to this work. Further details of our methodology will not be discussed here, but more information is available from the corresponding author on request.

Camtasia allows the production of video in a wide range of formats. Camtasia 6 introduced a Flash compatible MP4 format, which appears to offer a combination of good video quality and manageable file sizes. After some experimentation with settings, we settled on a format that produced files which could be delivered from within Blackboard (assuming a robust broadband connection) and were of a suitable quality for teaching purposes. Figure 1 shows the screen layout for the lectures given by the second of the two lecturers.[8]



Inductive Effects

- Inductive effects can stabilise or destabilise the carboxylate anion
- Electron withdrawing inductive (–I) effects will help to stabilise the negative charge by spreading it out
- Electronegative substituents are classed as –I groups
- Polarisation of the electrons in the σ-bond towards the more electronegative group
- Rapidly drops away through the σ-bonding framework of a molecule

Dr Richard Brown
Recorded on
13th November 2009

Index allows one-click navigation through the video.

This portion of the screen is captured from the Tablet PC

The lecturer is recorded using a camcorder, with branding added in Camtasia.

Figure 1: Screen layout.

In terms of evaluation of this project, we had two main goals. The first was to ascertain whether or not captured lectures are considered by students to be an adequate substitute should they be unable to attend the 'real' lecture. Secondly, we wanted to investigate the extent to which students would be willing to view recordings of lectures at which they had been present as part of their revision programme, or to reinforce aspects of their learning. The powerful statistics tracking features of Blackboard gave us insight into usage patterns, while interviews were used to garner detailed feedback from individual students. The findings are outlined in the relevant sections below.

Initial response from students

As mentioned previously, in the first instance these files were made available only to a small group of students who wished to attend another lecture in the same time slot. It happened that this group of students were quite conscientious and we received rapid feedback on the videos and their value. One student was particularly excited, pointing out that she:

> *"…watched the video with textbook in front of me. I paused it whenever there was a new concept so I could look it up in the book, before moving on when I was happy with it."*

This is an interesting point, as it is obviously not possible to pause a 'real' lecture, and there may be genuine pedagogical benefits to this capability. The initial response showed that it was worth the effort to continue recording all of the lectures, and further evaluation is discussed later.

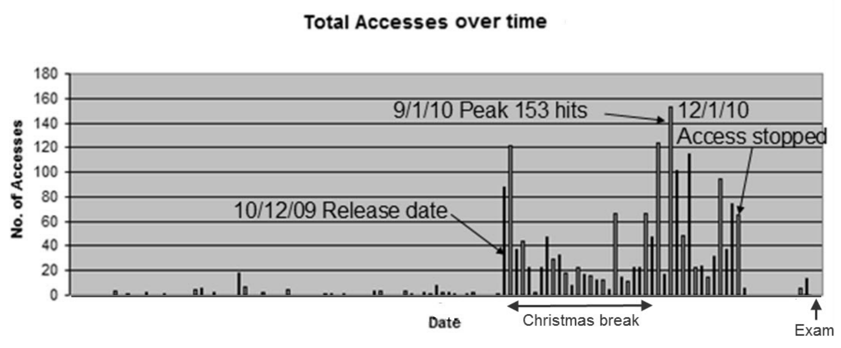


Figure 2: Total accesses over time.

Widening access to the videos

After some discussion, it was decided that the whole series of videos would be made available to the entire year group during the Christmas holiday and the first two weeks after their return to university. The aim was to help them with their revision for the end of semester exams and to give us an opportunity to investigate how students make use of such resources and to get feedback from a larger sample size.

We also experimented with the iPhone compatible video preset available in Camtasia. A survey of our first year showed that 18% of them had either an iPhone or an iPod Touch with similar capabilities. Although this is a small proportion we thought it would be valuable to investigate the extent to which students would take the opportunity to 'learn on the move', as uptake of smart phones certainly appears to be increasing.[9]

The availability of the videos was only announced on the day of the last lecture before Christmas, and this was met with a very positive response from the students. We monitored the usage of the videos over the holiday period using the statistics tracking functionality of Blackboard, and the resulting data was analysed using Excel.

Student usage of the video files

It should be noted that Blackboard statistics only record that a student clicked on the link to the video, meaning that we cannot say for sure what proportion of each video is watched by each student. When processing the data, we noticed that while most students registered only one hit on a given video, some of the students had unrealistically high viewing figures (e.g. 9 hits), and we took the decision to revise the figures to set all positive values on a given day to 1. This gave us information about how many students had viewed each video rather than the total number of hits.

Figure 2 shows the number of students viewing videos over the duration of their availability. It should be remembered that prior to the Christmas break, the videos were available only to the small number of students discussed earlier and this group also had access after the videos were made generally unavailable once again. The heaviest periods of usage were at the start of the holiday and after the students returned to Southampton. Figures 3 and 4 show the numbers of students viewing the captured lectures for each of the two academics. In the case of the first

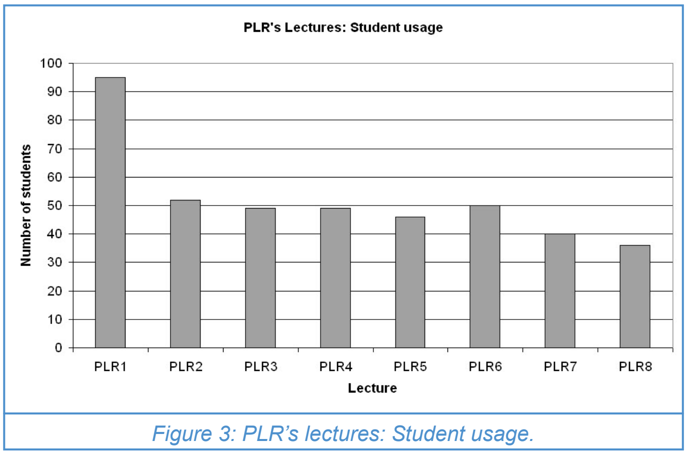


Figure 3: PLR’s lectures: Student usage.

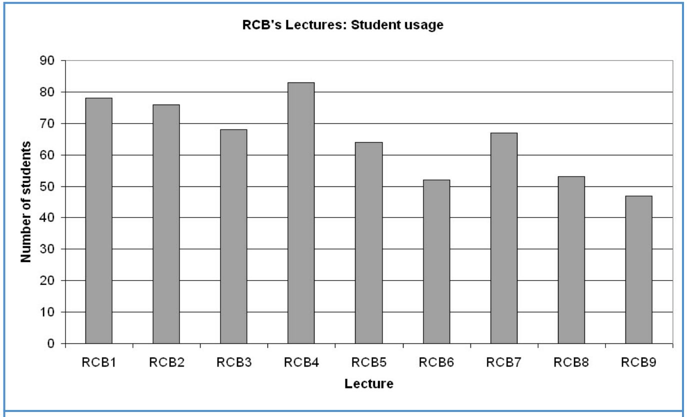


Figure 4: RCB’s lectures: Student usage.

lecturer (Figure 3), there was a decline in the numbers of students viewing the later videos compared with the first one (although viewing numbers were still good), but this trend was less noticeable in the case of the second lecturer (Figure 4). Overall, this suggests that a significant proportion of students found the videos useful and felt inclined to view most of them.

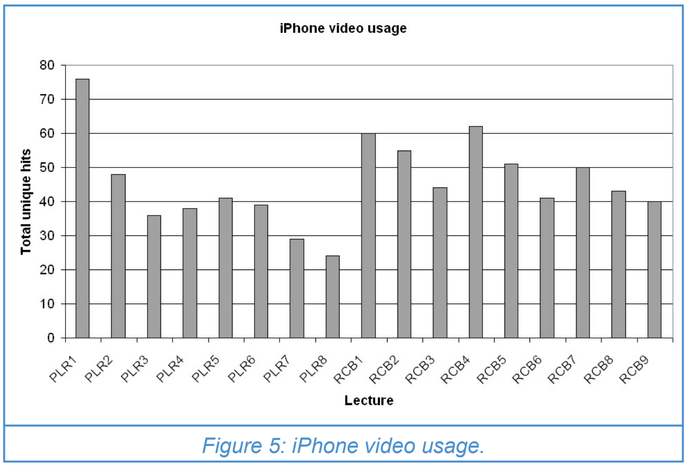


Figure 5: iPhone video usage.

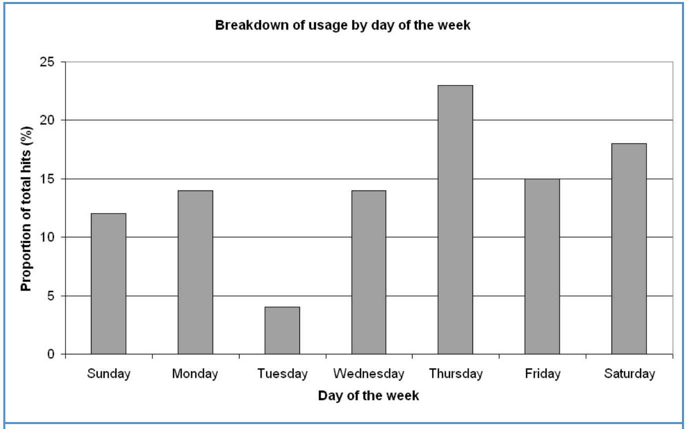


Figure 6: Breakdown of usage by day of the week.

In the case of iPhone video usage (Figure 5), it is worth noting that this format allowed students to download files to store and use on their own device or computer, whereas other versions of the videos were played from within Blackboard and download was not permitted. This partly explains why there are more hits than there are students with an iPhone or iPod touch, as discussed earlier. The video quality at this resolution (480x360 pixels) is not as good as the video delivered from within Blackboard (864x480 pixels), although most text is still readable. The data shows that the number of hits holds up well over the whole series, particularly in the case of the second lecturer.

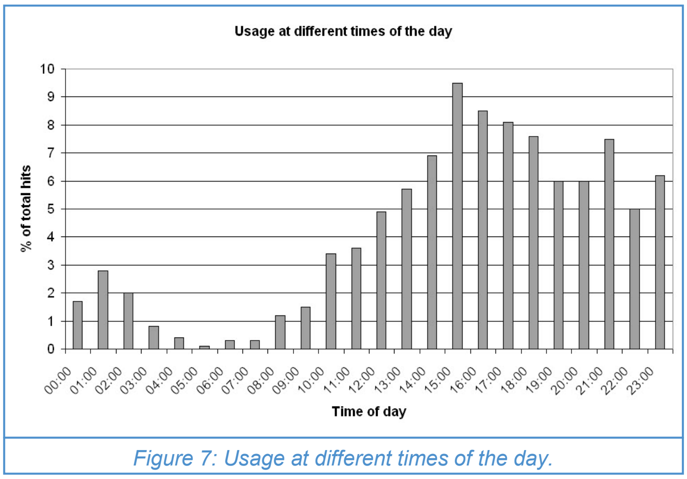


Figure 7: Usage at different times of the day.

The statistics tracking features of Blackboard log the date and the time of day that students are using resources, providing valuable insight into their study habits. The peak day for access was Thursday (Figure 6), although this may have been skewed by the fact that the videos were made generally available for the first time on a Thursday, and the five students who had access throughout the semester invariably watched the videos before the following session on a Friday. The small proportion of views on Tuesdays is hard to explain, and is perhaps somewhat anomalous. Discounting these points, one can see that the usage is fairly consistent over the whole of the week. The data regarding time of day is interesting, showing an upward trend through the daylight hours, with a peak at around 16:00. Usage is then fairly constant until around midnight, with small numbers of students accessing resources in the early hours. A key point to draw from this is the fact that students have made considerable use of this material outside of normal office hours, indicating that such resources have utility in what is becoming more of a ‘24/7’ culture.

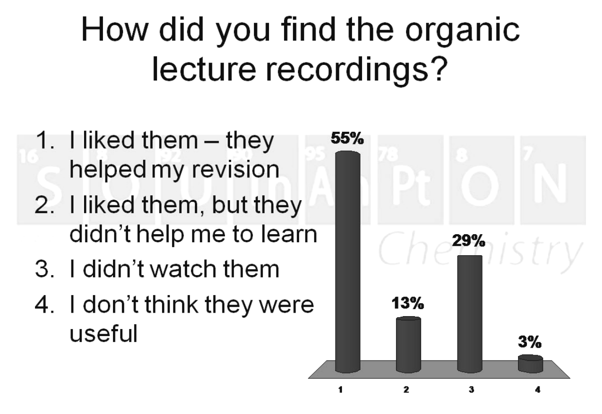


Figure 8: 'How did you find the organic lecture recordings?' - student responses.

Qualitative evaluation

In a routine survey at the end of the semester, we used electronic voting systems[10] to ask the students what they thought of the captured lectures. The data (Figure 8) indicates that a little over two thirds of students watched the videos, which was in agreement with the other data described. A large majority of students who viewed the lectures liked them, with most of this cohort feeling that they were helpful to their revision. Only a small number saw no value in using the resources.

We decided to tap into the student view further by inviting volunteers to a short interview to discuss their experiences. There are limitations involved in using a restricted sample, but we wanted to strike while the iron was hot, and we did not want to pressurise a random selection of students into being during the lead up to their first set of university exams. The interviews were carried out in an informal setting by a final year project student. The five students interviewed had made use of a number of the videos, with three of them being members of the cohort who had access to the videos throughout the study. Key points were:

- Videos were very useful, and key parts were often watched multiple times.
- All agreed that captured lectures are not a substitute for the real thing, but they have great value in helping students to maximise their learning by allowing them to work at their own pace.
- Some students found the layout to be quite 'busy', and the value of having the video of the lecturer was questioned, although this was offset by the fact that this supplementary video allowed the capture of improvised board work.
- Some felt that the ability to download a high resolution version of the videos would be useful as access to the videos through Blackboard was clunky at busy times.
- There were some technical issues regarding the visibility of the cursor, although these are easily fixed using Camtasia.
- Those who had viewed videos on an iPhone or iPod were non-committal about the value of having them in this format. Some had used them 'on the bus' or 'in the café', but it seems that it is preferable to watch the videos on the larger screen of a laptop.

