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Research-Teaching Linkages: enhancing graduate attributes

Physical Sciences

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Research-Teaching Linkages: enhancing graduate attributes

Physical Sciences

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Preface

The approach to quality and standards in higher education (HE) in Scotland is enhancement led and learner centred. It was developed through a partnership of the Scottish Funding Council (SFC), Universities Scotland, the National Union of Students in Scotland (NUS Scotland) and the Quality Assurance Agency for Higher Education (QAA) Scotland. The Higher Education Academy has also joined that partnership. The Enhancement Themes are a key element of a five-part framework, which has been designed to provide an integrated approach to quality assurance and enhancement. The Enhancement Themes support learners and staff at all levels in further improving higher education in Scotland; they draw on developing innovative practice within the UK and internationally. The five elements of the framework are:

- a comprehensive programme of subject-level reviews undertaken by higher education institutions (HEIs) themselves; guidance is published by the SFC (www.sfc.ac.uk)
- enhancement-led institutional review (ELIR), run by QAA Scotland (www.qaa.ac.uk/reviews/ELIR)
- improved forms of public information about quality; guidance is provided by the SFC (www.sfc.ac.uk)
- a greater voice for students in institutional quality systems, supported by a national development service - student participation in quality scotland (sparqs) (www.sparqs.org.uk)
- a national programme of Enhancement Themes aimed at developing and sharing good practice to enhance the student learning experience, facilitated by QAA Scotland (www.enhancementthemes.ac.uk).

The topics for the Enhancement Themes are identified through consultation with the sector and implemented by steering committees whose members are drawn from the sector and the student body. The steering committees have the task of establishing a programme of development activities, which draw on national and international good practice. Publications emerging from each Theme are intended to provide important reference points for HEIs in the ongoing strategic enhancement of their teaching and learning provision. Full details of each Theme, its steering committee, the range of research and development activities as well as the outcomes are published on the Enhancement Themes website (www.enhancementthemes.ac.uk).

To further support the implementation and embedding of a quality enhancement culture within the sector - including taking forward the outcomes of the Enhancement Themes - an overarching committee, the Scottish Higher Education Enhancement Committee (SHEEC), chaired by Professor Kenneth Miller, Vice-Principal, University of Strathclyde, has the important dual role of supporting the overall approach of the Enhancement Themes, including the five-year rolling plan, as well as institutional enhancement strategies and management of quality. SHEEC, working with the individual topic-based Enhancement Themes' steering committees, will continue to provide a powerful vehicle for progressing the enhancement-led approach to quality and standards in Scottish higher education.

Norman Sharp
Director, QAA Scotland

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Foreword

This Enhancement Themes project - Research-Teaching Linkages: enhancing graduate attributes - has over the last two years asked institutions, departments, faculties, disciplines, staff and students to reflect on the intended outcomes of HE, and has examined how links between research and teaching can help develop 'research-type' graduate attributes. The 'attributes' in question are the high-level generic attributes that are necessary to allow our graduates to contribute to and thrive in a super-complex and uncertain future where the ability to question, collate, present and make judgements, quite often with limited or unknown information, is increasingly important; key attributes, it is argued, that are necessary for our graduates to contribute effectively to Scotland's civic, cultural and economic future prosperity.

The Enhancement Theme adopted a broad, inclusive definition of research to embrace practice/consultancy-led research; research of local economic significance; contributions to the work of associated research institutes or other universities; and various types of practice-based and applied research including performances, creative works and industrial or professional secondments.

The Enhancement Themes comprise one sector-wide project and nine disciplinary projects: Physical sciences; Information and mathematical sciences; Arts, humanities and social sciences; Health and social care; Business and management; Life sciences; Creative and cultural practice; Medicine, dentistry and veterinary medicine; and Engineering and the built environment. The aim of the projects was to identify, share and build on good and innovative practice in utilising research-teaching linkages to enhance the achievement of graduate attributes at the subject level. The sector-wide project comprised an ongoing discussion within and between Higher Education Institutions, involving staff and students reflecting on and exploring research-teaching linkages, how they can be structured and developed to achieve 'research-type' attributes, and how students are made aware of the nature and purpose of these in order to fully articulate and understand their achievements as graduates.

Research-Teaching Linkages: enhancing graduate attributes has provided the sector with a focus for reflection on the nature and outcomes of HE - along with the opportunity to develop a rich array of resources and supportive networks to add to the student learning experience and enable our graduates to contribute effectively to Scotland's future.

Professor Andrea Nolan
Chair, Research-Teaching Linkages: enhancing graduate attributes
Vice-Principal Learning and Teaching, University of Glasgow

1 Executive summary

What is this report?

This report represents one of the outputs of the Physical Sciences discipline project of the Enhancement Theme on Research-Teaching Linkages: enhancing graduate attributes. It takes the form of an extensive series of case studies and snapshots of current practice from physics and chemistry throughout (and occasionally outside) Scotland, grouped according to practical ways of enhancing research-teaching linkages in the undergraduate curriculum.

We have attempted to identify the breadth of what research-teaching linkages in the Physical Sciences in Scotland actually map on to, in terms of activities at the 'coalface' of undergraduate teaching and learning. Contrary to what we think may be the common consensus within departments, this is not just about the final-year honours project (though that quite rightly remains a capstone of the undergraduate research-teaching experience), even in subjects where undergraduate curricula are built on the principles of predominantly linear construction of subject knowledge.

What does it contain?

Our project made contact with all deans of undergraduate study and directors of teaching/learning in all physics and chemistry departments throughout Scotland. From these contacts we obtained detailed information about practices within the departments and illustrations of how they forged links between teaching and research in the broadest sense. The members of the project team were genuinely surprised at the range and quality of what was being done within the sector in Scotland to more closely integrate these two key activities.

We never expected to unearth so much when we began this project in early 2007 - a handful of case studies was our initial expectation. But we found a great deal more. So rather than lose some of the detail captured, we chose to expound as many case studies as we could. We also opted to retain other insights, presented in the form of brief snapshots of a particular activity, along with further contact details and online information. The range of activities we uncovered is one reason why this document is as long as it is. We have tried to keep the wrapping around the case studies and snapshots to a minimum, as the most valuable part of this report is what they have to say. The accompanying project website (http://physci.rtl.googlepages.com) contains all the case studies and project documentation in a slightly more granular form.

The case studies and snapshots, which form the basis of this report, illustrate activities across the range of levels of the undergraduate programme, from first-year laboratories to the final-year project exercise. These examples cover the breadth of the discipline, from traditional physics and chemistry programmes to astronomy and forensic sciences. While a lot are specific to a particular course in a school or department, many have wide applicability beyond this specific area.

What are some of the project findings?

The project found several examples of ways to 're-invent' early-years practical laboratory work. It is often felt that early-years teaching in the Physical Sciences is one of the most difficult areas in which to integrate research-based activities, because of large class sizes and elementary (sometimes familiar) material. However, our case studies illustrated a variety of different ways in which this could be achieved. For example, the Physics Department at the University of Glasgow has replaced traditional laboratory work with 'experimental tutorials' that more closely couple the formally taught topics with practical activities.

We found a broad range of activities devoted to enhancing transferable or graduate skills. These were not bolted on as an afterthought to existing courses, but rooted firmly in the specific discipline context. The challenge in such courses is to develop these skills alongside extending physics or chemistry knowledge. A good example is the transferable skills module in the third year of the Physics programme at the University of St Andrews, which does exactly this while enhancing skills in finding and critically evaluating information, communicating orally and in written form, teamwork and information technology (IT).

Several opportunities exist for students on physics and chemistry programmes to experience research first hand well before their final-year projects. These research opportunities may be extracurricular or part of timetabled classes, in term time or as internships and placements. A unique opportunity is described from Liverpool John Moores University, using the Liverpool Telescope - the world's largest fully robotic telescope. As part of a number of level 1 distance learning courses in astronomy, students can apply for observation time using the telescope, going through all stages of the research process of planning observations and collecting then reducing data before analysis.

The final-year honours project is still the capstone of research-teaching linkage in practically all physics and chemistry courses, and we have tried to synthesise what is done in this area across the sector. Prior to the honours project in the curriculum, we found a range of different project skills preparation activities. The emphasis in these was on developing the required skills through structured activities, enabling students to make the most of the project work that subsequently follows. In the School of Chemistry at the University of Edinburgh, the Training in Research Methods course exposes students to a series of activities and mini projects across a range of topic areas. The aim is to develop students' practical research skills and provide an introduction to the methods, techniques and instrumentation in different areas of chemistry.

One final area we attempted to investigate was that of the views of graduates and what they believed were the aspects of their studies that had a direct impact on the attributes valued by employers and that would be valuable to them after having left university. In a project undertaken by a final-year Physics undergraduate at the University of Edinburgh, a survey of graduates illustrated how particular aspects of the taught programmes developed these skills, and the views of graduates looking back.

Who should read this report?

We believe this report is of relevance to, and hope it will be read by, staff from different backgrounds and with different responsibilities. For physical sciences discipline-based academic staff, it provides a complete picture of what is being done where, much of which would be transferable and adaptable to different contexts. Equally, it is of relevance to staff in leadership roles within academic departments and to those who contribute to academic policy within institutions.

Much of what is described here is also of relevance to colleagues in similar subjects (such as engineering, other sciences, and mathematics) and to educational developers. Finally, Higher Education Academy (HEA) Physical Sciences Centre colleagues and representatives will find a great deal of value within the breadth of case studies presented.

2 Introduction and background

2.1 The links between research and teaching

> 'Universities need to set as a mission goal the improvement of the nexus between research and teaching....The aim is to increase the circumstances in which teaching and research have occasion to meet' (Hattie and Marsh,1996).

This report is one of the outputs from the Physical Sciences discipline project of the Enhancement Theme on Research-Teaching Linkages: Enhancing Graduate Attributes. It sets out effective, practical ways in which research-teaching linkages can be useful in supporting and enhancing the acquisition of research-type graduate skills in the Physical Sciences in Scotland. Drawing on an extensive series of case studies, we survey the breadth of current practice in this area, providing practical insights for course developers and academic staff in the discipline.

But what is the relationship between teaching and research actually like in specific disciplines. Do the two co-exist peaceably, yet broadly independent of one another? Is the relationship more one of antipathy, where they compete for that precious commodity of staff time and effort? Or are there ways to integrate them, each benefiting from the cross-pollination of the other?