Overall, students were keen for us to develop further our provision in this area, although there was a recognition that a lot of hard work is needed and it is not possible to do this for every lecture course. Although we are not able to comment on the widely-held fears about the impact of lecture capture on attendance, our students indicate that attendance at lectures is more important than watching a video, in agreement with previous studies.[1,2]

Conclusions

Our evaluation of this project has been positive and very encouraging. As discussed above, students who were unable to attend the lectures did find the recordings to be very useful, with the ability to pause and look things up seemingly a genuine pedagogical benefit. Our investigations also show that students do make substantial use of captured material even when they have been in attendance at the 'real' lecture, although it would be interesting to find out if this would be the case outside of a revision period.

> The availability of material at all times of the day fits well with the lifestyle of the modern undergraduate student and may have a positive impact on the value that students extract from their individual private study.

Anecdotal evidence shows that the student view is very positive, but it is not possible to make serious claims about the educational value of such resources without a more controlled investigation. We don't feel that it is valid to compare this year group's exam results with last year's cohort as there are too many uncontrolled variables, but we do feel that a more detailed study would be valuable as there is no doubt that students are keen to supplement their private study with a range of learning resources which exploit developments in technology. The availability of material at all times of the day fits well with the lifestyle of the modern undergraduate student and may have a positive impact on the value that students extract from their individual private study. Furthermore, software such as Camtasia Studio allows the addition of interactive features to video, giving us the opportunity to greatly enhance student learning from online resources. Ultimately, such developments may allow us to provide learning opportunities for our students 'on demand' without necessarily adding to the burden on staff, and further work in this area is essential.

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> All agreed that captured lectures are not a substitute for the real thing, but they have great value in helping students to maximise their learning by allowing them to work at their own pace.

Development of a web-based teaching resource for analytical science practitioners

Mike Batham, Kate Brashaw,
Rob Janes* and Ruth Williams
Department of Chemistry
and Analytical Sciences
and Faculty of Science SWIM
group
The Open University
Walton Hall
Milton Keynes
MK7 6AA
***r.janes@open.ac.uk**

Abstract

This paper describes the production of multimedia teaching material aimed at working analysts in the water industry who are studying the Open University's Foundation Degree in Analytical Sciences. In collaboration with staff at Scottish Water, Edinburgh laboratories, audio and video materials were produced which demonstrate a number of basic laboratory techniques routinely carried out in chemistry and microbiology laboratories. Teaching laboratory techniques (and associated safety procedures) is by its very nature a visual process, and requires the cultivation of a skill base and good practice that can only be gained by repetition. However an initial 'show and tell' stage is required. This is extended to coverage of aspects of laboratory management, and how analysts work in teams to produce analytical data for the customer.

Background

The Department of Chemistry and Analytical Sciences at the Open University is currently working closely with industrial partners to produce a Foundation Degree in Analytical Sciences. Our 30 credit, level 1 work-based learning module (taught entirely on-line) is designed to complement the student's existing practice skills, and develop their understanding of the science underpinning the procedures and equipment used in their professional practice in chemistry and microbiology laboratories.

One outcome of meetings with an advisory group comprising managers and training officers from the analytical sector (specifically from laboratories dealing with water analysis) has been the identification of a need for high quality multimedia material to support the teaching of laboratory techniques in an applied context. This is not to say that excellent teaching material is not available; indeed in this module we include embedded links to Chemical Video Consortium videos[1], and indeed on researching this project, resources such as video and pre-lab material from the Bristol CETL[2], existing OU produced material and the plethora of clips available on YouTube were reviewed. However our feeling was that for the purposes of a work-based learning module such as this, the production of bespoke material, tailored to our target sector was preferable. A further outcome of these meetings was a strong steer in the direction of the most appropriate techniques to cover; in some cases apparatus not generally found in a conventional University teaching laboratory (e.g. a Turbovap for solvent removal) were included. From a practical standpoint, an invitation to use the laboratories of Scottish Water, Edinburgh as a production base was gratefully accepted.

...we In a broader sense, production of this resource forced us to think about what our work -based learning students, really take from a module such as this...

Taking a step back though, the phrase 'in an applied context' in the previous paragraph might appear somewhat trite. However, the ethos of this project was to extend beyond the science and create multimedia material which provided a holistic view of the analytical process, firstly by showing 'real analyses' going on in a 'real laboratory' incorporating some of the generic and transferable skills involved. To this end, two video podcasts were produced which followed two analytical operations from receipt of samples, logging on to LIMS (Laboratory Information Management System), through to completion, i.e. the production of fit for purpose data for the customer. Both integrate aspects of the science, presented in an accessible manner, with details of how these operations are managed, and the important function of team working in the laboratory. To add further value we introduced students to the analysts carrying out the work, giving them the opportunity to talk about their work, in particular how they relate to others in their team, and the necessity for good communication skills. As part of the work based learning module we ask students to reflect on how their own proficiency in these areas can be improved.

In a broader sense, production of this resource forced us to think about what our work-based learning students, really take from a module such as this to develop their own appreciation of laboratory methods. For example, does a student routinely using a balance several times a day, really need us to tell her/him how it should be done? The answer is probably no, but this is something that we are clear about from the start. We appreciate that students will most likely skate through some of the content quite quickly, but we make it clear that although they may be routinely using some of the techniques covered, they may not be using them all and so the material serves to enrich the student’s knowledge. In addition, we ask students to think about how particular operations are carried out in their working environment, whether it be the etiquette involved in using a communal balance or differences between ‘our way’ of carrying out a particular operation with what takes place in the student’s laboratory.

A summary of the content of the resources produced in the laboratories of Scottish Water, is given in the following section.

> ... production of this resource forced us to think about what our work-based learning students, really take from a module such as this to develop their own appreciation of laboratory methods.

Deliverables

i) Video podcast:
Monitoring of Cryptosporidium in Water: this covers a routine procedure for the detection of the oocysts of this pathogenic organism. The process begins with a sample of filtered water from a customer from a pumping station, this is filtered and oocysts are trapped. The filter is then washed and the solution is concentrated. The technique of immunomagnetic separation is then demonstrated, in which the oocysts are separated from any extraneous particles by using nanosized iron beads coated with antibodies which specifically lock on to Cryptosporidium, which are then removed magnetically. Finally a staining procedure is carried out and oocysts (if present) are identified under the fluorescent light microscope. Along the way, students are introduced to such processes as centrifugation, slide preparation and incubation.

ii) Video podcast:
Analysis of Organics in Water: this covers the theory of solvent extraction, and how separation may be effected using first a separating funnel, and then mechanical shakers to enable the laboratory to cope with a high throughput of samples. This is followed by a demonstration of evaporation of solvent under reduced pressure to increase the concentration of analyte in the sample, which is subjected to analysis by gas chromatography, and the presence of organic acids, a common indicator of sewage pollution, was confirmed.

iii) Interviews with laboratory personnel:
Audio files were also produced consisting of interviews with two scientists and one senior manager at Scottish Water. In response to scripted questions interviewees were asked to consider a number of issues: their day-to-day role; how good team working and communication ensures a constant flow of work and delivery of high quality analytical data; how team work is encouraged and supported; and the central role in this of an effective appraisal and review system.

iv) short video clips and stills sequences:
These illustrated how key analytical techniques are carried out by working analysts. These included a closer look at solvent extraction, solid phase extraction, pH measurement, aseptic technique and aspects of laboratory health and safety.

Finally, a few words about the practicalities: we found that thorough pre-planning was essential. This included two visits to Scottish Water to agree content with a laboratory manager, followed by producing a filming and recording schedule and preparing a script of questions for audio interviews (interviewees were provided with the questions prior to recording). Following filming, the films/audio recordings were edited and scripts for voice-over commentaries prepared and recorded. A sample script, simply to give an indication of coverage, is included below.

Sample voice-over script: solid phase extraction.

> *Solid phase extraction is widely used to purify and concentrate samples prior to analysis. A solid, often but not always, silica based, is packed into a syringe-like cartridge, this is known as the stationary phase.*
>
> *A common procedure is to chemically bond organic functional groups to the surface of silica, one example being the octadecyl -, or* C_{18} *group. Non-polar organic substances are attracted by Van de Waals forces at these points. This concentrates them on the column. They are then washed off the solid support by a suitable solvent and out through the bottom of the column – a process known as elution.*
> *An alternative approach is to remove the interfering substances on the column and let the sample of interest run through.*
>
> *Here the cartridges are incorporated into a manifold. This is connected to a vacuum pump which speeds up the extraction process by drawing the liquid sample through the stationary phase. You may also encounter the stationary phase in the form of flat discs or an array of 96 well plates which are used for tiny volumes of sample.*

> *What you have been watching so far is an initial step whereby the column is conditioned. The octadecyl centres tend to clump together – the analyst here is passing a solution of formic acid in methanol through the column which opens up the C_{18} groups allowing for more effective capture of the analyte. Next the column is flushed through with water to remove as much methanol as possible – this is important as methanol is going to be used in the elution step later on.*
>
> *Now we begin the extraction. The sample is siphoned into the column via a plastic tube. You'll also notice that although we're only showing one cartridge here, there is in fact space for others to run simultaneously. Note the flow rate into the column remains steady at about 5 drops per second at this stage. The waste passes through the column into a trough, again note the rapid flow rate.*
>
> *Once our sample has passed through the column, the tube is removed, a few taps to make sure all the sample has passed through, and now we move on to the elution stage. The glass collection vessel is thoroughly cleaned and a plastic housing containing a collection tube has been inserted. The elution solution is added. You'll notice the flow rate is much slower in this step – this to optimise the recovery of the analyte.*
>
> *One example of the use of solid phase extraction is drugs testing in sport. An athlete's urine is passed through a C_{18} -silica column that retains steroids and other organic molecules – whereas polar and ionic substances pass straight through. The retained compounds are then eluted using a solvent such as hexane. This solvent would then be evaporated and the residue dissolved in the minimum volume of solvent required for analysis using chromatography.*

Conclusions and future work

Our experiences producing the multimedia materials described above provided a template for a way of working with industry to produce teaching materials, which we wish to carry forward. We plan to make this material accessible to all by inclusion as podcasts on iTunesU, and as content on the Open University dedicated channel on YouTube – OU View. As the Analytical Sciences programme at the Open University grows we plan to build on this work and to produce analogous materials working with other areas of the analytical sector. In a more general sense the production of this material placed us in a situation where we were forced to think about curriculum in a work-based learning context and what material is appropriate to students. In a general sense our focus was on coverage of the underlying chemistry and extending to laboratory techniques a student might not be crucial to this was a strong steer provided by our industrial collaborators.

Acknowledgement

We are very grateful to the staff of Scottish Water (Edinburgh) who were involved in this project, and in particular to Mr Simon Gillespie for his enthusiastic support.

The project was funded by the Centre for Practice-based Professional Learning at the Open University.

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Our experiences producing the multimedia materials described above provided a template for a way of working with industry to produce teaching materials, which we wish to carry forward.

Combining a Tablet personal computer and screencasting for chemistry teaching

Patrick J O'Malley
School of Chemistry
The University of Manchester
Manchester
M13 9PL
patrick.omalley@
manchester.ac.uk

Abstract

This article describes innovative use of a Tablet PC and screencasting in delivering chemistry lectures. Introducing such technological innovations as an aid to chemistry lecturing is shown to be of immense benefit to both lecturer and student alike. The Tablet PC provides a clear method of presenting technical information in a dynamic fashion catering to both lecturer and student needs. It also permits archiving of lectures 'as delivered' to be achieved. Screencasting allows easy recording of the entire lecture and archiving for future viewing by the students. Student reaction to such innovations is universally extremely positive and the widespread adoption of these practices is to be encouraged.

Introduction

There is currently great interest in a number of universities in using technology to enhance student learning. In the UK this is increasingly driven by the importance attached to the National Student Survey (NSS) results and the need for many institutions to maximise output from teaching activities while managing to remain 'world-leading' in research as well. The change to an industrial-style competitive research ethos in universities together with the enhanced status placed on 'grantsmanship' skills leads inevitably to a sidelining of teaching skills development by many lecturers. In addition, since the introduction of student fees in England, university students rightly expect a better and more modern learning experience. As students can expect to contribute ever more to the cost of their university education in years to come, such expectations will inevitably increase, and a modern university will need to adapt their teaching roles and practices to reflect the most up to date technological advances.

As many technological tools become available sound pedagogical reasons for adapting such approaches must be present rather than adopting new technology simply for its own sake.

Various approaches at integrating technology to result in changes in pedagogical practices are available. As many technological tools become available sound pedagogical reasons for adapting such approaches must be present rather than adopting new technology simply for its own sake. The key measure of any such change must be judged as providing an enhanced student learning experience. Technology which aids comprehension of new material by the student is to be welcomed and in the chemistry area modern molecular modelling software which can often enhance visualisation of molecular and electronic structure is a good example of this.

In most university courses the traditional lecture format is still the favoured means of relaying information to a large body of students. This practice originated in medieval times when textbooks were not readily available to students[1] and why the practice has persisted throughout the years has sometimes been questioned. However, despite its critics it is still highly valued by the student body as evidenced in my own institution where a decrease in a school's lecturing hours drew student protest demonstrations to the vice-chancellor's office. Electronic projection, or e-projection, usually in the form of Power Point slides, while the instructor discusses the material on the slides, is increasingly being used to deliver lectures. Here is a case where the evidence of technology-enhanced learning is lacking and indeed there is evidence of a backlash against its widespread adoption[2]. It leads to lazy teachers, lazy students and not much learning. Most classes using this technology turn into simple slide-shows and are ineffective. In some cases people revert back to blackboard and chalk or overhead transparencies while some attempt to introduce some interactivity into PowerPoint presentation using for example classroom personal response systems.

The use of a Tablet PC provides another option for instruction which benefits from the interactivity and dynamism of the blackboard and chalk or overhead methods but also allows incorporation of pre-prepared diagrams or figures plus animations. In addition as the presentation is presented electronically it allows for archiving of the lecture as it was delivered and in addition as described here allows screencasts of the entire lecture presentation to be saved and archived for later viewing.

This paper presents a report on the use of a Tablet PC in teaching physical chemistry courses at The University of Manchester plus the recording and archiving of screencasts of these lectures for later student use.

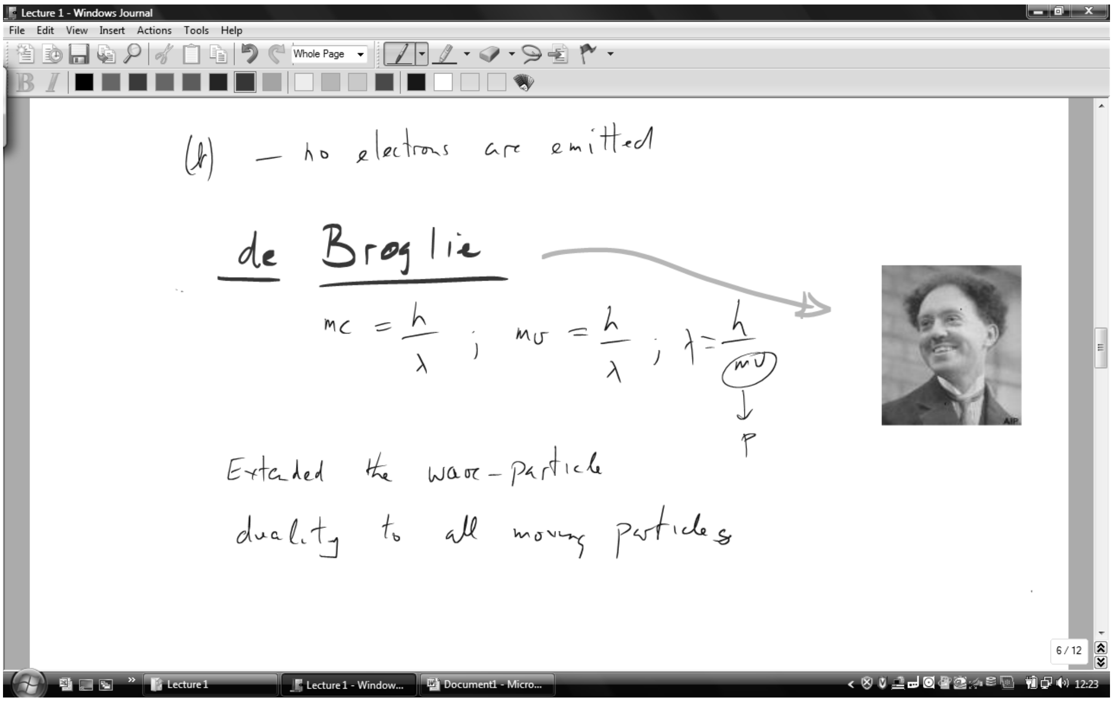
Methodology

Tablet PC

The Tablet PC contains a pen that can be used to write or draw on the laptop screen using digital ink. Digital ink is available in a variety of colours and it can be easily modified or erased. The ease of modification/erasure should not be underestimated as will be appreciated by any lecturer who has used overhead transparencies to deliver lecture material. While initially it can be difficult to write clearly on a computer screen, it is similar to writing on an overhead projector and with practice the author has found that he can write more clearly on the Tablet than on the blackboard or the overhead projector. In addition a variety of writing styles and colours are available simply by clicking on an icon. With e-projection the text appears on the display as written and again has the added advantage that the script is not hindered from view by the lecturers hand or body which is a drawback of presenting on the blackboard or overhead projector. All of these factors lead to clearer uninterrupted delivery with minimal interference of student concentration on the material being presented. A scrolling mechanism on most presentation software allows easy recall/recap of previously presented material plus the ability to cut and paste text or diagrams for presentation in any part of the lecture provides a seamless way of relating different parts of a lecture.

For the physical chemistry course that I teach the main reason for adopting the Tablet PC was to allow me to return to a more interactive form of teaching where mathematical derivations and structure drawing can be done more dynamically with student guidance and input as opposed to the lecture being driven by a pre-determined script as is often the case in PowerPoint lectures. Many students have commented on the much greater ease of understanding mathematical equations and derivations when the actual topic is delivered dynamically in real time. In addition complex chemical structures can be constructed progressively in a similar fashion. Guided by student comprehension the lecturer has the opportunity to change a particular strategy of instruction at any time introducing enhanced flexibility of delivery. All of these factors can lead to enhanced student learning and indeed enhanced teaching satisfaction for the lecturer. In addition to the above, complex molecules such as protein structures can be easily incorporated into the presentation using cut and paste facilities provided by the software and dynamic annotation used to explain structural or functional aspects. In addition animations can be introduced in a similar seamless fashion. A page of lecture notes demonstrating some of these capabilities is given in Figure 1.

For writing, the Windows Journal software was used which came packaged with the Tablet PC and the notes for the complete lecture as given can be saved and archived on Blackboard for students to consult at a later stage if required. In addition, as described in the next section, a screencast of the entire presentation can be made with the accompanying audio and made available for student retrieval.



(4) — no electrons are emitted

de Broglie

$$mc = \frac{h}{\lambda} \; ; \; mv = \frac{h}{\lambda} \; ; \; \lambda = \frac{h}{\underbrace{mv}_{p}}$$

Extended the wave-particle duality to all moving particles

Figure 1: A page of lecture notes from Windows Journal showing the writing, colouring and annotation capabilities of a Tablet PC.

Screencasts
Screencasts are a digital video recording of your computer screen activity and usually include synchronised audio commentary. Essentially they are equivalent to letting somebody look over your shoulder to view your on-screen activity while you provide a running commentary. You can limit the recording to a specific program e.g. a PowerPoint presentation or you can define the part of the screen that you wish to be recorded. You can also record a web camera image of yourself to accompany your presentation. There are a number of software products on the market which allow you to record screencasts. The most popular, and the one used in this work was Camtasia Studio. Screencasts should be distinguished from podcasts[3,4] which generally refer to audio only files which can be downloaded in a variety of formats. In a chemistry lecturing, where illustration and visualisation plays such a significant part, podcasting has limited potential whereas screencasts are ideally suited to the subject.

What is attractive to most students about the screencasts is the ability to be able to pause and replay at a particularly difficult topic. In addition after extra study many students find listening to the whole or part of the lecture again can be extremely beneficial.

In the last academic year it was decided to record screencasts of lectures the author presents on two modules; a first year Quantum Chemistry course presented to 202 students and a third year Molecular Simulation module presented to 51 students. Both used a Tablet PC for presentation of the material as described above. Effective use of the Camtasia software has a gentle learning curve although some basic knowledge of video formats and editing is useful. In general full screen recording was used so that all activity on the screen during the lecture was recorded. For audio recording a Hama microphone which clips on to the lecturer’s shirt or lapel was used with a long wire connection to the laptop. Although wireless versions of microphones can be obtained, these are generally quite expensive and unless the lecturer style is to wander excessively while delivering the lecture, the version used here is excellent.

At the end of the lecture the recording can be saved in a number of formats. Flash (flv) format was usually chosen to produce the video screencast as this is generally considered to be the most portable and compact format available. After saving the video file was transferred to Blackboard. In general the video was available to the students within thirty minutes of the end of the lecture.

While most lectures used a Tablet PC as described above some Clicker (Personal Response Sessions) using PowerPoint were given to assess student comprehension. These were also recorded and feedback after polling to each question is facilitated once again by the ease of annotation using Tablet functionality as shown in Figure 2.

Student Feedback
To assess student feedback to the use of screencasts and the Tablet PC, students were polled to rate these innovations on a scale of 1 to 4 where:

1 = useless
2 = ok
3 = good
4 = excellent

On a response rate of 70% most students selected 3 or 4, indicating overwhelming satisfaction by the students.

The students were also asked to provide further constructive comments. A sample of these are given below:

> *“I think that the screencasts are an excellent idea and would love to see them implemented in all courses. I have often wondered why the use of such technology isn't already implemented routinely, given the significant time for which it has been available.”*
>
> *“Too often, lecturers impose their preferred learning style on classes in a way that almost makes it seem like they don't want you to learn.*
>
> *If forced annotation (blank spaces) and lack of handouts are at one end of the spectrum, your methods are at the other.”*
>
> *“Tablet PC system works really well.”*
>
> *“It's brilliant, really useful if I need to go over anything and I imagine it will be a real benefit when I'm revising.”*
>
> *“The videos are excellent.*
> *They'd be very helpful if you'd missed a lecture due to illness, but they are really good for clarifying your notes or extending them. I think that all lecturers should do this.”*

Discussion and Summary
Based on student response in our school and previous other similar initiatives[5,6] it is abundantly clear that these innovations, in particular providing screencasts of lectures, is extremely well received by students. Use of a Tablet PC is generally welcomed and is the preferred medium compared with a static PowerPoint presentation. Some would argue that an overhead projector has similar capabilities however the clarity of the projected image from a Tablet PC presentation is much higher and as mentioned in the introduction the ability to

seamlessly incorporate graphics and animations together with the ability to archive notes and screencasts leads to significant advantages. With regard to screencasting, from a student learning perspective, it is clear that this technology leads to a significant gains. This perhaps should not come as a major surprise as the ability of most people to absorb new rather abstract concepts by attending a single lecture on the area is limited. What is attractive to most students about the screencasts is the ability to be able to pause and replay at a particularly difficult topic. In addition after extra study many students find listening to the whole or part of the lecture again can be extremely beneficial. Some students may have to miss a lecture for very valid reasons and the screencasts allow them to catch up on the material missed. There are also a minority of students who find a large, sometimes noisy lecture theatre distracting and not conducive to concentration. Some students have even mentioned that they concentrate better at different times of the day and hence value the opportunity to be able to listen to a lecture at any particular time. For these students the ability to be able to view the lecture in their own time and space is very welcome. There are many other reasons why students find this technique helpful, so in essence from the student perspective of learning and preparing for examinations there can be little doubt that this technology is extremely beneficial.

The major question mark over use of such technology comes from the perspective where some lecturers and educationalists argue that providing resources such as archived notes and now lecture screencasts encourages students not to attend the actual live lecture. A valid response to this would be that students are adults who can choose whatever method they wish to study and from the educational perspective this is fine so long as they learn the course material and are able to demonstrate this learning in an examination. From consultation with other lecturers, who did not provide screencasts of lectures, it would appear attendance at the live lectures was similar to others for both modules. Hence, at least for these particular modules, this concern was not confirmed. On raising this issue with some students, most feel that the screencasts cannot replace the real lecture experience where lecturer-student and student-student interaction is present. While some students do view the whole lecture again most use their notes together with the screencasts to review the more difficult topics. Despite these comments it is valid to query whether certain less motivated students will use the availability of screencasts to skip lectures and put off serious engagement with the course until nearer the examining period. Continuous assessment and tutorial attendance should be able to identify such cases however.

In summary therefore, introducing technological innovations such as a Tablet PC and screencasting as an aid to chemistry lecturing is of immense benefit to both lecturer and student alike. The Tablet PC provides a clear method of presenting technical information in a dynamic fashion catering to both lecturer and student needs. It also permits archiving of lectures ‘as delivered’ to be achieved. Screecasting allows easy recording of the entire lecture and archiving for future viewing by the students. Student reaction to such innovations is universally extremely positive and the widespread adoption of these practices is to be encouraged.

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> Some students have even mentioned that they concentrate better at different times of the day and hence value the opportunity to be able to listen to a lecture at any particular time.

Problem-based learning in physics supported by electronic assessment (Mastering Physics)

Lynn Moran
Department of Physics
University of Liverpool
Liverpool
L69 3BX
lynn.moran@liverpool.ac.uk

Abstract

Problem Based Learning (PBL) was introduced into a year 1 module in physics in the University of Liverpool in 2008/09. Mastering Physics (MP) electronic assessment from Pearson was also introduced to support this change. The main alteration was that for the purposes of continuous assessment the three tutorial-style homework assignments worth 10% of the module mark, were replaced with four group projects and 6 MP electronic assessments worth 30% of the module mark in 2008-09, and 50% in 2009-10. The most notable improvement is from ~45% of students submitting three assignments, claiming to have spent ~30 minutes per week on them, and achieving an average mark of <50%, to over 80% of students in 2008-09, and over 95% in 2009-10 submitting work for all projects and electronic assessments, with feedback indicating an average of 5-6 hours per week of work outside class. The average and median marks also improved dramatically from <50% in 2007-08 to >70% in 2008-09 and >75% in 2009-10.

Background

Thermal Physics is a short module which takes place during the first half of semester 2. Previously the ~100 students attended 15-18 lectures and completed three typical homework assignments containing of the order of 5 tutorial-style single or 2-step problems worth 10% of the module mark. Despite very positive feedback on lectures, it was clear that students struggled to apply the theory to simple problems in the assignments. A further problem arose as the examination date is approximately eleven weeks after the final session of the module.