> 'The questions of the students are often the source of new research. They often ask profound questions that I've thought about at times and then given up on, so to speak, for a while. It wouldn't do me any harm to think about them again and see if I can go any further now. The students may not be able to see the thing I want to answer, or the subtleties I want to think about, but they remind me of a problem by asking questions in the neighbourhood of that problem. It's not so easy to remind yourself of these things (Feynman, 1965 Nobel Laureate in Physics, 1986).

The reasons for wanting to forge closer links between the two core activities of a higher education institution (HEI) - the creation and dissemination of knowledge - are many and have been discussed elsewhere (Brew, 2006). There is a broad consensus that it is important that students learn how to learn in 'research mode', developing independent learning and exploration skills for the future. Another driver may be to dispel any view from outside HEIs that the often claimed benefits of closer linkage between research and teaching are no more than empty rhetoric. Many HEIs have mission statements stressing both research and teaching; articulating 'how' and evidencing 'what' is more difficult, and there is of course a subject-specific dimension as well.

> 'A meaningful science education involves transforming the way in which students think by promoting a progression from "novice" to "expert" in both their attitudes and their approaches to the discipline and problem solving in that discipline. Today's educator should aim not simply to produce more scientists, but rather to get all students to learn to think about science like a scientist. Similarly, the goal of education in general is to get students to think like experts more broadly' (Wieman, 2001 Nobel Laureate in Physics, 2004).

We started our examination of research-teaching linkages in the Physical Sciences from the two-dimensional (2D) model of curriculum design and the research-teaching nexus proposed by Healey (2005) (see figure 1).

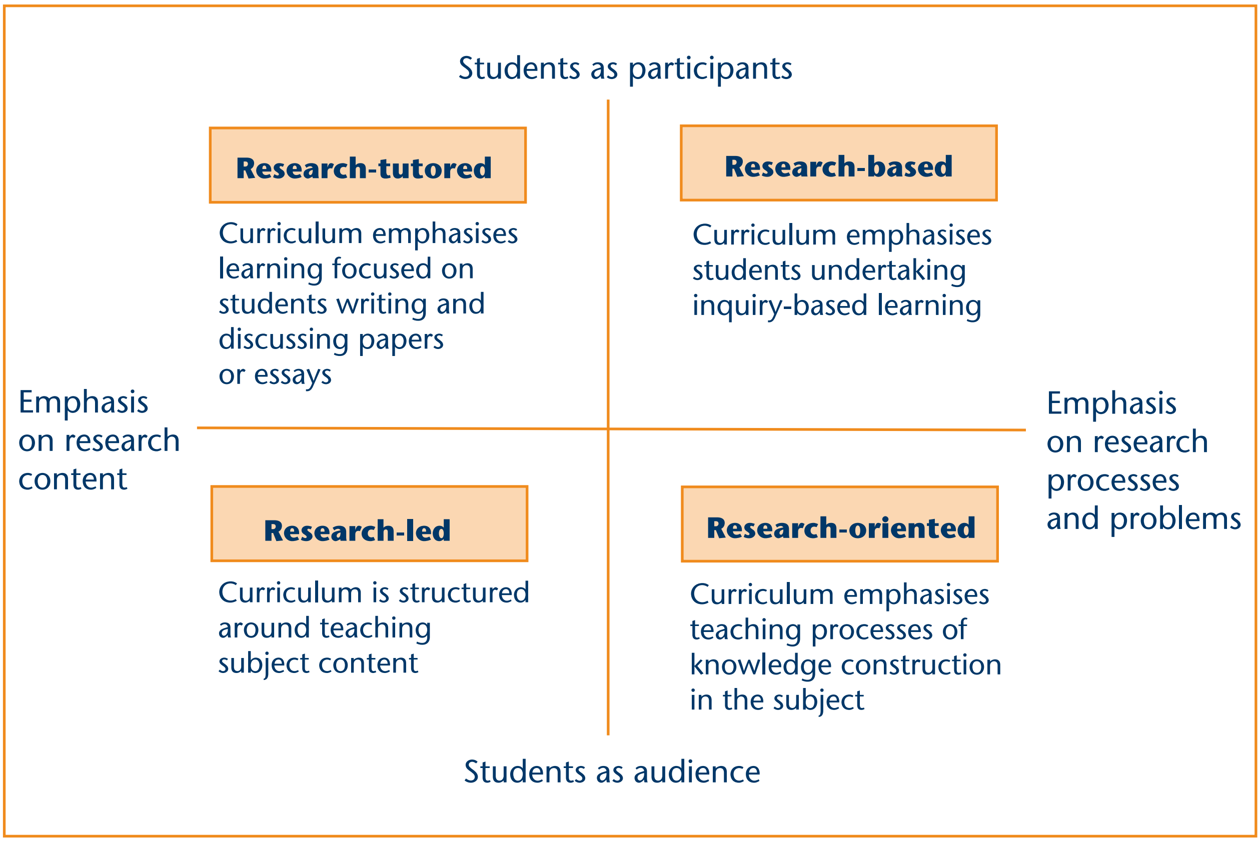

Figure 1: the research-teaching nexus, taken from Jenkins and Healey (2005, p.22)

According to this, teaching may be categorised into four non-exclusive quadrants, with dimensions relating to content and student engagement (University of Bath, 2007).

Starting bottom left, research-led teaching treats students as an audience. It can include, for example, students learning about the research in which the lecturer is involved, or research findings. The emphasis here is clearly on understanding the discipline content as opposed to research processes. General interest seminars or inspirational forward-look lectures are examples of this, as are parts of the core content of some lecture courses.

Research-oriented teaching places more emphasis on developing research processes and skills and an understanding of how knowledge is constructed in the discipline, as opposed to simply learning 'certified' knowledge previously created. In practice, for many staff this can be usefully summarised as students acquiring 'a research ethos' and inquiry skills. Courses or modules which prepare students for a research project exercise are examples of such linkages.

Research-based teaching, or sometimes synonymously enquiry-based teaching or problem-based learning (PBL), is where the emphasis is placed on 'learning in research mode', even if the outcomes for students do not result in 'new' knowledge for the subject. Students are learning in a community of researchers, with learning tasks focused on enquiry-based activities rather than accumulation of specific subject content. The role of staff in this mode is rather different from that in traditional 'lecturing' mode, and includes aspects of facilitator and partner to students undertaking such activities.

The final quadrant is research-tutored learning, where emphasis is placed on students as participants in the creation of research content. Typically, this might include practical experience in research laboratories, or where students learn about research findings in small-group discussions with a teacher.

> 'You will only see what you know to look for, and scientific training will give you much better eyes. Not because of the facts that you learn - they age quickly and you should always distrust them a little.... To a scientist, cramming facts is what practising scales is to a pianist: there is no way around it, but it's not enough' Gottfried Schatz, 2004).

One challenge we faced in this project was communicating this 'model' of ways to link research to subject colleagues, particularly when illustration by a particular course or activity they might be familiar with evidenced overlap with one or more quadrants. For example, the process of critical evaluation of research papers and reviewing existing (and sometimes conflicting) viewpoints from the discipline encompasses aspects of both research-tutored and research-oriented learning. We chose to simplify the 2D model and map onto a linear scale:

- learning **about research** - research-led
- learning in **research mode** - research-based
- learning to **do research** - a hybrid of research-oriented and research-tutored (a pairing often seen in Physical Sciences teaching).

In addition to its simplicity, this linear scale allowed an additional fourth category which is absent from Healey's model - that of **research-informed** teaching, sometimes called the scholarship of teaching. In this, academics become involved in research into the way in which their subject is taught, with a process of deliberate and systematic enquiry into teaching and learning in the discipline.

In the case studies that form the bulk of this report, the focus is on the first three categories, which map onto Healey's quadrant model. In passing, we note the growth and increasing visibility of the fourth category. Many Scottish physics and chemistry departments now employ teaching-only staff, not as second-class academics who bear heavy teaching loads to free up research time for colleagues, but as staff given the time and space to apply a scientific approach to science education. Bringing the same kind of research ethos to bear on problems relating to pedagogy is driving forward innovations and curricular change at a far faster rate than willing-but-short-of-time academics alone can manage (Kelly, 2008).

...'We believe an understanding of the research process - asking the right questions in the right way; conducting experiments; and collating and evaluating information - must be a key part of any undergraduate curriculum; whether...those involved in delivering it are actively engaged in research activity themselves' (Bill Rammell, Minister for Higher Education (HE), October 2006).

2.2 Research-teaching linkages in the Physical Sciences

Below we briefly describe the process the project team went through to make contact and gather data from around the Physical Sciences sector in Scotland. A starting point was to review what was currently visible in the published literature. This was much less than in some related disciplines such as bioscience, which has among other things a well-established undergraduate research journal (Bioscience Horizons), available freely online (http://biohorizons.oxfordjournals.org/). This publishes the best undergraduate bioscience research from the UK and the Republic of Ireland, from work based on final-year research projects.

Nonetheless, excellent examples of linkages in the Physical Sciences were to be found, including as follows.

- Chemists at the University of Glasgow have created 'interactive teaching units' in second-year classes. These cover topics such as finding replacement refrigerants and the industrial manufacture of titanium dioxide, a widely used whitener and pigment. A major aim of these exercises is to diversify the student learning experience by adopting the concepts of problem-based learning and providing students with the opportunity to develop their presentation skills in a variety of ways (Grant et al, 2005).
- Chemists at University College London (UCL) were involved in an ongoing pilot project aimed at full integration of teaching and research at undergraduate level. The chief innovation has been the mechanism of inheritance. Each year, students receive a body of work produced by the previous group of students and make improvements and additions to it; this process can be repeated until publishable materials are produced. This is part of a system of learning that enables students to function as a real and evolving community of researchers (Chang, 2005).
- In the Department of Physics at the University of Leicester, physicists have established a Journal of Special Topics, which aims to introduce students to the way in which scientific research is disseminated and developed. Groups of students produce 'papers' for the journal. They coordinate the editorial process as well, producing three issues of the journal during the course (Raine, 2003). The same Department developed extensive resources for deploying problem-based learning in undergraduate Physics in a Fund for the Development of Teaching and Learning (FDTL4) project that ran from 2002-06 (Project LeAP - PBL in Astronomy and Physics). A Practice Guide to Problem-based Learning in Physics and Astronomy published by the HEA Physical Sciences Centre provides a wealth of useful information and resources (Raine and Symons, 2005).
- Chemists at the University of Warwick have 're-invented' first-year undergraduate chemistry lectures, with the aim of putting learning through practical experience at the front of the undergraduate learning experience. This work is described in a case study within section 3.2.
- The Science Undergraduate Research Experience (SURE) (www.le.ac.uk/Physics/sure.shtml) is a six-week summer programme to support undergraduates to undertake research within the Department of Physics and Astronomy and the Space Research Centre at the University of Leicester. A range

of projects are available in astrophysics, plasma physics, space science and condensed matter physics. Regular seminars involving students and staff are held on current research topics. At the end of the summer, all participating students produce a written report and give a brief presentation about their work. The scheme has attracted very positive feedback from staff and students alike.