In making changes the aims were to improve student engagement with the material in order that the long period between delivery and examination be less of an issue, and to encourage the students to apply their knowledge to problems throughout the module.

Aims

In making changes the aims were to improve student engagement with the material in order that the long period between delivery and examination be less of an issue, and to encourage the students to apply their knowledge to problems throughout the module.

Logistical Changes:

Continuous Assessment (CA)

The portion of marks for CA increased from 10% to 30% in 2008-09 (50% in 2009-10).

- CA changed from 3 tutorial-style homework assignments to 4 group projects and 6 MP electronic assignments.
- Mastering Physics electronic assessment introduced.

Delivery.

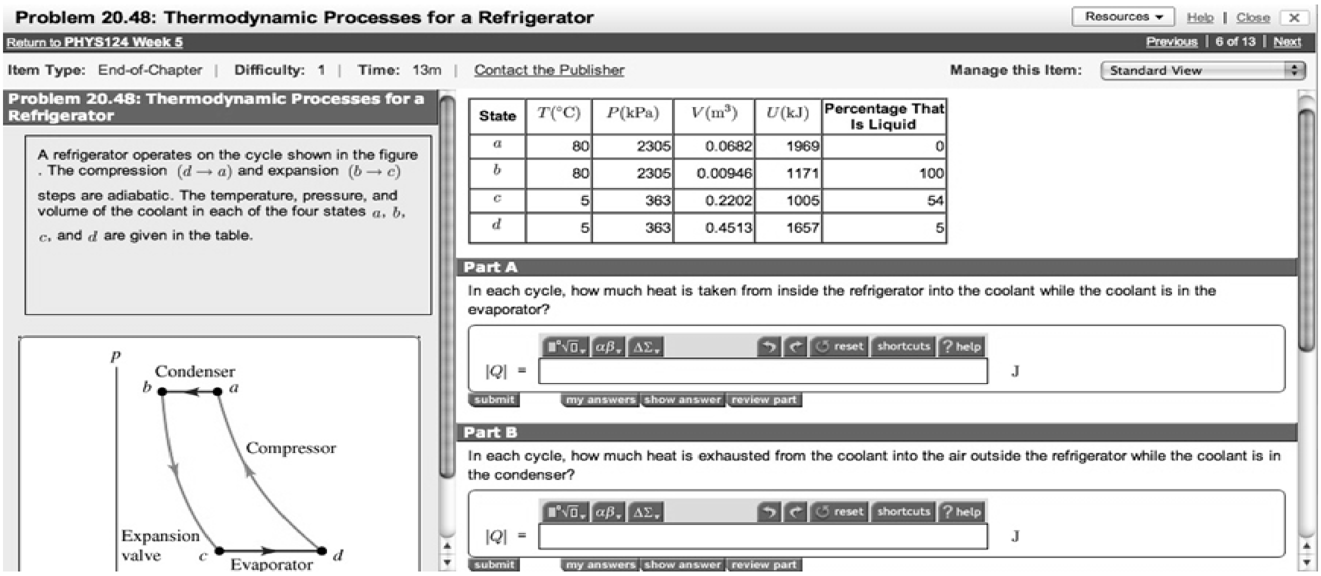
- Class divided into two groups for facilitation session once per week in 2008-09 (twice per week in 2009-10).
- Moved from tiered lecture theatre to flat room with moveable tables.
- Post-graduate facilitators present.

The Module in PBL Format

Introduction

The PBL summer workshop run by Derek Raine, Sarah Symons, and Cheryl Hurkett of piCETL at Leicester allowed me to benefit from advice from experienced practitioners. It was emphasised that the manner of introduction to PBL was very important. Therefore the first week of my limited time was devoted to an introductory project on a topic with which the students would already be familiar[1]:

> *'You are interested in purchasing a new 'green' car.*
> *Which one should you buy in order to minimise the overall cost?'*



Problem 20.48: Thermodynamic Processes for a Refrigerator

Return to PHYS124 Week 5

Item Type: End-of-Chapter | Difficulty: 1 | Time: 13m | Contact the Publisher

Manage this Item: Standard View

Problem 20.48: Thermodynamic Processes for a Refrigerator

A refrigerator operates on the cycle shown in the figure . The compression $(d \to a)$ and expansion $(b \to c)$ steps are adiabatic. The temperature, pressure, and volume of the coolant in each of the four states a, b, c, and d are given in the table.

State	$T(°C)$	$P(kPa)$	$V(m^3)$	$U(kJ)$	Percentage That Is Liquid
a	80	2305	0.0682	1969	0
b	80	2305	0.00946	1171	100
c	5	363	0.2202	1005	54
d	5	363	0.4513	1657	5

Part A

In each cycle, how much heat is taken from inside the refrigerator into the coolant while the coolant is in the evaporator?

$|Q|$ = J

Part B

In each cycle, how much heat is exhausted from the coolant into the air outside the refrigerator while the coolant is in the condenser?

$|Q|$ = J

Figure 1: Screenshot of a Mastering Physics 'End-of-Chapter' question, www.masteringphysics.com.

The level of physics varied in the reports submitted, but this project allowed the students to settle into PBL, for group dynamics to develop, and the facilitators to establish a relationship with their groups. Feedback indicates that the students viewed the introductory project as beneficial to their learning within PBL.

Running PBL

The other 3 projects were developed from those developed by Paul van Kampen and Eilish McLoughlin at Dublin City University[2]. A group report was submitted for each project, and marked overnight to increase the impact of the feedback. The next morning each group was paired with another group whose report had alternative strengths. The groups presented their work to each other, observed by the facilitators. The groups were expected to question and discuss the findings of the other group and make notes. This was the stimulus for a class discussion of the learning outcomes of the just-completed project.

There was clear evidence in the examination (2008-09) that some students had not understood all of the material in their project (highlighted by a few students on the evaluation forms); also students' ability to transfer their knowledge to new scenarios varied. In 2009-10 tutorial-style questions were introduced after the discussion of learning outcomes, requiring students to apply their knowledge to a new, albeit simpler, problem requiring understanding of the whole project, not just their own section.

Techniques Sessions

One session per week was labeled a 'techniques session' in which resources determined that the whole class work in a tiered lecture-theatre with one member of staff. Students were asked to sit in their groups and some new material and an overview linking aspects of the different projects were presented in the form of an interactive lecture. All material was delivered in the form of problems, which the groups attempted to solve, before the outline of a solution was presented.

Mastering Physics

Mastering Physics (MP) is an online system containing physics questions at year 1 level. The product is sold by Pearson Education as part of a book purchase or in a stand-alone format. Students register for the course linked to their programme of study, and complete assignments set by lecturing staff.

The question library is divided into chapters according to the associated book. Assignments can be set for a defined period, with a controlled marking system (e.g. three attempts, credit for first attempt only), hints are available, and feedback to their attempts is immediate. Questions are divided into three types: 'tutorial questions' include text to remind/teach the students, 'end-of-chapter' questions involve 2- or 3-stages of working out, and 'multiple choice questions' do exactly what it says on the tin. Marks and time taken are recorded for each student and assignment allowing easy analysis.

Analysis & Results

A major change from previous years was the amount of time the students spent on the module outside contact hours. The time spent on Mastering Physics is automatically logged and correlates both with their self-evaluation at the end of the module (average 5-6 hours per week outside of class), and the marks achieved in the final examination 11 weeks later.

Table 1: 2007-08 (pre-PBL): 3 homework assignments worth 10% of module mark.

Tutorial Homework	1	2	3
Average mark 2007-08	45	37	50
Median mark 2007-08	45	30	45
Students (%) 2007-08	62	49	40

Continuous Assessment
In 2007-08 62% of the students attempted the first homework assignment achieving an average mark of 45% (Table 1). Homeworks 2 and 3 were attempted by 49% and 40% of students respectively with average marks of 37% and 50%; these marks are representative of the trend over the previous five years. The reason for the increase in the final piece of work can be attributed to two main factors; first the material was based on use of the Ideal gas law, familiar to many of them from A-level (particularly those who did chemistry) and, second, the 40% who submitted work were those with better attendance and higher marks in general.

In the first year of PBL, over 90% of students submitted work for each project, and ~80% completed the individual, weekly Mastering Physics electronic assignments (Tables 2 & 3). The average (73% for projects, 74% for MP electronic assessments) and median marks (76%, 80%) are much higher than in previous years for this different type of assignment, although the level of the material is the same. The proportion of students submitting work and the marks, both average and median, increased further in 2009-10. Of 107 students only 3 students failed to submit work for every project. The average mark achieved was 76.3%, the median 78%. MP electronic assignments were completed by ~95% of students each week achieving an average mark of 78%.

Table 2: 2008-09/2009-10: 4 PBL projects worth 20% of module mark.

Project	1	2	3	4
Average mark 2008-09	69	73	73	76
Average mark 2009-10	75	70	80	79
Median mark 2008-09	75	76	75	78
Median mark 2009-10	77	70	85	82
Students (%) 2008-09	100	94	91	89
Students (%) 2009-10	100	100	97	97

Table 3: 2008-09: 6 Mastering Physics electronic assessments worth 10% of module mark.

MP Assignment	1	2	3	4	5	6
Average mark 2008/09	65	78	77	80	71	71
Average mark 2009-10	79	74	78	76	73	88
Median mark 2008-09	66	83	84	88	80	80
Median mark 2009-10	89	80	85	81	77	96
Students (%) 2008-09	91	87	82	68	74	77
Students (%) 2009-10	95	94	95	94	95	96

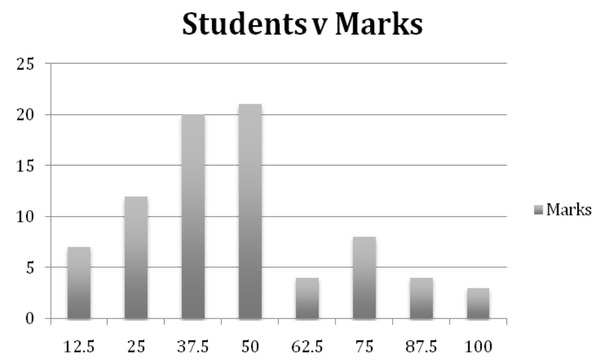


Figure 2: 2008-09 Waves and Optics Module class test worth 30% of module mark.

Comparison with other modules
In the same semester, two other short modules delivered to the same class, made significant changes to the delivery or assessment, in particular they also increased the portion of marks for continuous assessment from 10% to 30%. Attendance in both modules was significantly less, ~53% in both, compared to the PBL module where attendance was ~78%.

One module offered 2-hour problem classes where the students were encouraged to work in their groups and support was given through staff and postgraduate demonstrators. In the penultimate week a class test worth 30% was set, using only problems from the problem classes; only 40% of the class passed (Figure 2).

The other module changed two of the three tutorial-style homework assignments to MP electronic assessments. The second homework consisted of two parts: one paper-based, one electronic. This assignment was completed by 80% of students achieving an average mark of 73%. However, two weeks later the final assignment (electronic format only) was completed by only 58% of students achieving an average mark of 42%, although the material is not considered to be more difficult and the decrease in effort and marks does not correspond to what was seen in previous years for that section of the module.

As the increase in the portion of marks for continuous assessment was consistent across all three modules, but did not result in a similar improvement in attendance, submission of work, and marks, it strongly indicates that the students were motivated by the PBL projects. This is supported by feedback received in the evaluation process.

Examination
In order to be able to both compare with previous years' marks and evaluate the influence of PBL, half the examination paper was left in the old format, while the other half was changed. The average mark was within the usual 3% fluctuation, and on average 44% of students' marks came from the newer style question. This question attempted to assess the students' ability to model problems after their exposure to PBL[2].

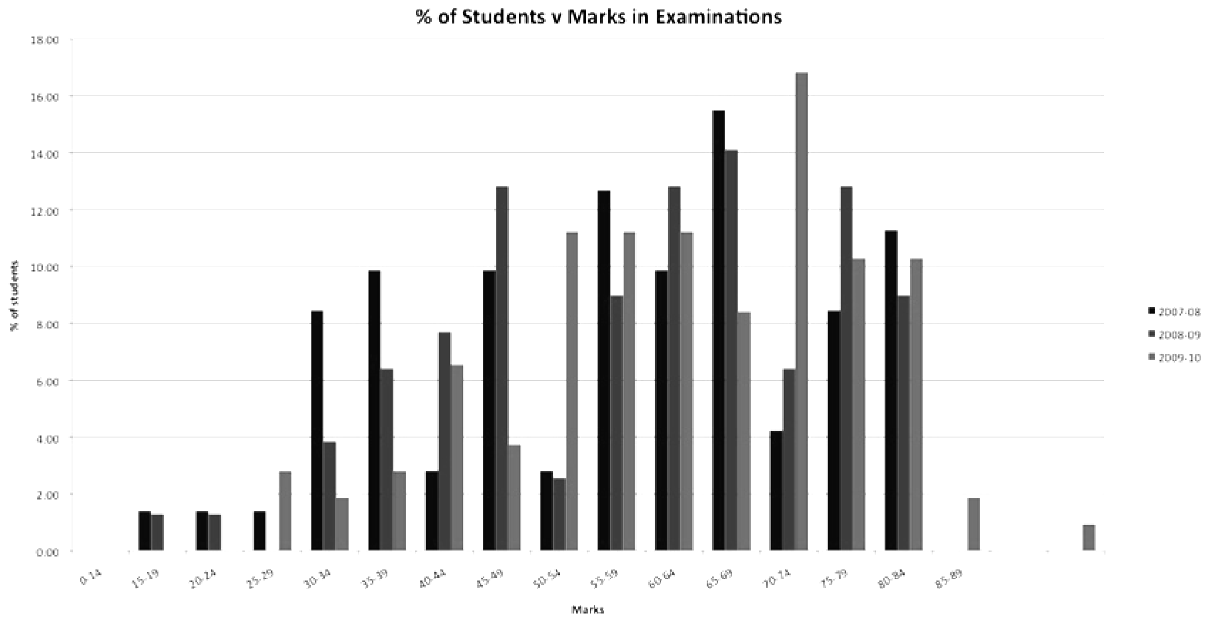


Figure 3: 2007-08/2008-09/2009-10: % of students v examination marks.