- The Engineering and Physical Sciences Research Council (EPSRC) vacation bursary scheme (www.epsrc.ac.uk/PostgraduateTraining/VacationBursaries/default.htm) provides funding for undergraduates to gain first-hand experience of research in a UK university to help them to consider a research career. Students carry out a research project lasting around 10 weeks during the summer vacation. EPSRC has selected 31 universities to take part in the activity, based on their EPSRC research income.
- Many departments have adopted personal response systems in large-class lectures (for a recent review in the Physical Sciences, see Bates et al, 2006). While not strictly a linkage between teaching and research, these methods have proved remarkably effective in enhancing students' engagement with conceptually challenging material and their critical thinking and evaluation skills, all examples of attributes we would wish our graduates to attain.

2.3 Progression of the project

Before describing the way the project progressed and how that is reflected in the rest of this report, it is worth highlighting some of the discipline-specific aspects regarding the linking of teaching and research. Learning Physical Sciences, and science in general, is often thought of as a predominantly linear construction of understanding. One needs to understand classical (Newtonian) dynamics before considering special relativity, before general relativity. There are lots of building blocks to be assembled, often leading to the assumption that the only place in the undergraduate curriculum to 'work as a researcher' is towards the end, when all the required blocks are firmly cemented in place. This, as we have found, is far from the truth of the broad range of activities we have researched.

In the first year of a physical sciences degree, despite pressures of large student numbers and finite space and resources, there are examples of research-based and research-oriented activities, such as teaching labs with open-ended problem-based learning rather than prescriptive 'recipes'. A number of interesting examples are described in section 3 of this report. Almost universally, the capstone experience is the final-year honours or master's project, to which a great deal of time, care and attention is devoted in all institutions. It is tempting in a report such as this to overlook the commonplace and focus on the novel, but here we try to capture a range of instances of the final-year project from across the sector in a case study on this topic.

The project team made contact with all deans of faculty and directors of teaching in physics and chemistry over the spring of 2007. Between them, the four project team members were able to visit most of them in person during the summer. From these visits we began collating information into themes across the disciplines and institutions. We were anticipating in the order of a dozen case studies of innovative and interesting practice. In the event, we unearthed far more than this. Not willing to see all this material go unreported, we devised a briefer communication to include in this final report: a snapshot of a particular course or activity. Most of the case studies are drawn from Scottish institutions. However, through contacts via the Higher Education Academy Physical Sciences Centre and the Institute of Physics (IoP), we learnt about innovations and exemplars from south of the border, some of which are also included here.

The main body of this report (section 3) presents the case studies and snapshots in detail. One case study was contributed by a final-year MPhys undergraduate from the School of Physics at the University of Edinburgh; rather than tuck it away at the back of the report, we present it here, reflecting the importance of the development of graduate attributes to the Enhancement Theme. In the summer of 2007, this student undertook a summer vacation project to try to elucidate what some recent graduates thought were the attributes they took away from their degree. It produced a rich and varied illustration of the ways in which specific graduate attributes were fostered and developed during the degree programme.

2.4 Case study on developing graduate attributes

Case study: Graduate stories - a survey of perceptions of graduate attributes

Much effort is invested in trying to understand and enhance graduate attributes from the academic perspective; what we think will better improve the way we link research and teaching in undergraduate curricula to achieve enhanced graduate attributes. But what perspective do graduates have on this? While feedback is often sought on course-specific issues, it is less common to obtain detailed information at whole-programme level, or about specific skills and attributes taken away from a degree. In the summer of 2007, we undertook a survey of physics graduates from the University of Edinburgh to distil their views about the most important attributes they took away from their university degree.

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Discipline area: physics

Brief description of activity

This study attempted to uncover what graduates from the School of Physics at the University of Edinburgh thought were the most important attributes they acquired from their time at university. It also sought to discover why students chose to study physics, and if the course lived up to their expectations.

The original aim for this study, which pre-dated the Research-Teaching Linkages Enhancement Theme, was to capture information on the broad range of careers that physics graduates go on to after graduation, beyond the 'traditional' and prevalent view of academia or teaching. We wanted to highlight the breadth of what was available, with a view to promoting the opportunities offered by physics degrees to students who have already chosen to take physics as a Higher or A Level subject choice.

We undertook an online survey of about 200 physics graduates whose details were provided via the University of Edinburgh's alumni office. Of these, 32 completed a detailed questionnaire about their degree and career since graduation. The questionnaire required mainly free-text responses rather than quantitative tick-box answers, so that the details of graduates' opinions could be judged properly (www.surveymonkey.com/sr.aspx?sm=weGA3hltX0j1kUTkJZrWfQyuPN7WXeUomBj69C7KuzA_3d). From these responses, a subsection of graduates were interviewed via telephone to gain a more complete idea of their opinions and give them the opportunity to expand on previous answers. The interview included questions that probed more into their career and university life to find out the parts they valued, the skills they gained and the parts of the course they felt could be improved upon.

In what way does the activity encourage linkages between teaching and research?

This project was somewhat different from the other case studies presented in this report, since it was not concerned with the undergraduate curriculum as such. However, the relevance to linkages between teaching and research is clear, through the attempt to discover what attributes graduates and employers valued and how well these are provided for within the current degree programmes (specifically at the University of Edinburgh, but of generic significance to others as well).

From the questionnaire it was clear that many respondents felt that it was very important to develop more strongly the links between teaching and research in the curriculum. One graduate observed that their exposure to research during their undergraduate study made it clear that at the forefront of the subject, knowledge and understanding were much more open and debatable than in the early years of the undergraduate programme:

> 'It is important, though, for lecturers to say explicitly what is still unknown and puzzling, such as wave/particle duality, relativity paradoxes, etc.'

Many felt that the part of their degree which most directly involved research was invaluable, whatever their future career choice. One graduate said that the most important thing he gained from his degree was the 'experimental techniques from a practical point of view, patience and appreciation of uncertainties'.

For some, the research experience was of direct relevance to succeeding in their chosen career:

> 'My degree was proof I could lead a research project on my own and make sure to make progress along the lines expected by my employer.'

Similarly, another graduate commented that it was the combination of the knowledge he had gained during his physics degree and the research experience he developed from it that led him to his career:

> '…I was invited to join a major electronics company because of my physics degree and research experience.'

For some who progressed into careers where specific research skills and subject knowledge were required, the expertise gained during university could be used throughout their lifetime:

> 'I now do my own research so all the research experience I've gained at uni helps me every day.'

The same value appeared to be placed on the experience by those who did not go into careers directly using the subject knowledge of their degree:

> 'The degree has little direct impact now, but I believe that the project work, the presentations and challenges to work, and the logical methods were invaluable.'

Outcomes from the survey

The most useful aspect of the project was that it provided a well-rounded view of the attributes that physics graduates possess and would like to possess to be successful in a diverse range of workplaces. An investment banker said that having a physics degree 'demonstrates intelligence across disciplines and is valued by many employers'. Some of the most valued attributes were 'time management', 'study skills', 'perseverance to grasp difficult concepts', and 'the confidence to project ideas/thoughts to large groups through the medium of presentations'. Some of these attributes would apply to graduates from any degree. Other attributes gained were more specific to physics:

> 'Apart from the obvious answers (development of analytical skills etc) I think the most important skill I developed during my time at university was the ability to keep an open mind and to be open to new theories and ideas.'

In the Physical Sciences, a great deal of emphasis is placed on the development of problem-solving skills and ability throughout the undergraduate degree. This phrase is seen on many module or course descriptors and learning outcomes but covers a wide range of more general attributes. Some of the survey responses helped to unpack what it actually means. One respondent described it as developing 'a clear, logical yet flexible approach to problem-solving', and that a student would 'gain the ability to think clearly and get to the roots of a problem, to generate ideas and to assess them in a sensible and systematic way'. Another focused on the requirement to be able to simplify complex problems: 'an ability and willingness to break a problem down to its smallest parts'. One respondent reinforced the primacy of problem-solving as the most important graduate attribute, suggesting that:

> 'Problem-solving is probably the most valuable skill for any scientific or engineering job.'

One of the hardest aspects of problem-solving is the ability to identify what is not yet known but needs to be known in order to go on to solve the problem. In a physical sciences degree, intimately linked to problem-solving is the ability to express oneself in the natural language of the discipline. In physics, this is the language of mathematics; hence the mathematical grounding that a physics degree provides was also seen as hugely important:

'The ability to understand difficult concepts, and to understand how physical systems can be described mathematically. Learning how to employ a rigorous scientific approach to problems is also very valuable.'

Mathematics is an area of considerable challenge for everyone in the Physical Sciences sector in HE. While we want to strive to maintain the high value of mathematical mastery in the upper reaches of our degree programmes, many have first-hand experience of how the mathematical ability of entrant undergraduates (the so-called 'maths problem') is making pre-honours teaching even more of a challenge.

In conjunction with the acquisition of subject-specific skills, the graduates in the survey all believed that promoting transferable skills during an undergraduate degree was essential:

> 'The most valuable skills I gained from my undergraduate career were all the transferable skills that are auxiliary to the core physics, maths and IT topics which were covered. Being numerically agile and having broad-ranging analytical skills have been particularly valuable, in addition to the ability to communicate complex topics clearly and concisely.'

These and other similar comments evidenced a clear understanding of the higher-level skills we would wish all our graduates to have.

It is also satisfying that most comments illustrated that graduates recognised and valued the ways in which the School of Physics had embedded the training in, and acquisition of, these skills into the curriculum. We suspect that this is not unique to this department or this institution, but is generally the case across the discipline. Graduates were unanimous in their support for the project and the idea of closer curricular links between research and teaching. One graduate explained that the most important part of the skills gained from the degree was through the bridge from teaching to research, gaining 'an understanding of basic science through how research is carried out'.