The main difference observed was that students wrote a great deal more than in previous years. Students attempted to justify their choice of equations in words even when not directly asked to, as in the question which remained in the same format as previous years. The examination was further developed in 2009-10 to include more ‘unseen’ questions, and organised in such a manner that it is no longer possible for the students to complete the paper if they chose to ignore a section of the module. Although the paper was considered to be more difficult by the staff, the average mark increased by 6% to 63%. Of those who missed projects, 2 obtained <30% in the examination and the other 44%. Unsurprisingly, the four students with the poorest attendance also obtained <40% in the examination. Figure 3 illustrates a comparison of the examination marks for the two years.

Repeat Students

Two students had completed the module in 2007-08 but failed to progress to year 2; their marks are shown in Table 4. Both students are (young) mature students who entered university through access programmes, and described their experience of the module as ‘Very engaging and inspiring’ and ‘Applying methods allowed me to absorb information better.’

Both students were also repeating two other modules in the same semester and showed only a very small improvement in the continuous assessment and examination marks in both modules.

Conclusions

Overall the introduction of PBL and MP has been a success. There has been an improvement in both engagement and marks. As the portion of the marks for continuous assessment was increased to 50% of the module, meaning ~10% of students passed on the basis of CA, it was very positive to see full attendance and good understanding shown in the exam. Both the 2009-10 examination and the year 2 follow-on module examination from the previous cohort show excellent ability to work through a problem via an understanding of the underlying physics, not obvious in other modules of the same cohorts of students.

Further evidence of achieving our original aims is that feedback from both years confirmed, in agreement with student comments highlighted by Van Kampen et al. (2004)[2],

> *‘it was easier to revise as I remember what was covered in the module better from having to research the information and apply it.’*

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Table 4: Continuous assessment (CA) and final examination marks for 2 repeat students.

Assessment	CA 08	Exam 08	Repeat 08	CA 09	Exam 09
Student 1	0%	4%	36%	77%	52%
Student 2	0.60%	0%	12%	87%	62%

School-university partnerships: Lessons learned from 10 years of spectroscopy for teachers and post 16 students

T G Harrison*, A J Shaw,
K L Shallcross, S J Williams
and D E Shallcross
Bristol ChemLabS
School of Chemistry
Cantock's Close
University of Bristol
Bristol
BS8 1TS
***t.g.harrison@bristol.ac.uk**

Abstract

Spectroscopy covers a wide range of analytical techniques, a small sub-set of which UK pre-university chemistry students are required to study. The expense of such equipment means that it is not available to the vast majority of schools whilst it is commonplace in university chemistry departments. This article discusses the evolution of the Bristol ChemLabS spectroscopy outreach activities. The advantages and disadvantages of this method of engagement for both the participants and the providers are discussed from 10 years of activity.

Why engage schools in spectroscopy?

For several successive changes in pre-university courses UK school students have needed to study various spectroscopic techniques. Spectroscopy is a broad term but for pre-university it can be described as a range of analytical tools and techniques used to study the way matter is assembled. For pre-university courses, these include infrared spectroscopy (IR), nuclear magnetic resonance spectroscopy (NMR), mass spectrometry (MS) and, depending on examination board for the courses undertaken, ultraviolet-visible spectroscopy (UV-Vis). Such instrumentation is out of the range of schools and it is against this background that some university chemistry departments provide opportunities that support secondary school teachers by allowing post 16 students access to this instrumentation. The students' courses do not require them to use the instrumentation. The students do need to know 'the way in which spectroscopic techniques are used to determine the molecular formulae and structures of organic compounds'. The emphasis is on problem solving rather than on spectroscopic theory[1].

Spectroscopy Visits to Bristol ChemLabS

For over ten years the School of Chemistry at the University of Bristol has run spectroscopy tours and workshops for post 16 students who are studying either Advanced (A) level, the International Baccalaureate (IB) Chemistry or whose vocational course have elements of spectroscopy embedded.

For over ten years the School of Chemistry at the University of Bristol has run spectroscopy tours and workshops for post 16 students who are studying either Advanced (A) level, the International Baccalaureate (IB) Chemistry or whose vocational course have elements of spectroscopy embedded.

The Outreach programme at the School of Chemistry began with spectroscopy tours about ten years ago. These gradually built from a few days in September, where schools would visit for a morning or afternoon session, to a whole week of morning and afternoon sessions for up to 15 schools. The format also changed in this time: as funding became available to support some local administration and as feedback was obtained, so the individual sessions were gradually modified. In the last four years the scale of this outreach activity has increased through the Bristol ChemLabS initiative[2]. A major difference is the role played by the school teacher fellow (STF)[3, 4]. During the last four years an average of 400-600 students per year have visited the School of Chemistry on spectroscopy tours, a doubling of numbers from the previous five years. Many thousands more have experienced hands-on infra red or ultraviolet-visible spectroscopy through workshops and summer schools in this period and by loaning equipment to schools.

The spectroscopy tours[5] are designed to promote chemistry generally and support secondary school teachers in their teaching. The spectroscopy tours take place in the autumn term with the majority in September and the remainder usually in December. The eighteen half-day experiences accommodate up to 50 students at a time.

Each half day experience comprises a two and a half hour session. The morning or afternoon visits start with a welcome and introduction to the department and a brief, general talk about spectroscopy (this was introduced in the last four years). This takes place in a lecture theatre to give the students probably their first opportunity to be in such a standard university environment. The cohort are then split into smaller, more manageable group sizes with an average of 10 students each, and are escorted by postgraduate chemists to the individual talks. All tours involve twenty minute sessions on mass spectrometry, infra red spectroscopy and nuclear magnetic resonance. Depending on the availability of the equipment additional talks on scanning electron microscopy and X-ray crystallography are given. Ultra violet-visible spectroscopy is used to substitute techniques that are not available for a particular session. The talks are given in the rooms where the instrumentation resides so the group size is limited to one that is both comfortable and safe. The infra red and UV-Vis spectrometers are hosted in the undergraduate teaching laboratories. As each student hears five talks this means that some demonstrators can give the same talk up to ten times per day, sometimes for several days in a row. A major modification since 2004 has been that the STF, a highly experienced former secondary school teacher, has worked with all groups to hone the twenty minute sessions and to update supporting literature given to teachers and students. (This could be achieved in collaboration with any A level chemistry teacher). Such an intervention has had a significant impact on both the deliverer and learner. Appropriate language is, of course, very important and the use of examples that are used in schools takes the learner from familiar territory onwards[6]. The theme of how individual techniques can provide different information on the same molecule is also a simple, yet effective innovation. Feedback is excellent for all aspects of the tour.

The postgraduate chemists involved in these spectroscopy tours, either deliver sessions or accompany students, and have all been through a Science and Engineering Ambassador Scheme (SEAS) training programme[7]. This national scheme, together with some informal in-house training, equips the postgraduates, many of whom are overseas students, with knowledge of the UK education system, the rights and responsibilities in working with school students and the importance of the appropriate level of communication. The postgraduate guides are encouraged to talk with the students, point out places of interest and to answer questions on all aspects of being a student as they move them around the department. Those chemists using PowerPoint slides or handouts in their talks have, of course, discussed the content with the School Teacher Fellow. The two and a half hour sessions are punctuated by a refreshments break. It has been noticeable that feedback has commented on the improved congruence of the content with that presented in school. During this period, the biggest single school group was 45 students with an entire session to themselves, and the smallest school group was just 2. The greatest number of schools in one session was 6.

Advantages of this outreach activity

For the students the visits to a university science department and contact with (postgraduate) students gives them insight into what it would be like for them to be an undergraduate in a practical science subject. It is common for this to be the first opportunity that the students have had to look around a university department. It is for this reason alone that the introduction to the visit takes place in a lecture theatre so that the visit is as complete an undergraduate experience as possible. Usual comments on entry to the lecture theatre include ‘It’s just like on TV or just like in films’! On open days students often visit with their parents. On these visits they are with their peers and there is a different dynamic. Students often ask questions about university in general and feedback suggests that this is an important opportunity to experience university that is different from open days.

For the teachers the visits serve several purposes. First, the experiences encountered by their students support their previous or future lessons. For some less experienced chemistry teachers the information given out supports their own understanding of the techniques. The brief informal discussions with those delivering the talks or with the postgraduates accompanying the groups also adds to their subject knowledge, and armoury of ‘stories’ and examples used by good teachers, to further enliven their lessons. Many of the teachers have no experience of the state-of-the-art instrumentation apart from pictures in the more modern text books (which are likely to be considerably out of date). Comments such as ‘it’s all changed beyond recognition from my day’ are common.

For non-subject specialist teachers the visits give an opportunity to see a different type of university department and, for biologist and physicists, to see a different slant on their own specialisms, since all the techniques are essentially applications of physics. Some of the analyses, in a modern chemistry department, may be of biologically active specimens or of biological interest such as enzymes.

For accompanying technicians they can take the opportunity to talk with the department’s technicians. Several examples of exchange of information on storage, availability of resources, safety, techniques and maintenance have been noted.

For the postgraduates, post doctoral research assistants and university technicians the events provide an opportunity to practice their science communication skills and their teaching skills. Several postgraduates report that such activities forced them to understand the technique far better than they did previously and that the activity as a whole was as much an education for them as the visiting students.

Table 1: Numbers of school students attending each session from 2005-2008.

Year	September		December		Total Number of Students Attending	Total Number of Schools Participating	Total Number of Sessions
	No. of students	No. of sessions	No. of students	No. of sessions			
2005	411	12	88	2	499	30	14
2006	~500	11	150	4	650	29	15
2007	402	12	(Nov) 90	2	492	24	18
2008	428	10	94	2	522	24	18

For the university there is an element of promotion with the schools engaged. Frequently photographs taken during the visits end up in school websites, posters in the science departments or school newsletters. More importantly it provides an informal opportunity for members of the academic staff to talk with teachers to find out what is currently going on in schools. The heavy involvement in outreach activity featured prominently in a recent very large, successful grant application to replace NMR instruments and increase their number.

Disadvantages

Whilst a few visiting students can experience hands-on spectroscopy with IR and UV-Vis not all can. Even undergraduates do not typically handle some modern instrumentation, such as NMR and mass spectrometers, as the instruments have dedicated technical staff to run samples submitted to them.

For the teachers the timing of the tours within the year does not always coincide with convenient times either because of local rules such as ‘no school trips in the first month (September) of the school year’ or the ‘rarely cover’ policy or because some for the spectroscopic techniques are yet to be covered in lessons. The ‘rarely cover’ policy was put in place in 2009 to ensure that teachers ‘rarely cover’ the classes of colleagues who are absent. However, if the activity has been booked in advance, as suggested, this should include provision for teacher cover and will not be affected by this new policy. It should be noted that this policy was not designed to prevent outside activities but to ensure that teachers are not overloaded with additional teaching; therefore the need for good planning and preparation is essential. Due to the need for the valuable instrumentation to be available for their prime use in teaching undergraduates and research we can normally only provide these tours in September and December each year. Other outreach activities at different times of the year make demands on resources.

For the School of Chemistry there are nine days per year when the various facilities are not working to their normal capacity for their prime function. However, the timing within the year is such that there is no workload being generated by the undergraduates as the spectroscopy visits are normally out of undergraduate term time. There is also a considerable secretarial input into the communication and management of both large numbers of schools and staff involved. As this is now a well established annual series of events the School of Chemistry considers that the advantages outweigh the disadvantages!

Financial support

There are of course costs associated with activity at this level. Funding in recent years has come from three sources. Bristol’s School of Chemistry pays the salaries and running costs of the academic staff, secretarial support and post doctoral chemists. The local section of the Royal Society of Chemistry contributes financially to the costs of the consumables and, as of 2008; the schools themselves are making a nominal payment per student for the experience.

The Value of the Visits to us

It should be noted that these visits are not just of benefit to the students and their teachers. As we have noted in previous publications[3,4], there are many benefits to the department. First, having run this activity for such a long time we have been able to work with teachers to shape and modify the activity and this dialogue has naturally moved beyond just the spectroscopy tours. Therefore, a major benefit is that it has opened up meaningful and useful dialogue with teachers that have informed us about new aspects of curricula and new teaching methods. Second, the handouts we have produced have gone through numerous teachers and students who have provided clear and expert feedback. Such feedback has not only improved these handouts but has also influenced first year material and in particular induction week. Third, over the course of this project, postgraduate students have done more of the demonstrating, e.g. infra red and ultra violet spectroscopy. All students have reported that this has been extremely beneficial to them, because they have been able to hone their communication skills and because it has forced them to really understand the technique they are demonstrating. The many questions they have been asked by teachers and students have improved their knowledge of the various spectroscopic techniques as they have then had to ask a senior colleague when they didn’t know the answer. In two cases we know about, these interactions have had a direct positive impact on their PhD studies as they have found out about an analysis that they could do which has propelled their research forward. There is little doubt that there are many more of these cases that are not captured by us in our debriefing sessions with postgraduates and staff. Fourth, in interviews, postgraduate students have used these sessions to talk about times when they have solved problems or shown initiatives and several report that interviewers have been impressed with their responses. Fifth, over the years about one third of the academic staff have taken part in various aspects of the spectroscopy tours and this has been beneficial to them in two ways; they have interacted with students and teachers first hand and enjoyed several useful discussions, second, they have been able to build up a portfolio of interactions that they can put on grant applications illustrating a different type of impact. In one direct example, sponsorship from an instrument manufacturer, that lent weight to an ultimately successful grant application for new NMR machines, was directly related to the success of the tours. Sixth, this activity brings together people in the department who would not normally interact in the general running and operation; that in itself is a good thing. However, there are examples over the course of this long-term project where this has benefitted the running of the department (e.g. input into first and second year teaching modules) and has brought PhD students into contact with new academics, with several discussions leading to interesting and fruitful collaborations. Finally, the diversity of schools visiting the department has increased and new schools are added each year. This activity was never designed to increase recruitment but it is no coincidence that students from schools who come to these events apply to Bristol.

Monitoring

The common question asked by many funders of outreach activity is ‘How do you know what you are providing is of any value or doing any good?’ Most evidence is qualitative through discussions with teachers and students. In an attempt to quantify the value of each talk, questionnaires are given to accompanying teachers. Teachers handle these in one of two ways: either they give a teacher’s impression or they seek feedback from their students collectively. Such feedback has informed the level of language and examples used in presentations and any literature given, the role of the accompanying postgraduates, the inclusion of ultraviolet-visible spectroscopy and, for next year, time-of-flight (TOF) mass spectrometry. Some suggestions cannot be addressed for various reasons, such as the scheduling of tours at other times of the school year. Participating staff and postgraduates also give informal feedback.

> *‘......... They [the students] were wowed by the machinery and what it could do. All that theoretical A-Level stuff seems so much more real now. I have to say that Sue and I were also pretty gob-smacked by some of the up-to-date versions of what we used when we were undergrads!’*

This, from a recent teacher via unsolicited email is typical of the replies.

Additional quantitative feedback can be gained by noting the number of students and schools on waiting lists because the sessions are full, looking at the distance travelled by visiting schools as a possible function of the value of experience and the number of schools making or wishing to make repeat visits. We also carried out some data analysis to see whether there was any significant correlation with examination results. Surprisingly, there does appear to be some correlation, although we are extremely hesitant to read anything into these data.

Correlation with Exam Results of Schools in CHeMneT

As part of the research on schools in our network, called CHeMneT, data were collected on A-level performance, focusing on two measures:

- % of high performing students achieving A or B in A-level Chemistry, and
- % of students achieving A - E in A-level Chemistry.

These data were collected from science teachers, schools’ examinations officers or school websites (Table 2).

Independent-samples t-tests were run using the Statistical Package for the Social Sciences (SPSS) to establish whether there were any statistically significant differences between the average results of engaged and non-engaged schools. The p-values indicate whether the difference in average percentages was significant at the 95% confidence level. It is of course very important to note that several caveats must be taken into consideration when looking at these data and these will be discussed later.

Inspection of students achieving grades A-E in chemistry suggests that the schools that have engaged with Bristol ChemLabS have on average a significantly higher percentage of students obtaining those grades, in 07/08 and 05/06 than those that do not. The significant differences (for A-E grades rather than A/B grades) suggest that any effect is impacting most on students at the lower end of the spectrum, rather than the top performing students. It may be that the spectroscopy tours themselves are having an impact but equally likely is the fact that the visit selects out those students who want to do well at A level in Chemistry. There are several confounding factors that could lead to any elevation in results. For example, by the very fact that the school/class have attended, this may indicate a more engaged and enthusiastic teacher and this may influence results. However, there are a few possible reasons for an enhancement based on the visits. First, the visit may inspire the students to come to University and especially those at the lower end. Second, seeing the equipment and talking with postgraduates, academics and technicians may help the students to understand topics in this area that they didn’t understand. What is clear is that far more data are required to ascertain whether there is an impact on results and such analysis is on-going.

Bristol ChemLabS’ top tips for running similar activities

- Use well trained postgraduates as guides and technical helpers who are used to working with school students.
- Give schools plenty of notice so they can act on the offer of this type of outreach.
- Make the activity available at the same time each year so that teachers can build it into their schemes of work from one year to the next.
- Once established do not be afraid to ask for a token charge for the activity. This not only helps recover costs and makes such a programme sustainable but severely reduces the ‘no shows’.
- If in doubt about the suitability of content enlist the help, in advance, of two or three local teachers and get them to feedback on their own examination course requirements. Whilst this can be obtained from the relevant examination specifications the teachers will understand the interpretation.
- Provide a refreshment break with biscuits and a variety of drinks. The school students like being made welcome and those participating in the delivery will need a break too. The interval also allows the accompanying teachers to talk with their students about what they have seen and to answer questions. It also allows teachers to informally ask questions of university staff and postgraduates present.

Conclusion

The spectroscopy outreach programmes offered by universities such as Bristol are very popular, providing not only an opportunity to see equipment that students would not have access to, but at the same time allowing students to have a brief experience of University. Provided that the level of the communication is appropriate and the content supports the examination requirements the availability of a regular programme can be an important engagement activity for a chemistry department with all the benefits that this entails. The inclusion of teachers in the programme preparation from the content through to the training of the postgraduates is important. Whichever format of visit is offered, this is valuable to all parties. We have seen that regular revision and regular but modest modifications of the programme have gradually made the activity very useful for both the provider and the recipient.

Acknowledgments

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> The spectroscopy outreach programmes offered by universities such as Bristol are very popular, providing not only an opportunity to see equipment that students would not have access to, but at the same time allowing students to have a brief experience of University.

The mole misunderstood

Karen Moss* and
Amisha Pabari
Centre for Effective Learning in Science (CELS)
Nottingham Trent University
Clifton Lane
Nottingham
NG11 8NS
***karen.moss@ntu.ac.uk**

Abstract
In every area of science there are some ideas that many students find difficult to grasp. A lack of understanding of key ideas can limit a student's ability to grasp and apply fundamental principles of their discipline. Previous work in this area, by Taber, has focused on this problem at school level. However, little work has been done to systematically investigate and analyse this phenomenon in undergraduate science programmes, beyond the anecdotal. A previous study involving students and staff from a range of scientific disciplines at our university identified that the mole (and its associated applications) was a difficult area for a wide range of students. The mole shows characteristics of being a 'Threshold Concept' for students. Having identified the mole as a problem, the aim here was to explore why it is difficult and whether the conceptual issues can be systematically overcome, by using multiple perspectives. A sequence of questionnaires was used to survey over 100 people, involving school students aged 14-17, first-, second- and third-year university students, and secondary school teachers, in detail about the mole. We considered respondents' learning preferences and the type of activities in science lessons from which they felt they learned the most. Over 50% of respondents reported problems with the mole at some stage of their education. Further insights into how people conceptualise the mole were explored through the use of an educational research technique called 'Hot Pen Writing'. The outcomes of the research identified some of the reasons for student's lack of understanding of the mole concept including poor teaching in schools, difficulty in relating the concept to real-life situations and, not surprisingly, the fact that it involves maths. We consider what this suggests about how and when the mole should be taught within school education.

Introduction – chemistry a challenging subject

Chemistry as a subject divides people: some love it and others find it exceptionally difficult[1]. As it is perceived by many students to be hard[2], a significant percentage of good students in science fail to take the subject further - in 2009, only 55.7% of students that achieve an A* in Chemistry at GCSE and 35.9% of students that achieve an A grade go on take Chemistry as an A-level subject.[3]

> *'11-year olds arriving at secondary schools are keen to study science, and enthusiastic about the prospect of practical work in exciting laboratories. Some maintain this interest over the next five years, but sadly the majority find science lessons boring and irrelevant compared with other subjects'*.[4]

School chemistry often includes two very different types of learning experience: one involves bangs and smells, pouring coloured liquids and collecting gases, and using equipment such as test tubes, balances and Bunsen burners; the other comprises mole calculations, balancing equations, learning atomic and molecular structures or considering how blast furnaces work. For many secondary-age students the first type of chemistry lesson is fun; the second type is confusing and boring; significantly students make limited connections between 'fun' chemistry and 'boring' chemistry. Taber challenges us to consider that when we blithely state *'chemistry is a practical subject'*, what we really mean is *'chemistry is a practical subject... as well as a theoretical subject'*.[1]

Programmes which use a context-based approach, (e.g. Salters A-levels), teaching science through everyday contexts can encourage engagement with the underlying principles and concepts; but this is only a partial solution- there is also the need to address the deeper issues of how people learn chemical concepts.

Programmes which use a context-based approach... teaching science through everyday contexts can encourage engagement with the underlying principles and concepts; but this is only a partial solution- there is also the need to address the deeper issues of how people learn chemical concepts.

Previous research suggests learning difficulties in chemistry arise because of the challenges such as:

- Chemical concepts are presented in the classroom as the solutions to problems in which the learners have little interest in or have never experienced[5] - conceptual material that was developed over decades or even centuries, invented to solve particular chemical issues for chemists! This is a real disadvantage of chemistry as many of the key concepts are not immediately highly significant in children's lives and its applications to real life tend to be less obvious than for other subjects. Examples include: i) a focus on 'pure substances' rather than everyday materials that students are familiar with such as fabrics, plastic, wood and air; ii) the basic explanatory framework of chemistry is in terms of atoms, electrons, molecules and ions (and how they interact and are arranged) which is very different to the everyday nature of matter as students experience it: as Kind[6] found:

  'When students cannot 'see' particles they cannot really understand chemical reactions and so the fabric of chemistry is lost to them in a haze of impenetrable events completely at odds with their every day experiences of a 'continuous' world.'

- Students are given examples to demonstrate the 'solution' however they are unable to see how this 'solution' was constructed or to understand the importance of it which makes the idea abstract and so students commonly fail to grasp the intended meaning of many concepts.[1]

- When chemistry is taught there are constant shifts between talking about actual substances that can be seen or touched and explanations in terms of abstract models. This is one of the major causes of learning difficulties in chemistry as a real understanding involves bringing together these conceptual ideas meaningfully[2]. One example is the confusion between the macroscopic scale and the molecular scale. Talanquer's work describes examples of alternate student conceptions such as perceiving an atom of copper to be red in colour. Students will frequently believe the following:

  'Atoms and molecules have macroscopic properties: they expand and lose weight when heated, have uniform densities and well-defined colours, are malleable, change shape under pressure, etc.' [7]

- The working memory space in our brains has limited capacity – typically 5-7 pieces of information at once- so when students are faced with new and complex material which is usually abstract, they can have difficulty organising these ideas together which leads to an overload of the working memory space and then students resort to memorising rather than understanding (work of Johnstone, Reid etc.)[8]

  'This limited space is a link between what has to be held in conscious memory, and the processing activities required to handle it, transform it, manipulate it, and get it ready for storage in long-term memory.'

- Language also contributes to information overload and is an additional complication when students are learning chemistry. Typical issues include:
  - Specialist language explained: words/forms of language that are unique to the subject and teachers explain these to students.
  - Tacit language not explained: this is specialist language which teachers assume that students understand them from previous work or that they use without realising.
  - The language of science which incorporates not just words but a multitude of signs and symbols, graphs, charts, diagrams, equations and chemical formulae.[1, 5]

- An example of where unfamiliar and misleading vocabulary is used is the world 'volatile' which in everyday life students understand as unstable, explosive or flammable, however its scientific meaning is 'easily vaporised' which students are unfamiliar with but science teachers are used to.[2]

- Mathematical ability - The Higher Education Academy Physical Sciences Centre carried out research on chemistry undergraduates in England and Scotland to explore the difficulties university staff experience when teaching undergraduates. The largest problem was said to be the level of mathematical skills that students have. Students who have the potential to learn chemistry but are hindered by poor backgrounds in mathematics will panic when faced with problems. When students were asked what they were worried about before starting a chemistry course, the response of one of the students was *'Maths- absolutely petrified of the math and the conversions.'* [9]

- When a student has different ideas to the accepted models they are expected to unlearn these ideas – this can happen (a *labile* idea) but other misconceptions may be very stable and more difficult to modify. For more info consider Keith Taber's work on 'alternative frameworks' and 'alternative conceptions.' [5]

For university students, topics that cause students problems were previously identified to include electrochemistry, chromatography, bonding, functional groups, spectroscopy, chemical equations, analytical science, dilution factors, structural formulas and the mole.[10] The mole concept has been recognised as difficult by a number of researchers. A survey with Irish first year university students revealed that this was the topic that most students perceived as being difficult.[11] A teacher states:

> *'Moles as a concept is too alien for most to cope with and so many students give up trying to understand the real concepts... and end up rote learning the equations and applying them...this means that they can't cope with anything out of the standard question.'* [12]

Specific research on the mole[6, 13-14] reveals:

- Teachers can be confused about this concept, and transmit it incorrectly.
- Mathematical approaches to the mole obscure its chemical meaning, especially the use of ratio and proportion calculations.
- Difficulties in visualising Avogadro's number which cannot be 'seen' cause problems with learning.

The concept of the mole was first introduced by Oswald in 1890 when he was seeking the chemical formula of 'oxygenated water.' His 'mole' was:

> *'The normal or molecular weight of a substance expressed in grams.'*

Its meaning has since changed and the IUPAC (International Union of Pure and Applied Chemistry) defines the term as:

> *SI base unit for the amount of substance (symbol: 'mol'). The mole is the amount of substance of a system which contains as many elementary entities as there are atoms in 0.012 kilogram of carbon-12. When the mole is used, the elementary entities must be specified and may be atoms, molecules, ions, electrons, other particles, or specified groups of such particles.*[13]

Into the conceptual arena has stepped a new theoretical framework across a wide range of subject areas: *Threshold Concepts* and *Troublesome Knowledge* (Meyer and Land[15]). A *Threshold Concept* is a 'core concept', a conceptual 'building block' that leads to progression in understanding of the subject. It can be described as:

- *Transformative* or seismic: once 'got' its effect creates a significant shift in the student view of a subject.
- *Irreversible*: once 'got' this different view is unlikely to be unlearned.
- *Integrative*: understanding it exposes relationships with other areas.
- *Bounded*: it affects other new concept areas.