We always knew that physics graduates went into a wide variety of different careers. First-destination statistics collated by the University each year have given us some indication of the breadth, but were often mapped onto wide categories ('managerial', 'professional' etc). The richness of information yielded by this survey confirmed that the majority who study the subject at undergraduate level go into a very wide range of careers. From this small sample, they included RAF pilot, energy consultant, investment banker, computer games programmer, weather presenter and product manager.

The information obtained has been used to produce flyers to advertise the University of Edinburgh to prospective students. In addition, some of the information already has, and will continue to be, used to inform current discussions about the structure of the courses and programmes at the University.

2.5 Structure of the report

The remainder of this report structures the presentation of the case studies and snapshots approximately chronologically, traversing a path through a degree programme from fundamentals to frontiers. The order of presentation, and loose classification, is summarised in table 1; [CS] refers to a case study, and [S] to a snapshot of a particular course or element of that course.

3.1 Telling students about research, encouraging an atmosphere of independent learning	Strathclyde, chemistry, vertical themes [CS] Glasgow, physics, Frontiers of Physics lectures [S]
3.2 Implementation in first-year classes	Glasgow, physics, interactive labs [CS] St Andrews,physics, first-year PBL labs [S] Edinburgh, physics, weekly workshops [CS] Warwick, chemistry, reinvented labs [CS]
3.3 Transferable and professional skills development	St Andrews, physics, transferable skills module [CS] Edinburgh, chemistry, integrated research skills in practical classes [S] Glasgow, physics, Skills Revolution workshop [S] Aberdeen, physics, Research Skills in Physics [S]
3.4 Communicating science	Strathclyde, physics, Communicating Physics [S]
3.5 Learning through case studies	Aberdeen, physics, Case Studies in Physics [CS] Abertay, forensic sciences, forensic investigation [CS]
3.6 Research opportunities	Glasgow, physics, astronomy weekend [S] St Andrews, physics, use of observatory [S] Liverpool John Moores, astrophysics, use of robotic telescope [cs]
3.7 Internships and placements	Strathclyde, chemistry, Industrial Placement [CS] St Andrews, chemistry, summer vacation project [S]
3.8 Project skills preparation, learning what research is	Edinburgh, chemistry, Training in Research Methods [CS] Strathclyde, physics, Project Training [CS]
3.9 Group research project	Glasgow, chemistry, Frontiers of Crystallography [CS] St Andrews, chemistry, group mini project [S]
3.10 Final-year research project	Review looking at a number of examples [CS]

Table 1: list of case studies and snapshots

The discussion after the case studies (section 4) picks up common threads from them, and also from another output from the project. In December 2007, we held a workshop on 'Research-Teaching Linkages in the Physical Sciences', attended by 26 staff from physics and chemistry departments around Scotland and the rest of the UK (see http://physci.rtl.googlepages.com/home). The outcomes from discussion groups at this workshop also fed into our discussion and final recommendations in this report.

The workshop was supported in part by the HEA Physical Sciences Centre. We gratefully acknowledge this and their support of the entire project and its findings.

3 Case studies and snapshots

3.1 Telling students about research, encouraging an atmosphere of independent learning

Case study: Integrated transferable skills

This case study describes a series of classes on transferable skills, which feature in years one, two, three and five of our courses. The first is a Scottish Credit and Qualifications Framework (SCQF) level-7 class of five credits (approximately one-twentieth of a full-time year) entitled Transferable Skills 1. This is followed by an SCQF level-8 class (five credits), Transferable Skills 2; an SCQF level-9 class (five credits), Transferable Skills 3; and finally an SCQF level-11 class (five credits), Transferable Skills 5.

All classes are compulsory for chemistry students (approximately 150 students per year). They cover topics such as IT skills, oral and written presentation skills and group working skills. Up to 12 staff are involved, but only to a minimal extent. The bulk of the teaching is carried out by two members of academic support staff trained to PhD level. The activity is supervised by an academic member of staff, the Transferable Skills Coordinator.

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Brief description of course

In year one, the activities centre on IT skills (three hours of instruction and six of independent work) and personal development planning (PDP) (three hours of independent work). The IT skills component aims to teach students a basic level of familiarity with items such as file management, word-processing and spreadsheets, search catalogues and online information sources, and where and how to seek assistance for IT support issues. The PDP component encourages students to reflect on their strengths and weaknesses and identify strategies to address weaknesses and build on strengths.

The year two activities are chemical drawing, scientific writing and teamworking. Following initial tutorial sessions, students are required to independently complete a series of individual chemical drawing tasks, which are assessed by the course tutors (two hours of instruction and six of independent work). The scientific writing skills workshop is designed to prepare students for a range of scientific writing tasks, which they will encounter as students and ultimately as professional chemists. Topics covered include style (correct use of language), conventions (figures, tables and references), proof reading and thesis/report writing. A written assignment is assessed by the course tutors (three hours of instruction and 10 of independent work).

The team-skills activities place students in teams of five or six. A problem-solving case study provides a framework for a wide range of teamworking and problem-solving skills in a general chemistry-related context. Students contribute to planning the overall strategy for their team and making a broad range of decisions under tight time deadlines. They are assessed by the course tutors during the course of their assignment. This assessment is based on the individual and team performance of each student (four hours of instruction and 10 of independent work).

The year three activities are oral and poster presentations, and a quality systems workshop; PDP is also revisited. After a brief introductory session outlining good practice in oral presentations, each student prepares and delivers an oral presentation on two separate experiments from the third-year laboratory classes. Each presentation is assessed by the course tutors (four hours of instruction and eight of independent work).

The poster presentation exercise gives students the opportunity to develop the above skills, and to extend and use their teamworking abilities in a new and chemically related context. Within teams of five or six, students produce a poster describing an important area of science; the topics available to them relate to significant breakthroughs made in the recent past. Each team has an academic member of staff as their supervisor for the unit, and each poster is prepared within a limited time period. Students are assessed by the course tutors, their peers and an invited panel of experts. This assessment is based on the individual and team performance of each student (two hours of instruction and 14 of independent work). A prize is awarded to the best poster.

The final component is a quality systems workshop to introduce students to the issues associated with the validity of analytical measurements and to consider and assess the purpose of formal systems of accreditation (Good Laboratory Practice, UK Accreditation Service, International Organisation for Standardisation). In groups of three or four, in these interactive workshops (two hours of instruction) students are required to role play, devise strategy and summarise and report back their deliberations. Students encounter many of the issues covered in this exercise in their industrial placement year, so this is an important introduction. During the course of the exercise each student completes a workbook, which is assessed by the tutor.

Activities in the final year centre on oral presentations, and PDP is again revisited in preparation for employment. Following an introductory session on the important aspects of oral presentations, students plan and prepare a short talk. Within small groups and in the presence of academic tutors, each individual presentation is videotaped. In turn, the whole group reviews each presentation and offers opinions and constructive criticism. Staff tutors also provide written assessments (three hours of instruction and six of independent work).

Following completion of the final-year research project, each student prepares and delivers a 20 to 25-minute presentation on their research programme. This talk is delivered to a cross-section of their peers and academic staff. Students are also expected to answer questions on and around their research topic. Presentations are assessed by academic members of staff (six hours of contact time and 20 of independent work).

Linkages between teaching and research

The above activities encourage linkages between teaching and research in a variety of ways. The IT skills students gain in the first year are geared to assist research in later years (for example general file-handling to ensure data safekeeping, instruction in how to conduct literature searches, how to use Excel to present data). Starting on PDP introduces students to undertaking a reflective assessment of their strengths and weaknesses. This reflective attitude can be adapted to research as they mature. The chemical drawing package in the second year allows students to learn how best to use this platform to present research findings. The scientific writing activity also assists them in developing concise methods for presenting research findings. The teamworking exercise teaches them not only to work as part of a team, but also to manage their time, decide on a strategy to move activities forward and assess and select analytical techniques based on their findings and experience. These are all skills used in research, regardless of discipline.

The poster presentations and oral presentations in the third year give students the opportunity to present a piece of science in a concise and hopefully clear way. The aims of the posters, in particular, are to be attractive and factually correct, but also to stimulate interest in funding the particular area of science presented. The quality systems workshop again allows students to work as a team, devise strategy and report their findings, in a similar way in which a research group might report back to their supervisor. The final-year presentation on the research project allows students to reflect on how research is approached and how it should be presented.

Course history

The course has been running in its current format for about five years. Many of the activities were originally part of other classes but when the Department of Pure and Applied Chemistry carried out a course review in 2000, it was agreed to develop the current system in which a number of transferable skills are incorporated into a 'string' of easily identifiable classes. This was in recognition that many people - and employers in particular - view transferable skills as extremely important.

A number of other classes obviously use, and indeed build on, the skills in these specific classes. Laboratory work, for example, benefits from the scientific writing and chemical drawing activities. Our industrial placement partners have indicated that many of the skills learned in years one to three are used when students spend their fourth year on a 12-month industrial placement. Students also complete a molecular modelling and data retrieval class in their third year; this extends the skills learned in the first year when they explore online library catalogues. The numerous presentation skills acquired as students approach their final year are also useful when they prepare their dissertation as part of their final-year project.

Course assessment

The course is both summative and formative in parts. Students gain a pass or fail mark for each year, but this decision is reached in different ways. In the first year, students are set IT assignments and the pass mark is 70 per cent. This may seem high, but most students are computer literate and the high pass mark keeps them engaged with the material, even though they may be familiar with some of it. The assignments set, however, are such that someone with no computer experience but who attends the instructional session can still do well in them. For the PDP exercise, students must submit a summary sheet indicating that they have completed their PDP, but the Department does not insist on seeing the completed document. This is because we feel that students would write what they think we would want to see if we insisted they submit their PDP, and that is not the point of the exercise. Both activities must be completed to gain a pass.

In the second year, the chemical drawing exercise is submitted and marked and students are provided with formative feedback about where they could improve their skills. This is the case for the scientific writing exercise too, but this also carries a mark and students must resubmit until their report is of an acceptable standard. As part of the team-skills exercise, assessment is formative and oral and all students must participate in the activity. A small prize (sponsored by industry) is awarded to the best team as agreed by the tutors. All three activities must be completed to gain a pass.

In the third year, the class tutors assess the oral presentations and provide formative feedback. This is also the case for the quality systems workshop, where feedback is provided on the workbooks submitted. Academic and peer review of the posters take place. While marks are not revealed, the best poster is selected and the team of students that produced it is presented with a prize (sponsored by industry). All three activities must be completed to gain a pass.

All feedback in the final year is formative, but a number of sponsored prizes are available in different areas of chemistry for the best research presentations. All students must participate to gain a pass.

Course evaluation

The development of this class in its current form arose from a departmental review of all undergraduate degrees in 2000. The Department felt that it was important to highlight these activities in specifically named classes rather than have them 'hidden' within other classes. The classes have been evaluated by the Royal Society of Chemistry (RSC), inasmuch as one of the main criteria when applying for course accreditation is that departments must indicate how they teach transferable skills. All four of our MSci degrees are accredited by the RSC.

Students are requested to complete evaluation forms for each class they undertake, and the feedback for these classes has always been extremely positive. Students enjoy these different types of activities, which complement their theory and practical classes.

Key aspects and transferability

These classes have been specifically designed to address a variety of transferable skills - particularly those highlighted by employers. In that regard, all aspects are useful and transferable. While a small number of activities are subject specific (for example chemical drawing exercise, quality systems workshop), many are generic and could easily transfer across disciplines (for example IT skills, PDP, poster and oral presentations, scientific writing, research presentation). The team-skills activity in the second year, while specifically chemistry-focused, could be adapted to other disciplines.

Course development and delivery issues

The appointment of two members of staff whose sole responsibility it is to look after these classes has helped in the development of them. An academic member of staff has been appointed as Transferable Skills Coordinator; while he fulfils a supervisory role, the two academic support staff teach all the classes and deal with assessment. Previously, academic staff were drafted in to help out with these classes as and when available, and this had to be fitted around all their other activities. Academic staff contact in these classes is now restricted, for example guiding a group through the poster session or attending the final-year research oral presentations. This has the benefit that academic staff have more time to pursue their research interests. Additionally, students are taught transferable skills by support staff who are fully committed to the task and know the subject matter well. Since this is the sole responsibility of the support staff involved in these classes, they are keen to develop the classes further and are bringing forward ideas to enhance or modify the classes.

Effect on student experience

These classes have changed the student experience inasmuch as students now possess a range of transferable skills that make them attractive to prospective employers. This in turn increases their confidence, and student feedback has been extremely positive regarding all aspects of these classes. All MSci students in the Department spend the fourth year of their course on a 12-month industrial training placement (see University of Strathclyde case study in section 3.7), and the relationship with our industrial partners is good. These classes were designed in part to address issues raised by our industrial partners, who obviously feel that our students have desirable attributes since 90 have been placed in industry in the current academic year.

Strathclyde has taken the decision to move all classes to 20 credits. Our next challenge is to address how we continue to provide this valuable set of classes within the new framework.

Further details

This work has previously been disseminated by a colleague at an RSC Analytical Chemistry Open Learning event. The Centre for Academic Practice and Learning Enhancement at Strathclyde also runs Learning Enhancement Network events; this work has been disseminated at one of these gatherings.

Snapshot: Frontiers of Physics lectures

Level 1, approx 180 students, part of the 20-credit level 1 courses Physics 1X and Physics 1Y. (These courses are merging to become the 40-credit Physics 1 course from September 2008).

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The Frontiers of Physics course was introduced more than five years ago, offering (at that time) an attractive package of lectures on cutting-edge research topics designed to appeal to students taking our 'accelerated' level 1 Physics courses P1X* and P1Y*. Essentially, Frontiers of Physics replaced some lectures on dynamics and electricity and magnetism that largely duplicated material covered in the Advanced Higher Physics curriculum. Thus students taking the 'starred' (*) courses would follow a streamlined curriculum, supplemented by cutting-edge material. Following this route was entirely optional, but proved popular among more able students who came to the University with Advanced Highers.

Two years ago, the starred level 1 Physics courses were discontinued. After careful consultation it was concluded that our regular courses would be challenging enough - even for more able students. The Frontiers of Physics lectures were retained, however, and integrated into the regular Physics 1 courses, thus opening them up to the entire class. Since then, they have proved to be very popular with the class as a whole.

Three Frontiers of Physics topics are delivered each semester - two lectures per topic, making 12 lectures in total. Subjects covered span the full range of physics research within our Department and in the wider physics community. Examples of the topics covered in recent years include:

- searching for extra-solar planets
- quantum cryptography
- gravitational wave detection
- neutrino oscillations
- nanoscale physics.

The topics covered are reviewed each year, with changes continually introduced to the detailed syllabus to reflect the latest developments (for instance, the number of extra-solar planets detected and the range of methods used to detect them has evolved substantially, even over the few years these lectures have been running). Occasionally, new topics are introduced to reflect significant new advances or areas of substantial interest; examples of this for 2007-08 were new topics on dark matter and dark energy, and on the Large Hadron Collider.

In all cases the lectures are much more than simply a series of photographs and facts. They are delivered very much in the manner of a research seminar, with a lengthy introduction setting the background physics context to the topic. Theoretical arguments are developed carefully, even if some approximations and simplifications are introduced. For the Frontiers of Physics assessment component, students are expected to be able to derive simple results, carry out numerical calculations using them, and discuss their relevance to the wider physics context of the Frontiers of Physics theme.

Thus far, Frontiers of Physics has been assessed via degree exam questions (one per semester, selected by the external examiner), which students are given in advance. While this approach recognised the challenging nature of the material, in other respects it was less than satisfactory as some students could simply try to memorise a solution parrot fashion. In future, the Frontiers of Physics lectures will be assessed via a series of continuous assessment workshops (which will also examine the other level 1 Physics courses). This will ensure that all Frontiers of Physics topics are examined, which in turn should help to maintain good attendance at all Frontiers of Physics lectures.

The popularity of the Frontiers of Physics lectures can be attributed to several factors identified by students and staff. The material is undoubtedly stimulating and fascinating in itself, often covering topics students have read about before coming to university. Delivery of the lectures has generally been of very high calibre, as we have chosen Frontiers of Physics lecturers who are all enthusiastic and effective communicators. Above all, students have responded very positively to material which is still firmly at the cutting edge of physics with many open and intriguing questions - all the more so since the lectures are given by staff who are actively engaged in trying to answer those questions.

Further information is available in the Physics 1 course guide, which can be downloaded through: http://moodle2.gla.ac.uk/physci/moodle/mod/resource/view.php?id=1715 (log in as a guest).

3.2 Implementation in first-year classes

Case study: Experimental tutorials

This case study describes a Physics 1 laboratory class at SCQF level 7, which forms 20 per cent of the 40-credit Physics 1 course. It is compulsory for students studying physics in the first year (approximately 175 students per year). Staff involved: up to seven academic staff (lab head, deputy lab head and demonstrators); up to 30 post-docs and PhD students (demonstrators); two technicians.

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Brief description of course

The Physics 1 laboratory class forms part of the level 1 Physics course taken by all students intending to study physics to degree level, as well as those who simply have an interest in the subject.

The laboratory course has been radically redesigned to update the content and create direct links between the practical work covered there and the theory covered in the lectures. The aims of the revised lab course are to:

- demonstrate the basics of experimental physics
- develop skills required for the clear presentation of scientific results
- develop problem-solving techniques
- experimentally demonstrate concepts discussed in lectures
- encourage group work as a means of effective problem-solving.

The lab course is split over two semesters. The first-semester sessions are designed to highlight the links between the practical and theoretical sides of physics through the use of experimental tutorials (ETs). These take the form of a tutorial question which is then directly mirrored by a practical experiment. The same format is used in the second semester, but the focus is altered to introduce students to practical skills such as using more advanced laboratory equipment (for example digital oscilloscopes and spectrometers).

Semester 1

The material covered in the ETs falls into the same categories as the lecture courses: dynamics and relativity; thermal physics; optics, waves and lasers. 12 ETs run in semester 1 (two per week), with students attending one session of 2.5 hours per week for six weeks. The class is split into four groups, with students attending on one of Mondays, Tuesdays, Wednesdays or Fridays each week. Each day group is then split into two sections, and the members of each section attempt one of the two ETs on offer in a given week. This means that students attempt six ETs over the course of the first semester. While students only attempt the experimental component of one of each week's two ETs, they attempt both tutorial questions to ensure that they have covered the theory.

To ensure that all students know something of the practical side of both ETs, the sessions end with presentations by pairs of students from each section to the whole group. While not the same as getting all students to attempt all the experiments themselves (which was tried initially but proved ultimately unworkable), this gives them some insight into both experiments. It is also an excellent opportunity for students to improve their presentation skills.

There are two additional exercises in the first semester. An IT exercise takes up the first 2.5-hour session of the year. It introduces students to the many uses packages such as Microsoft Word and Excel can have for modern physicists (for example drawing experimental diagrams, tabulating data, handling large data sets). This is designed to provide students with the skills they will need for the data-handling side of the ETs which follow, and for creating a good word-processed lab report.

A teamwork exercise takes up the final session of the semester. This sees students working in groups of about six to tackle two exercises: a theoretical one on various aspects of special relativity and a practical one in which they construct roller-coasters from kits. Both exercises are assessed by means of a presentation. In the roller-coaster exercise, students have to use their roller-coasters to illustrate various aspects of dynamics and kinematics.

Semester 2

The material covered in the ETs again falls into the same categories as the lecture courses (electricity and magnetism; quantum phenomena; properties of matter). Six ETs run in semester 2. They are collected into two groups of three, and students rotate through the ETs on a weekly basis, so that by the end of semester 2 they have all attempted all six ETs. No presentations are used in the second semester, as all students attempt all the experiments.

In addition to a better understanding of experimental equipment, the ETs in semester 2 are structured to include a greater level of error analysis. Students are given an introduction to error analysis at the beginning of the semester, and are then encouraged to use this to better justify their results as the semester unfolds.

One of the overall aims when it came to writing the scripts for the ETs was to move away from prescriptive, recipe-like instructions, where students just work through a checklist of tasks. The practicalities of running a class for 170 or so students have restricted how open-ended we could make the instructions, but efforts have been made to give students more apparent freedom in how they tackle the exercises. For instance, if students are asked to test a simple theory by plotting a graph, they are not always explicitly told which graph to draw. Also, all ETs end with an additional work section. These additional sections expand on the work covered in the earlier sections and tend to be more open-ended in nature. They are designed for very able students, allowing them to gain extra credit.

Linkages between teaching and research

The ETs encourage linkages between teaching and research by getting students to tackle the practical work in what could be called a 'research mode'. The exercises are designed to get students using research-style methodology to tackle their work. The experiments use modern data acquisition (DAQ) systems, then PC software packages like Excel are used to analyse the data. In other words, students adopt the techniques used by researchers to assist their learning.