Potentially areas of *troublesome knowledge*. *Troublesome Knowledge* is defined by Perkins[15] as topics which are major barriers to learning if not understood: students are able to perform mechanical tasks and techniques, yet fail to understand the underlying concepts and the bigger picture. Students typically show behaviour such as:

- *Ritual knowledge*: perform superficial tasks and techniques to get a result but fail to understand the complexity that lies behind it.
- *Inert knowledge*: concepts are understood but not actively used or connected to the 'real world' and so there is a failure to see the 'big picture'.
- *Conceptually difficult and alien knowledge*: concepts are found difficult to grasp due to their counter-intuitive or complex nature.
- *Troublesome language:* problems caused by the type of language used during any teaching e.g. a word can have two meanings.

Threshold concepts and troublesome knowledge can cause students to become stuck in an 'in-between state' where they oscillate between their own less sophisticated idea and the understanding required by the teacher.

The mole concept is a very important topic and failure to understand the concept fully causes difficulties in understanding subsequent topics especially stoichiometry problems including volumetric calculations and concentration of solutions.[11,14] We would therefore suggest that the mole shows all the characteristics of being both a *Threshold Concept* and *Troublesome Knowledge*.

What do we do about this? Current research in threshold concepts is exploring exactly this point. Our aim was to consider why students at different stages of their education felt this way about the mole and to explore ways in which we can support students in understanding and applying the concept correctly.

Our approach

Questionnaire Design

Three questionnaires were designed to survey teachers, secondary school and university students in depth about topics in chemistry and specifically about the mole. Many of the questions on the three surveys were in common, with specific questions added or removed depending on their relevance to the respondents. All three questionnaires looked at which science-related subjects they found most difficult, their preferred learning styles and most beneficial activities during chemistry lessons, the importance of linking science concepts to real-life and the use of practical activities, the most difficult topics in chemistry and questions about their knowledge of the mole and the importance of the mole concept.

- The school student questionnaires asked about the educational background of the students, when the mole concept was first introduced, whether they found it difficult and what improvements could be made to help their understanding of the concept.
- The university student questionnaires also aimed to find out how difficult they found the transition between GCSE and A-level and reasons behind this.
- The teachers were asked about their routes into teaching and the length of their teaching experience. They were also questioned on how difficult they find topics to teach, what resources they use when teaching the Mole and how they would help out students and new teachers that were struggling with the concept.

The questionnaires were semi-structured and included a range of open and closed questions. One of the techniques used was 'Hot pen writing.' This was a type of open question that involves asking the respondents to write down as much as they can about a certain topic (the mole) in a certain time-period (5 minutes).[25] The responses provide an indication of what people do and do not know about the topic.

The closed questions in the survey included dichotomous questions (e.g. yes or no) and category questions in which respondents have to choose from a range of categories. The survey also included list questions, which required choosing more than one response from a list of options and Likert-type scales, which involved ranking chemistry topics in order of difficulty using a scale of 1-10. Closed questions tend to be preferred by respondents as they are less time-consuming but in order to gain further explanations it was essential to also include open questions. Ethics approval for the questionnaires was gained prior to their distribution.

The results from the survey were both quantitative and qualitative. Quantitative data was analysed using statistical tests and qualitative date required coding. All the responses had to be organised into a smaller number of categories which were then used to form frequency tables.[26]

In addition bibliographic research was used in this study to research how different text books present the mole to students and also how the content of the mole varies in common GCSE specifications. The specifications were all found on the websites of the examination bodies which are also used by teachers in schools and hence these documents are authentic and representative for the purpose of this study.

Participants

University student questionnaires were distributed to first year, second year, third year and fourth year chemistry students' as well as to other students at Nottingham Trent University with a background in chemistry. These questionnaires were handed out using opportunity sampling to all students during specific lectures and also in the Student Union and the library to students willing to participate. The remaining questionnaires were handed out to some students at different university libraries such as DeMontfort University and the University of Leicester. This was to ensure a wide range of responses were received from a variety of participants. The university students who responded had all previously studied chemistry further than GCSE level in the form of A-levels, access course or other equivalent qualifications.

Two secondary schools were chosen using opportunity sampling. Two tutor groups were randomly selected from each of the two schools (one year 10 group and one year 11 group from each). The students were then given the questionnaires to fill out during their tutor periods. The remaining questionnaires were distributed randomly to AS level chemistry students at a college, who had completed science GCSE exams a year ago and so still remember the contents that they had studied. This was done by giving one chemistry teacher the questionnaires who distributed them during different classes which ensured that students with different levels of ability were surveyed to avoid bias. This was also maintained in the secondary schools as a tutor group contains a range of students with different science abilities.

Teacher questionnaires were also distributed to randomly selected teachers whilst at the schools and college and also to lecturers at university. All the teachers and lecturers surveyed teach science. The period of time they have been teaching varied from less than 1 year to 15 years.

Results

Of 270 questionnaires handed out, a total of 111 responses were received a response rate of 41%. The profile of respondents was 61 university students, 44 secondary school students and 6 teachers/ lecturers. The subject profile of the university students is shown in Table 1.

Table 1: Degree titles of university students surveyed.

Degree title	Frequency
Pharmacy	5
Chemical Sciences	4
Pharmaceutical Science	3
Chemistry	45
Forensics	1
Childhood Studies	1
Biosciences	1

Popularity of subject choice amongst 14-17 year olds surveyed

Some results showed similar outcomes to previous work[3]. For example, all the respondents felt that physics was the most difficult subject of the three core science subjects, with biology the easiest and chemistry in between. The secondary school students revealed that 38% of them were studying or planning to study science A-levels (Figure1).

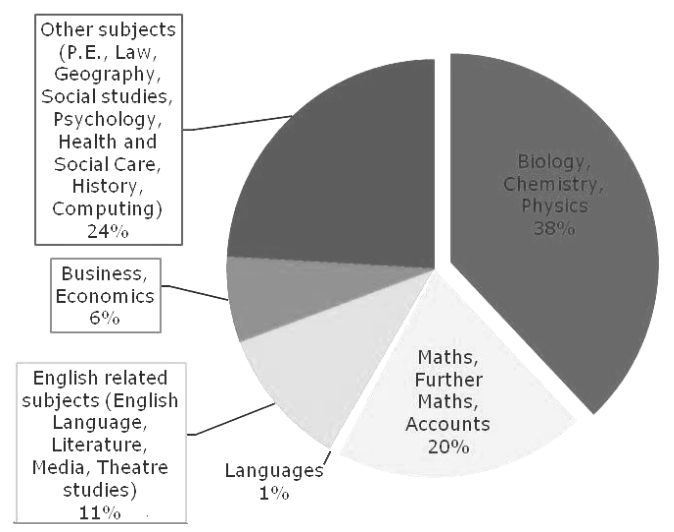


Figure 1: Popularity of science subjects at A-level amongst 14-17 school respondents.

Difficult Topics

When asked 'In your experience what are the most difficult topic(s) in chemistry to learn?' Chemical calculations, the mole and organic chemistry were topics mentioned by all groups as difficult topics (Table 2), in line with previous studies.

The mole and chemical calculations were also shown as the

Table 2: Ranked list of the most difficult topics in chemistry cited by respondents.

Teachers	University students	Secondary school students
Chemical/Mole calculations	Physical Chemistry	Chemical/Mole calculations
Organic chemistry	Chemical/Mole calculations	Bonding
Electronic configurations	Organic chemistry	Titrations
Thermodynamics	Reaction mechanisms	Organic chemistry
Quantum mechanics	Kinetics	Balancing equations
Bonding	Thermodynamics	Redox
Isomers	Quantum mechanics	Periodic table
Thermal decomposition	Transition metal theory	Chemical reactions
Balancing Equations	Energetics	Electronic configurations

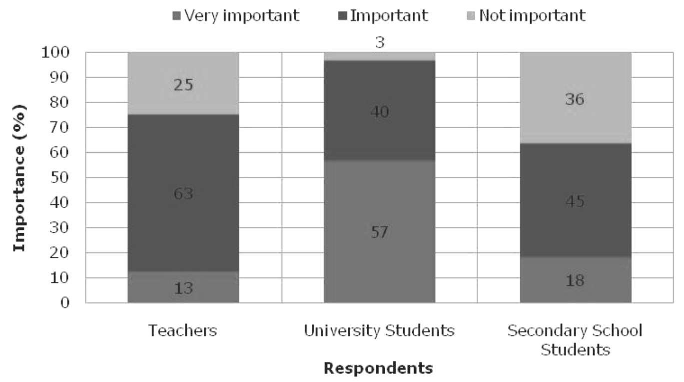


Figure 2: How important respondents feel it is to understand the mole.

most difficult chemistry related areas when the three groups of respondents were asked to rate certain topics according to difficulty using a scale of 1-10, where 1 is very easy and 10 is most difficult. Teachers scored the mole at 7.3 for difficulty in understanding, whilst pupils rated it as 5.8. University students scored it as 4.1, which implies that most chemistry students do eventually overcome issues with the mole. This needs to be considered, however, in the light of the answers to the question *"Have you ever struggled to understand the concept of 'the Mole'?"* 68% of GCSE and A-level students and 55% of the university students (who had studied the mole) stated they had struggled with this concept at one time or other.

Reasons cited by each group for this difficulty were:

- For GCSE and AS level students – "*poor resources in lessons", "confusing text books", "poor teaching", "the concept itself is confusing", "complicated", "new", "difficult to understand", "not enough lesson time is spent on the topic", "it involves maths".*
- Similar results were obtained from university students, 30% of the respondents cited *"poor teaching"* and 22% said *"it was a difficult concept to understand"*. Also cited were *"poor maths ability", "confusion", "difficulties in remembering and manipulating the equations", "no direct definition of the mole provided" and "difficult to relate to real life".*

Perceptions of importance of the mole

Given that the mole is problematic how did respondents view its importance? In Figure 2 there are clearly differences in perception here (acknowledging that our teacher sample was small compared to the student sample). Explanations for these views, where given, are listed in Table 3 for students. It became obvious after our analysis that we should have explored this aspect in more detail with teaching staff.

When is the mole studied at GCSE?

The answer is 'it depends'.

- The new OCR specification *Twenty First Century Science 'features many of the major theories of science, presented in a way that will encourage young people to appreciate their significance.' 'Students explore the key science explanations which help us to make sense of our*

Table 3: Reasons stated for rating how important it is to understand the mole.

Reasons	Frequency of secondary school students	Frequency of university students
NOT IMPORTANT		
do not understand how it is related to chemistry	2	0
not used in everyday life	4	0
not going to study chemistry in future	1	0
only need to know how and where to use it	0	1
never used	0	1
IMPORTANT		
useful to calculate concentrations and volumes	3	4
need to know	2	1
important to chemistry	2	5
used in calculations	2	5
used for balancing equations	2	0
used a lot throughout degree	0	2
VERY IMPORTANT		
fundamental in calculations	1	13
a lot of chemistry revolves around it	1	9
in exams	1	2
Required to study/understand chemistry	0	7
a lot of other topics expand on knowledge of mole	0	3
required to design reactions in industry	0	1

lives...these are what we want students to take with them from the course and carry with them into their adult lives, whether or not they use science in their work.'[16] This course has proved successful in making science more relevant to students and there has been a 30% increase in the number of students taking up AS-level science subjects after taking this GCSE course[17] but nowhere in the course is the mole concept introduced to students unless they are taking triple award science in which they are required to carry out an extra module (C7) known as *Further Chemistry*. This introduces the idea of carrying out calculations using concentrations and volumes to calculate the mass but the term 'mole' is not introduced at this level.

- The OCR Gateway specification[18] encourages GCSE students to learn about the mole in module C5 called 'How much?' Foundation students are required to have a basic knowledge about the mole and higher students need to understand the concept in more detail, but all students will be familiar with the concept.
- The Edexcel GCSE specification requires students that are taking triple award sciences to have an even more extensive knowledge of the mole than the other specifications mentioned previously.[19]
- The AQA GCSE specification requires higher students to have a basic understanding of the mole but they are not required to carry out any calculations.[20]

Students' knowledge of the mole at GCSE level will, therefore, be dependent on what science specification their school follows and whether they have studied triple award science. This will also effect when the concept is first introduced to them. Of the school students, 50% of the total group had studied the mole, a majority of this group were AS students and relatively few of the year 11 students had any mole experience. Of the university students surveyed, as expected, 100% of them had learnt about the mole, 44% had first done the mole at GCSE, 48% had studied the mole during A-levels. (The rest had either studied it before GCSE or once they started their degrees; this is typical for Access students, for example.)

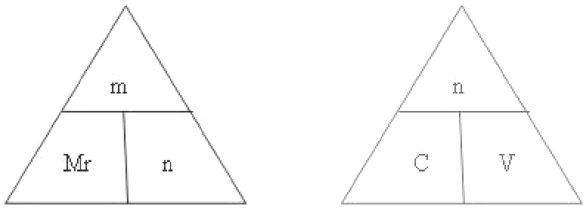


Figure 3: Mole equations in triangle forms.