In the previous structure for the lab class, students recorded data manually in lab books. While there were benefits in teaching students how to record data in this fashion, it meant that they had to undertake a lot of repetitive tasks which, in the modern world of research physics, are better handled by computer. For example, in an experiment which involved calculating the period of oscillation of a mass on a spring, students used to have to manually count the number of times the mass bounced in a given time. The motion of the mass is now monitored by an ultrasound detector connected to a PC, which has removed the tedium from the data gathering. This form of data collection also allows students to explore graphically the relationship between the mass displacement and the force on the support of the spring.

When it came to analysing the collected data, graphs used to be hand-drawn and gradients, for example, were calculated by hand. Again, there were benefits to this approach, but it was felt more important that students learned how to handle their data using modern techniques - particularly as the use of PC-based DAQ systems means that there are larger data sets to handle. Care was taken when writing the ET scripts to make sure that students understood what they were getting the PCs to calculate, as we were all too aware of the danger of the situation where students let the computer do all the thinking.

Course history

This revamped lab course began in September 2006. The original motivation was to update the content of the lab class and improve students' learning experience in the class. Anecdotal evidence of the previous structure suggested that students were finding the practical class a chore and, as a result, were not learning anything meaningful from it. The Physics 1 lab course leads on to a practical class in Physics 2 and 3, followed by project work in Physics 4 and 5.

Course assessment

The Physics 1 lab course is assessed in the following way:

- students write up a lab record for each experimental tutorial; these are all marked after each session
- students submit one lab report based on one of the records
- students submit a report on the IT exercise they complete at the beginning of the course.

In total, the above assessment contributes 20 per cent of the marks students gain for the Physics 1 course. The records are marked by the demonstrators assigned to each session (typically one member of academic staff, one post-doc and two PhD students); they generally spend an hour per session marking. The reports are marked by academic staff and post-docs, with each person getting around a dozen reports to mark.

Course evaluation

In 2006-07, the first year the lab course was run under the new format, students were given questionnaires at the end of each semester so we could find out what they thought of the course. For semester 1, 60 per cent rated the course as excellent or good, with another 37 per cent rating it as fair. For semester 2, 61 per cent considered it excellent or good, and 27 per cent fair. Staff opinions were also sought, though informally. The general view was that the lab course was a great success, greatly improving the level of student interest and interaction.

Key aspects and transferability

The most useful aspect of the course is that it encourages students to approach their practical work in a methodical manner. They become familiar with modern experimental techniques as used by actual research scientists, giving them an idea of how a qualified scientist works.

Another aspect of the course, which is of great transferable value, is the teamwork and presentation skills that students get the chance to practise. Being able to work in groups and then present concepts and ideas in a clear, concise manner are skills that benefit the students, whether or not they ultimately end up in a research environment.

Course development and delivery issues

The development of this course was greatly helped by the enthusiasm of the staff involved. The initial development of the ETs was a group effort involving all lecturers on the Physics 1 course. Without their contribution, such a major redesign would not have been possible. Similarly, without the backing of the Department as a whole - and a teaching-friendly Head of Department - we would not have received the necessary funding for such a wide-scale investment in new equipment and teaching spaces.

Implementation of the redesigned course was not without its problems though. Initially it was hoped that all students would attempt three ETs per session in semester 1, but this simply did not work. Reducing the workload to two ETs helped, but while we hoped that students would experience as diverse a range of experiments as possible, ultimately it was only really feasible to have them attempt one ET per session.

Effect on student experience

The revised lab structure has greatly improved the student experience. Students are far more active during the labs and seem to enjoy the work more, as evidenced by the ratings they have expressed (as noted above). Questionnaire feedback of students taking physics and astronomy also suggested that the new physics labs compared favourably with the astronomy labs. In the past, students always viewed physics as the 'poor sibling' (this view was based on anecdotal evidence from speaking to students in later years of their degrees).

Further details

Early results from the new structure were presented at the Science Learning and Teaching Conference 2007 at Keele University (Sneddon, 2007).

Snapshot: First-year labs

Level 1 course, Physics 1B, second semester of year one Physics, 30 credits. Taken by 60-80 students per year, including all those on physics degrees, plus a substantial number as an elective module. Students have one lab afternoon (2.5 hours) a week, in groups of 12-16 students. The Physics 1B syllabus covers properties of matter, quantum phenomena and general relativity.

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We developed and implemented an introductory problem-based learning lab in the second semester of our first-year Physics course. Students, in groups of three to four, were given a problem requiring the measurement of the wavelength-dependent transmission of sunglasses. The scenario involved students working in a firm producing sunglasses and checking claims of a rival firm that their sunglasses block virtually 100 per cent of UV and high-energy visible light. The student groups needed to come up with their own experiment, request the relevant apparatus, carry out the experiment and analyse the results. There was substantial variation in experiment design by the students: set-ups included a dual-band UV lamp, a mercury lamp with diffraction grating, a prism spectrometer and a white light source with colour filters. At the end of the lab afternoon, students were shown a spectrophotometer in one of our research labs.

An evaluation questionnaire showed that most students preferred this type of lab to 'traditional' labs because of its relevance to their everyday experience, the teamwork and the scope to design their own experiment. Students were able to apply the lab skills they had learned in the more traditional labs, and saw how the same problem would be solved in a real research environment. Though students were not doing real research, they were working in 'research mode', which means having to decide for themselves what they needed to measure, how they would go about doing this, and how to analyse and represent their data.

We are adding two more PBL labs into the first-year curriculum: one is centred on the ultrasound technology used to assist in reverse parking of cars, the other on mobile phone radiation.

For details of the module, see links from www.st-andrews.ac.uk/physics/Staff_Stud.shtml

Case study: Weekly workshop

This case study describes the role of weekly workshops - collaborative problem-solving sessions that occur in various pre-honours courses at the University of Edinburgh. They are taken by all students studying towards physics degrees, and are generally part of 20-credit SCQF level 8 courses. The sessions last two or three hours and are staffed by academics supported by a number of postgraduate demonstrators.

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Brief description of course

This case study describes an instructional design for collaborative group working of pre-honours students in physics, implemented in teaching activities we call 'workshops'. These workshops were originally introduced six years ago as a replacement for the standard tutorial-plus-laboratory format that is almost ubiquitous in the early years of undergraduate science teaching. The case study focuses on workshops as part of a first-year introductory course (Physics 1A: Foundations) taken by approximately 275 students each year, both those reading towards a physics degree and those taking it as an elective option.

The workshop sessions comprise groups of students (usually about five or six, allocated randomly at the start of the course and fixed for its duration) working on a variety of different activities each week. Activities differ within each course, but a major component in all sessions is the time that students spend collaboratively each week working on a set of problems relevant to the course material for that particular week. The set will number anywhere between six and 15 problems, and students are advised to plan within their groups which problems they are going to tackle within the allocated time (the expectation being that other problems are done out of class). Typically, the questions are such that a group can reasonably expect to be able to tackle approximately six within an hour.

None of the activities within the workshop are explicitly assessed (but the problem-solving ones feed into assessment - see below), and students are encouraged to make full use of the postgraduate tutors and staff members who facilitate these sessions. Students are advised not to spend workshop time generating perfect solutions to problems, but to 'work through' them, focusing on the process of how to solve them rather than attaining the final product (often, but not always, a numerical answer).

Linkages between teaching and research

The key educational aim of the workshops is to foster not just the 'hard' skills needed by the professional physicist, but also the more qualitative (or 'thinking') skills of value to all students, whatever their chosen career. Implemented within a group-working environment, the workshops give students low-stakes opportunities to acquire and refine such skills as stating and defending a point of view, and presenting or explaining material to peers (students are given flipcharts for their group problem-solving).

In these sessions, which students encounter during their very first semester at the University, we are progressively moving them away from a view that problems within the subject are closed and solved by a rather formulaic approach, towards one where the student must develop a problem-solving strategy, and there is often more than one route that can solve the problem. Allied to this is the aim that our students should be actively engaged with the material (despite much of it being rather familiar in this course) and on a pathway towards more autonomous and independent learning. The overall design of the workshops and related assessment are geared to support this aim.

Course history

The workshop format was originally introduced into second-year courses six years ago, as part of a raft of measures to arrest a declining pass rate. It has subsequently been adopted widely across pre-honours courses in physics programmes and other disciplines besides physics.

Course assessment

Every Friday afternoon, once all students on the course have attended their workshop for that particular week, three of the set of questions are designated as hand-in questions for which students are expected to individually write up full solutions to hand in the following Wednesday. The scripts are collected prior to the Wednesday lecture, distributed to staff and postgraduate student markers, and handed back to students at the beginning of the following week's workshops. All staff have a detailed marking scheme to refer to, and rather than spend time writing out perfect answers, they are advised to use the time to provide appropriate diagnostic feedback to students. The marked hand-in assignments contribute (along with pre and post-course diagnostic testing) to a coursework component mark worth 30 per cent of the final mark for the course (the remainder being assessed by written exam).

Workshops typically start with the return of scripts to students. Staff spend 10-15 minutes going over general feedback on the previous week's assignment (common 'banana skins' etc), give students an opportunity to compare their scripts with full solutions online, and allow time to enable them to digest the feedback on the scripts. At certain points in the course, student scripts are returned to them with one question unmarked. They then spend the first part of a workshop peer-assessing someone else's script with the aid of the online solutions. The cycle of attempting, writing up, submitting and receiving feedback on questions spans three weeks; the semester-long course contains a total of nine such cycles.

Course evaluation

Student feedback - as evidenced from staff-student meetings and course questionnaires - is extremely positive, more so since problems with the physical room layout have been addressed (see below). Attendance is consistently good at these sessions, which energises (and in some cases rejuvenates) staff involved in a positive feedback loop. A tea-break midway through the three-hour sessions also provides the opportunity for social interactions between staff, demonstrators and students. The workshops have also given us a specific activity on which to focus when providing training and support to postgraduate student demonstrators. We are cautious in trying to draw firm conclusions from exam results, as year on year many variables can affect performance in either direction.

Having been through several years of workshops, we can confidently say that this is not just a 'halo' effect where a new practice is initially met with great enthusiasm from staff and students but which proves harder to sustain in subsequent years. Indeed, the opposite is probably the case: this practice is gathering momentum both within and beyond the School of Physics. Within the School, students in other courses have requested the workshops, to the point where they are now deployed as a teaching method in nearly all physics courses in years one and two. Interestingly, students have also requested this style of teaching and learning in other disciplines.