Students who study, or have studied, triple award science GCSEs are more likely to have studied the mole compared with those students that took double awards and single awards. Only 34% of 15-18 year olds surveyed have taken or are taking triple science. Of these students, 78% have studied the mole at GCSE level and therefore these students will have an advantage over the other students. There is a mixture of students who have studied different specifications, taken triple award exams, double award exams and other access courses that take up chemistry at A-level. This can lead to confusion when this topic is studied more in depth at A-level. Those that have never learnt about the mole will struggle and this can lead to the student never gaining a proper understanding of the mole. When asked for ways of improving the understanding of the mole, some AS level students suggested that the concept was taught to everyone at GCSE level.

This is the sort of issue reflected in the views of 44% of university students who said that they found the transition between GCSE and A-levels difficult or very difficult and one of the reasons for this was bad preparation by their previous school. Many students also felt that their knowledge was lower or slightly lower compared to their peers due to having poor background knowledge and to teachers expecting a high level of understanding from all students. Could ensuring that all the students learn the basic concepts at the same level overcome this problem?

Hot Pen Writing

For this section respondents were asked to write down as much as they could about the mole in 5 minutes. The responses were then coded. The reason this approach was used was to use a non mathematical way of assessing conceptual understanding. Table 4 shows a summary of the coded responses that were given.

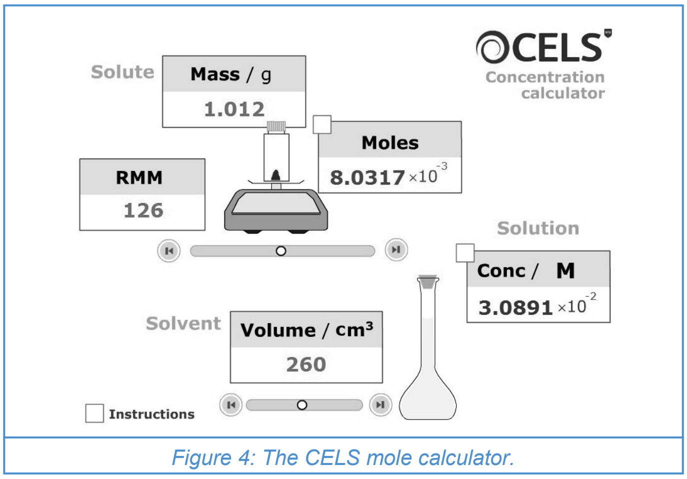
The results show that key words from the IUPAC definition were mentioned frequently by all the respondents; no secondary school students referred to the mole symbol. The most popular response given by university students was the equation relating moles with mass and molecular weight ($n = m/Mr$). This response was also common with teachers and secondary school students. A lot of responses also showed the relationship between the mole and Avogadro's constant and the equation $n=c \times v$. The most common response by secondary school students was the link with the number of atoms in 12g of carbon-12.

All three groups of respondents showed a standard knowledge of the mole. A key point though is that most people just wrote down the equations that were associated with the mole and some of them gave these in the forms of triangles. Very few people explained them in written form. Just stating equations does not always show that people understand the theory behind the concept as they did not often provide clear definitions. Such behaviour could be labelled as 'ritualistic' according to Perkin's 'Troublesome Knowledge' model.

If this emphasis on equations is because the mole is only being taught mathematically then this will increase the difficulties of students with poor maths ability. Some students are not able to manipulate and rearrange the equations easily to the format that is required. The triangle form of the mole equations as shown in Figure 3 can be an easier format to handle but this is not necessarily true for all students. Some students prefer a written explanation of how to carry out the calculations as they do not respond as well to symbols.

Table 4: Results from hot pen writing technique about the mole.

Secondary school frequency table		
mole knowledge	**Frequency**	
number of atoms in carbon-12	7	
used to calculate concentration	4	
equal to mass number	3	
certain number of atoms in an element	2	
unit of measurement	1	
amount of substance	4	
Avogadro's constant (6.02 x 10^{23})	3	
Titrations	1	
gas equation	1	
EQUATIONS:		
n = m/ Mr	5	1 in triangle form
		4 in equation forms
n = c x v	1	
Teacher and lecturer frequency table		
Mole knowledge	**Frequency**	
relationship to Avogadro's constant	2	
6 x 10^{23} (Avogadro's constant)	3	
relationship to amount of a substance	6	
mol (unit)	1	
example of number of moles in a molecule	3	
used to carry out chemical calculations	1	
symbol (n)	2	
useful in titrations	1	
EQUATIONS :		
n = m/ Mr	5	1 in triangle form
		2 written explanations
		2 in equation forms
gas equation	1	
n = c x v	4	
University students		
Mole knowledge	**Frequency**	
relationship to Avogadro's constant	19	
Avogadro's constant (6.02 x 10^{23})	24	
relationship to molecular weight	9	
weight of an element/ compound	3	
amount of substance	13	
large number	1	
number of atoms in 12 g of carbon	11	
symbol (n)		
unit (mol)	2	
EQUATIONS :		
n = m/ Mr	37	3 written explanations
		4 in triangle forms
		20 in equation forms
n = c x v	23	5 written explanations
		5 in triangle forms
		13 in equation forms
gas equation	1	



Mass / g 1.012

RMM 126

Moles 8.0317×10^{-3}

Volume / cm³ 260

Conc / M 3.0891×10^{-2}

Figure 4: The CELS mole calculator.

What did students think could be done to improve their understanding of the mole?
They said (in order of popularity);
University students

- Practice questions regularly.
- Introduce the concept earlier at a simple level.
- Worked examples.
- Provide a clear definition.
- Regular review of the fundamental principles.
- Useful diagrams and animations.
- Smaller classes.
- Develop a phrase or rhyme to remember the equations.
- Reminder of calculations before starting a degree.

School students (14-17)

- Provide a clear explanation.
- Practical activities.
- Teach to everyone at GCSE level.
- Revision.
- Clear explanation in text books.
- Better teaching.
- More time spent learning the subject.
- Make learning more fun.

Recommended mole resources

- The Letts GCSE AQA revision guide[21] gives a good simplified explanation of the mole, it makes good use of colour and presents information in a simplified form. The equations are presented in full word form and worked examples are provided. Whilst not a teaching aid it was the only book commonly found during the research that explained the mole in a simple and effective way and related the mole to ideas that the students are familiar with.
- Interactive resources such as the CELS mole calculator (and dilution factor tool)[22] allows students to practice the calculations involved in the concept (Figure 5).
- The BBC GCSE Bitesize website[23] also provides a range of interactive activities for a range of different topics. The chemical calculations activity involves a step by step visual and verbal explanation that contains useful animations and diagrams to help bring the learning to life but it only covers some of the concepts involved with the mole. A resource like this to cover the whole of the topic would be particularly useful for students as it is fun, interactive and starts with the basics and builds on these.

Summing up – where next?
These findings reinforce previous findings that calculations, especially those including the mole, are amongst the most difficult subjects in chemistry to understand and to teach. We have looked at different perspectives, using a range of techniques. Students stated that they struggled with the mole because of poor teaching and poor resources. It is important that students' learning styles are taken into account when teaching and also when selecting resources to aid students' learning. That there can be a mismatch in how material is delivered by teachers versus how students prefer to learn is shown in Figure 5 (recognising this is a small teacher sample).

Our student cohort preferred to learn by working in groups with colleagues and visually, whilst the teachers surveyed tended to prefer individual working and verbal delivery. Calculations should be taught in a way that embraces multiple formats so students can learn from their preferred method and for those that struggle with mathematics, step by step examples should be worked through. The theory of the mole as an amount of substance should also be emphasised to help develop understanding of the concept.

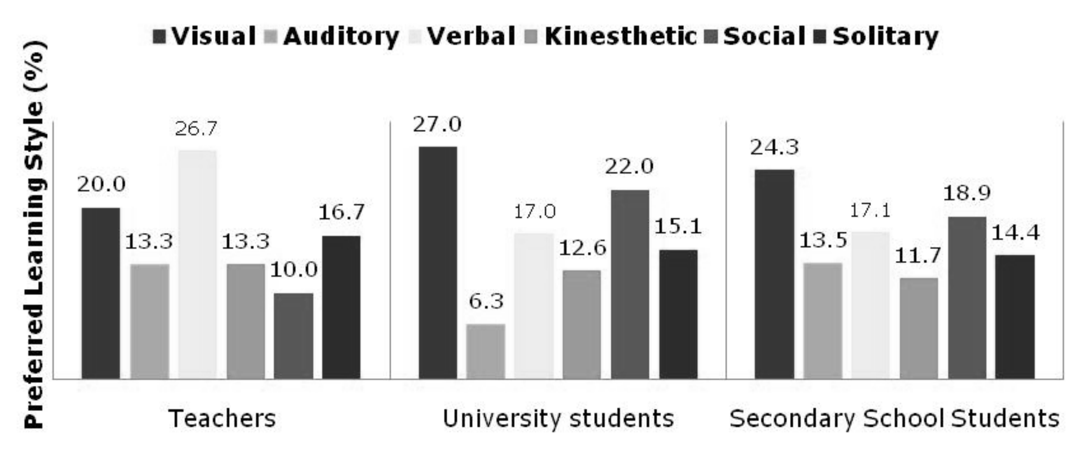


Figure 5: Preferred learning styles for students & preferred teaching styles of teachers.

Based on our survey results we suggest that by adjusting how and when the mole is taught the problems we identified could be overcome if we:

- expose all students to the mole at same time, ideally early in GCSE.
- the concept is taught from a basic level using words and analogies.
- ideas are developed stepwise as the students' education progresses.[11]
- students are shown the importance of the mole and its relationship to real-life.
- extra support is provided to students who struggle with maths.
- a variety of learning styles and resources are used to make the learning more interactive and fun.
- frequent checks on understanding are made using a range of assessment tools.
- don't assume prior knowledge and full understanding of the concept.

Why introduce early in GCSE? All our student cohorts suggest an earlier introduction to the idea of the mole. We would recommend representing the mole as a 'number of items' during year 9 or 10 regardless of the specification being studied. Using a purely word format, one can emphasise the idea that the mole represents a (very large) number of items in exactly the same way that the dozen is a way of representing 12. On this first encounter we would recommend not using any equations. Once the concept of a 'number of items' has been grasped then attempts to introduce calculations could be made. It is obvious that the mole as a concept is affected by transitions in education. It is also clearly a transformative Threshold Concept: once people have 'got it' they move on and then the whole thing becomes just part of their background.

There are issues here over what is appropriate to be taught within the GCSE science curriculum, acknowledging that not everyone will take the study of chemistry further, a landscape complicated by the seemingly perpetual changes in syllabus and increasing popularity of both applied science and triple award science. However if students stop at GCSE science we feel it would be better they leave with a qualitative understanding of the mole as number of atoms rather than a muddle of misarranged equations.

Further research is needed to look at how effective the suggestions of this study are for improving students understanding of the mole concept. There is also similar research to investigate the other areas of chemistry that students find difficult and investigate what can be done to improve them. Further work should look at a wider selection of teachers and academic staff as learning is about the students and staff working together to tackle learning difficulties, as Piaget's said '*it is not just about what is taught, but how it is taught that matters*.'[24]

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Contribute to the next issue!

If you would like to contribute to the next issue in the first instance please send an abstract, by **1st March 2011**, to the editor...

Tracey Madden
UK Physical Sciences Centre
Department of Chemistry
University of Hull
Hull HU6 7RX
Tel: 01482 465418
Fax: 01482 465418
Email: t.madden@hull.ac.uk

The deadline for full articles is **1st June 2011**.

This is your chance to contribute to a journal highlighting education in the physical sciences at the tertiary level.

There is a lot of innovation within the community but not always the opportunity to share it with like minded colleagues.

New Directions is 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 *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.

We are seeking the following as contributions…

Reviews of topics in physical sciences education and educational research

These are normally invited contributions from 'expert' practitioners. Typically they would be informed, accessible articles of up to 3000-4000 words and would cover the teaching, learning and assessment literature for the previous 12 months. Examples would be: Pedagogic research in the physical sciences; E-learning; Assessment; Outreach (for recruitment).

Communications

These would be contributions in response to a 'call for papers' from the physical sciences education community (and might include: innovations, effective practice, what worked for me, what failed for me etc). These articles should present the context, the problem, how it was tackled and the evaluation and possible further work. They should not be just descriptive or narrative. Communications would typically be up to 1500-2000 words although longer contributions would also be considered.

Initiatives

These would be invited reports from projects (e.g. FDTLs and CETLs). Typically, these reports would be up to 1500-2000 words.

All submissions also should include contact details and a short summary/abstract.

Style guide for contributors

These notes are a guide for those preparing contributions for New Directions.

They are not intended to be mandatory but using them facilitates production.

The notes cover the major areas of the formatting used *in-house*.

General
Contributions should normally be submitted as email attachments from a wordprocessor (although other submissions may be acceptable).

Text
Text is aligned left, with a single line space, and no additional space added before or after paragraphs. Paragraphs are not indented but between paragraphs there is a single line space.

Titles for contributions are Century Gothic, 18pt, Academy Blue (R77: G144: B205).

Normal (body) text is Arial, 9pt, black.

Main headings within the text are Arial, 9pt, Bold.

Abstracts are in Arial, 9pt, Italic text.

Contributor information is in Arial, 9pt, Bold text.

Bulleted and numbered lists are aligned left with subsequent text indented by 0.25 inches.

References
References in the text should be denoted via superscripted numbers.

References should be listed at the end of the contribution in the format shown in the following examples:

1. Polanyi, M. (1962) *Tacit Knowing: Its Bearing on Some Problems of Psychology*, Reviews of Modern Physics, **34** (4), 601-616.
2. Laurillard, D. (1993) Rethinking University Teaching: a framework for the effective use of educational technology, London: Routledge.

Images
Images should normally be supplied separately (as email attachments) in a high resolution format as jpeg or gif files (although other formats - e.g. inline graphics - may be acceptable), with legends. Images will be rendered to grey-scale for printing.

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