A particularly striking turnaround has been seen in a mathematically demanding course that was becoming our Achilles heel in recent years, with an increasing (and worrying) failure rate. The attitudinal shifts of staff and students involved with this course have been remarkable and the success of the workshops confirmed by markedly improved exam performance.

Key aspects and transferability

The inherent design of the workshop sessions is immediately transferable across a wide range of disciplines, and has been taken up by other schools at the University of Edinburgh. The context can easily be adapted to different subjects.

Course development and delivery issues

The development of the workshops - and their widespread adoption across the pre-honours programme - has benefited from changes in how the teaching estate is designed and used. A refurbishment project allowed us to campaign for refitting four traditional face-the-front tutorial rooms as a single 100-seat workshop studio. This is now a centrally booked teaching space located in the central area of the University. Subsequent refurbishment on the science campus (King's Buildings) has provided another similar-sized facility of this type. This has improved the workshops for staff and students alike, as it is much more pleasant to teach (and learn) in appropriate accommodation. Previously, the workshops were forced to use traditional laboratory space.

Effect on student experience

There is clear evidence that students are much more motivated to attend, prepare for, and participate in the workshop activities compared with the traditional tutorials these workshops replaced. In addition, students benefit from a greater degree of support from staff facilitating the sessions - yet the overall 'cost' of implementing these sessions in a large pre-honours course is no more expensive in terms of staff time.

Further details

These developments have been published as part of the Re-engineering Assessment Practice (REAP) online conference (Bates, 2007) and in CAL-laborate (Bates, 2005).

Case study: Reinvented labs

This case study describes a redesign of the first-year organic chemistry lab, taken by approximately 100 students in the second term.

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Brief description of course

The course is a continuation of the practical course from term one (Foundations). All experiments are designed to promote enquiry-based learning of organic chemistry. The purpose of the course is fourfold:

- practical skills already acquired are reinforced through further practice (use of recrystallisation, solvent/solvent extraction, distillation, melting point determination and thin layer chromatography)
- further basic experimental techniques used by organic chemists are introduced (for example nuclear magnetic resonance spectroscopy, column chromatography, Soxhlet extraction)
- new organic chemical reactions are introduced, which students are required to read about before the practical sessions
- practical and deductive skills are used to identify unknown organic compounds.

Linkages between teaching and research

This course strengthens the links between teaching and research in two ways: firstly by teaching students to be researchers, and secondly by improving the learning experience through research-like activities. Arguably the most powerful way to strengthen the links between teaching and research is to remove the distinction completely. The Reinvention Centre promotes a new model of a university, harking back to a much older model in which staff and students work together to develop themselves as researchers and agents of knowledge transfer.

This case study seeks to show that even if undergraduates are not engaged in original research, they can engage in research-like activities that prepare them for the reality of research in later years. There is ample evidence that enquiry-led laboratory teaching has a significant positive impact on students' ability to learn both the desired practical skills and the underlying theory. It was not the purpose of this programme to reinvent the wheel, but to apply these ideas in a simple manner to the organic chemistry laboratories at the University of Warwick and capture in a narrative sense the impact on students.

Course history

The motivation for changing the course came from our own final-year students, who were strongly supportive of introducing more enquiry-based lab classes. Reflecting on their experience, they felt that the organic practical units had taught most of the necessary lab techniques, but had failed to explain the theory underlying practical techniques. Material taught in lectures was reinforced, according to the students, yet they did not feel prepared for their final-year projects.

The style of the experiments was perceived to be very 'recipe'-like, with little scope for original thought. Additionally, the students felt that the labs, as they originally were, gave the impression that 'most chemistry works'; after a research project, they appreciated that the reality was somewhat different to this. An earlier introduction to issues such as failed reactions and low yield would be more representative of what research in the discipline is really like.

The students felt that the transition from traditional undergraduate labs to research projects was particularly demanding, and that taking steps to ease this transition would be most helpful. This feedback informed the redesign of the course, which was introduced in January 2006 and has now run in its revised form for the third time.

Course assessment

Assessment used to be in the main as in a traditional lab class, with postgraduate demonstrators giving regular formative and summative feedback - which means marks and comments in lab books every week. The changes arose from the way in which the assessment was now set via the lab manual. In particular:

- each experiment was restyled as a problem to be solved, with all references to the expected outcome removed
- more comprehensive references to textbooks were added
- learning outcomes were revised
- assessed questions relating to both theory and practice, which would normally be set subsequent to the class, were instead given at the start of each experiment

- experimental procedures were changed to be in the style of methods published in research journals, insofar as was sensible with safety considerations in mind
- mark schemes were completely revised accordingly.

The impact of these changes on the lab manual was significant - most sections required extensive revision.

The main changes were to the 'pre-lab' sessions. Since students carried out work before the scheduled lab session, it was necessary for these sessions to be more responsive. The traditional whole-class pre-labs were deemed inappropriate, so more interactive, smaller group sessions were organised in parallel, many led by postgraduate demonstrators. Apart from this, the main effect was to force teachers to support enquiry rather than give straight answers, which is in any case good practice.

Course evaluation

Predictably, examination of average marks from the lab units and the standard feedback forms, which were not designed to capture issues related to preparation for research, revealed little. It seemed, however, that the reinvention of the unit had not had a negative impact on these standard indicators.

Much more revealing was information gained from a focus group of first years. Around 13 students (an alphabetical selection of the cohort) were invited to a focus group, of whom five attended. The students were asked to reflect on the Organic Unit and compare it with the Inorganic Unit they were currently taking. They were briefed beforehand to think about what aspect of the course they found most enjoyable and what most difficult, suggest improvements to the unit, and compare it to others they were taking concurrently.

As well as very many specific points about the Unit, which were incorporated into the revised handbook where appropriate, a number of general observations were of relevance to the wider aims of the proposal.

The points expressed more positively were:

- 'the pre-lab assignment was good since it forced you to read the manual before the lab session, which is not something you would normally do'; 'I understood what I was doing before I turned up'
- the organic manual was easier to understand than the inorganic one
- the procedures were easier to follow than in the inorganic lab
- 'it was good to have plenty of time to think about what I was doing'
- 'the course has encouraged me to read more...'
- the half hour between handing in the assignment and the pre-lab was a good opportunity to socialise.

The points expressed more negatively were:

- a higher level of theory was required for the organic lab
- 'the questions at the end of the lab report were very tricky, and required extra reading and lots of thought'

- 'it was difficult to deal with some of the questions because we hadn't covered the material in lectures'
- 'the manual didn't give enough detailed instructions, which made doing the experiments quite stressful'
- some of the demonstrators 'breezed through the stuff' and the pre-lab talks were far too brief.

These results were extremely pleasing, suggesting that our aim of putting learning through practical experience at the front end of the undergraduate learning experience had largely succeeded. Indeed, most of the negatively expressed comments could be read as positive in the light of the fourth-year students' reflections on the failure of more traditional classes to prepare them for research.

Key aspects and transferability

Introducing new lab experiments carries significant resource implications for a department, both in technician time in trialling them and in purchasing materials and equipment. We therefore proposed to minimise the need for this, in order to maximise the chances of the educational context being adopted. We believe this model to be widely applicable to science courses, and many of the 'tried-and-tested' experiments currently used are perfect for reinvention.

In general, the experiments have been designed to illustrate an important point of theory and give useful results in a relatively short time with a large group of students. The following example shows how this can readily be done. Previously, students were told that adding bromine to a particular alkene would give a particular one of the two possible isomeric products, thus illustrating an important stereochemical issue. They then carried out the reaction and proved that they had indeed made the expected isomer. In the reinvented version of the experiment, students were instead asked to think about the possible isomers that could result from adding bromine to the alkene, carry out the reaction (less experimental detail was given than previously), and devise and carry out a simple test to identify which isomer was produced. This simple reinvention led to students having to:

- think about the stereochemical possibilities in such reactions
- elucidate the details of the experimental procedure
- devise a diagnostic test.

We sought to reinvent as many of the existing experiments as possible along these lines. Additionally, we did not hesitate to include techniques for which students were not yet prepared (safety permitting), believing that with some guidance they would better learn this material through experience.

Importantly, the impact of the changes on resources was, as planned, low. For the four (which became five) experiments retained, no additional calls on equipment, consumables or technician time were required (these were actually reduced in some cases). The addition of one new experiment to a Unit would be considered 'normal' and was designed in consultation with technicians to have a low-resource impact.

Effect on student experience

The effect on the student experience is best evidenced from the student voice; the following are excerpts from a student's blog at Warwick:

'For me, this approach to learning organic methods is far superior to the style of the XXX practicals. It makes me think about why I am doing the experiment this way. If presented with a similar situation in the future, I will instinctively know what kind of process I should take and why.

'My instructor thinks that the popular choice of students is older methods because they take up the full allotted lab time and the organic labs are not taxing enough as they generally took half the time to complete.

'However, as I have transferred here from XXX University, I have a somewhat unique viewpoint. The style of teaching there was very similar to the XXX practicals here. We would follow some insanely complex recipe to cook up a product, which would sometimes use obscure methodology.'

This work has been presented orally at several professional development events and departmental seminars. A full report can be found online at www.warwick.ac.uk/fac/soc/sociology/research/cetl/fundingopps/reports/taylor_final_report.pdf).

3.3 Transferable and professional skills development

Case study: Transferable skills for physicists

This case study describes a compulsory 15-credit junior-honours module for all students studying for an honours degree wholly within the School of Physics and Astronomy at the University of St Andrews. Class sizes have ranged from around 30 to around 70. Most academic staff in the School are involved to some extent, though the core team size is the class size divided by five.

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Brief description of course

This module allows students to practise and extend their knowledge and understanding of Physics (including astronomy) at the same time as gaining important and useful experience in transferable skills. These skills, which are sometimes referred to as professional skills or key skills, are a vital part of the abilities of a graduate physicist. The module is designed to strengthen student skills in the following areas:

- using their physics knowledge and solving 'new' problems
- finding information from books, journals, the web and via discussion with specialists
- critically evaluating and interpreting information gained from the above sources

- managing their own learning and development and exploring physics topics without external guidance
- applying initiative
- communicating orally and in written form
- working as part of a team
- using a variety of IT skills
- extending their knowledge and understanding of physics and astronomy.

While many of these skills are developed in 'conventional' modules, concentrating on these skills in this module should ensure that all our students have all these important abilities to a high level. Our students meet this module in their second or third year of study, depending on their year of entry to the programme. The module is based on a series of assignments, with students receiving guidance on tackling each of them through whole-class and small-group activities.

After an introduction from the module coordinator and an industrial physicist, the first assignment is a team skills exercise. This is the only assignment where the topic involved is not solidly grounded within the subject discipline. After instruction on the scientific publishing process and the use of Web of Science, students individually compare two research papers and then discuss their findings in a small-group skills tutorial. These skills groups consist of four or five students and a tutor, who is usually a member of academic staff or a post-doctoral research associate (PDRA). The skills groups are strengthened and students' problem-solving skills enhanced by group work on open, context-rich, physics-based problems. Next comes advice on researching the literature; the associated work is preparing a talk on a chosen aspect of physics to their skills group.

The last part of the first semester is taken up with exploring the literature to write a review article on a chosen topic which is different to that of the first talk. This article is meant to be along the lines of those that appear in *Physics Today*. Students choose from topics provided by academic staff, in many cases reflecting the research interests of the people concerned. Students are invited to discuss the science they are researching with the person suggesting the topic. The article is the subject of staff, self and peer assessment. At the end of the first semester, there is a short PDP part of the module, where students reflect on assignments and prepare a CV.

Work on this module in the second semester contains two major assignments. The first is to prepare and deliver a talk to a large group of students and staff, usually on a topic related to the review article. This talk is given in the format of a research conference, which takes place on a weekend and is often at Burn House in Edzell. The second is an assignment where each skills group prepares a 'proposal' for a new teaching lab experiment or for telescope observing time. The group then presents its case and is interviewed by a panel of academics in a style meant to be similar to a research grant panel, but which we are told is reminiscent of a friendlier version of the *Dragons' Den.*

Linkages between teaching and research

Students spend most of their time in this module working in 'research mode', gathering, critically evaluating and presenting ideas and data. Some of the time is spent interacting with the research literature directly and with local research experts. The major talk is given in a manner similar to a research conference, with the questions, discussions and networking associated with conferences. The final assignment can see students producing and defending a research proposal for time on a major telescope, and the panel session mirrors that of research grant panels.

Course history

Oral and written presentations had been in the physics course at St Andrews for a very long time, but modularisation and increasing pressures on students and staff had led to these activities being somewhat squeezed by the late 1990s. We considered various options for bringing these important activities fully within the modular system, including integrating skills training within core discipline-based modules and the generic skills module for all students seen at some institutions.

We decided that for our situation a dedicated module in level 3 would allow the development of advanced transferable skills while at the same time advancing our students' knowledge of physics through the topics they were working with. The fact that the skills development occurs in the language of physics is, we believe, one of the reasons for the success of this module. The module started in 1999 and has been running since, with various amendments from year to year. Our students bring subject knowledge and skills into the module from their previous and current education, and the skills learnt in this module are practised and developed further in subsequent modules.

Course assessment

Each assignment has assessment built into it. The first team exercise counts for a small fraction of the module total (two per cent) and is coarsely assessed on student input by the module coordinator (and honorary lecturer) and industrial speaker who helps us to run this module. The written and oral work on the comparison of two papers is assessed summatively (10 per cent) by the skills tutors and formatively by the tutors and the students in each skills group. The group problem-solving session (two per cent) is assessed by the skills tutors.

The review article takes 21 per cent of the module assessment, with the summative assessment carried out by at least two members of teaching staff. The students assess each other's and their own articles formatively, and their input to this is summatively assessed by the tutor (four per cent). The major talk is practised in the School and feedback is given by members of the skills group, then the 'real' talk at the Burn House conference is summatively assessed by up to six members of staff, and formatively assessed by the 25 or so students and staff at the talk. It is heartening to see a good correlation between the marks provided by students and by staff. The group-based proposal (20 per cent) is assessed by a panel of three academic staff. Peer assessment is then used to distribute the group's mark, usually non-uniformly, across the members of the group.

A small (six per cent) amount of credit and hopefully useful feedback is provided for the PDP parts of the module (CV preparation, reflection on what has been learnt in particular assignments.) The CVs are formatively assessed by members of the University's Careers Centre, and marks provided (coarsely) by the module coordinator on the basis of that feedback.

Course evaluation

Our favourite piece of feedback on this module came from a member of a subject review team who told us that when she first saw this stand-alone module she thought it was 'daft', but having seen what we were doing she had changed her mind and was now convinced of its merit. In the first year of operation, an external person was brought in to gather students' views through structured group discussions, and produce a review. This was a useful document to steer the development of the module. It was generally highly supportive, talking of 'customer satisfaction' with the module. On the basis of this review, and the views surveyed directly from students and tutors via a questionnaire, we reduced the total student workload by removing an assignment associated with computer programming.

Students are surveyed each year about their views on the module. They commonly regard themselves as being expected to do too much work in the module for 15 credits. We did a major analysis of the results from the group finishing in 2005 and found, for example, that the major talk was the best received assignment, with average 'scores' of 3.7 out of 4 for importance and 3.8 for the perceived gain through doing this assignment. The review article came in at 3.2 and 3.4, whereas the group problem-solving was only 2.6 and 2.5. Through discussion with students it is clear that they value the fact that the module is done in the language of physics.

Key aspects and transferability

The design of the module and the activities within it are all transferable. Indeed, we have transferred into this module examples of things that have been done elsewhere. A number of Physical Sciences departments across Scotland are currently running modules which share some common themes with this one.

Course development and delivery issues

This module is expensive to run in terms of staff time, so we are fortunate that the School is very supportive of what the module is trying to do. Although most students seem to appreciate the importance of this module, a few are yet to be convinced.

Effect on student experience

This module is an important part of our efforts to help students to become more independent learners and researchers and to gain the techniques needed to be confident in analysing material and presenting their conclusions orally and on paper.

Snapshot: Integrated research skills training in practical classes

A 25 per cent component of the SCQF level 9 Chemistry Practical course (C3P), typically undertaken by 100 students.

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Discipline area: chemistry

All degrees contain a coherent programme of course components aimed at developing students' transferable skills, particularly in years three to five, with the emphasis on research-teaching linkages to achieve these aims in the latter years. In year three, 25 per cent of the practical course (C3P) comprises such activities. In addition, many of the third-year laboratory exercises include computational components, thus providing opportunities for the development of IT skills. Brief details of each component are provided below.

Abstracting exercise - students learn how to extract the key points from an article in a chemical journal and present them in the form of a concise, informative abstract. The abstracts are marked in a way that helps students to learn how to do this task more effectively.

Problem-based learning - as part of a small group, students work through a specific problem or case study facilitated by a member of staff. The case studies include the following activities: discuss the problem, together with the approaches and information that will be required to solve it; gather the information required; solve the problem; and present the findings orally. Currently available topics are: pigments for paint and paper; fresh air for astronauts; metal extraction; gas generation; development of new disinfectant liquids.

Oral presentation - students give a short talk (10-15 minutes) on a chemical topic taken from the third-year lecture material to a small group of people, including some of their colleagues and a member of staff who assigns a mark and provides feedback on performance.

Full report - students write up one of their lab experiments as if it is being prepared as a paper for submission to a chemical journal. The full report is marked in a way which helps students to learn how to do this task more effectively.

Poster - working in a group (typically of four), students prepare a poster such as is commonly presented at a chemical conference, explaining some chemical topic to a chemically educated but non-specialist audience. A poster presentation session is held at which students have an opportunity to present their posters to staff. Prizes are awarded to the groups providing the best posters.

For further information, see www.chem.ed.ac.uk/teaching/chem3/transfer.html

Snapshot: Skills Revolution workshop

This 2.5-day course is taken by students in the third year of their degree (SCQF level 9). All students take it, whether they are reading single honours physics or one of our combined degrees. The course is designed to enhance students' transferable skills (for example teamworking and presentation skills).

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The Skills Revolution workshop runs over three days early in the second semester of students' third year. It consists of a series of presentations, interactive workshops and role-play scenarios designed to highlight the importance of, and improve students' abilities in, the following areas:

- creative thinking
- teamwork
- making presentations
- problem-solving
- working to deadlines.

While the workshop's main focus is designed to illustrate to students some of the aspects of what life for a physics graduate could be like once they enter industry, several of these areas apply just as well to research physicists. This point is made to students during the course. In particular, the exercises in creative thinking and problem-solving help students to view physics less in terms of 'correct/incorrect' and more as a field in which there are very few absolute certainties.

The teamwork sessions feed into the group project work which students attempt after the course has run. These projects see students undertaking small-scale, research-style exercises in groups of six or seven over an eight-week period. While various different group exercises have been used over the years, the current one is run in conjunction with Freescale Semiconductors. It uses a one-day role-play scenario where students have to create an adventure holiday company and try to convince potential investors (in a Dragons' Den fashion) that they should invest in their company. The students have to come up with a viable business plan and make a sales pitch in the form of a group presentation.

The workshop also features a Question Time-style session where students are invited to ask questions of a range of panellists from various walks of life - academics, industrialists, a representative from the University's Research and Enterprise wing, and so on. This gives students an insight into what potential employers are looking for from physics graduates, as well as gaining a better understanding of what the career of a professional research physicist is like.

Overall, the main aim is to make students see the skills they are learning during their degree within a wider perspective, and appreciate that their subject is not simply a black and white world of right and wrong answers, by introducing aspects of a research-style approach to tackling problems.

Snapshot: Research Skills in Physics

SQCF level 10 course, 15 credits (one-eighth of year three) entitled Research Skills in Physics. Taken by all physics third-year students, including those on joint or combined degrees (8-16 students).

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This 12-week course is dedicated to enhancing both subject-specific and transferable skills. All topics focus on physics/scientific applications. The course has been running since 1996 but allows us flexibility to adapt to the needs of employers and students and the expertise of the staff from year to year. It also gives students 'space' to concentrate on skills, albeit within the physics environment, and allows them to interact with what is going on in the Department in terms of research. This prepares them for their fourth-year honours project as well as the possibility of postgraduate work.

The course is delivered as two three-hour blocks each week, allowing time to develop each topic. The current topics covered (2007-08) are: presentation skills (one week); research, ethics and intellectual property rights (two weeks); programming in C (two weeks); advanced HTML (two weeks); careers (one week); library skills (one week); science in society (one week); and project organisation (two weeks).

All topics are continuously assessed, except for the careers session and presentation skills. This allows students to learn these skills in a formative manner. Later in the course, presentation skills are used as part of the assessment and all skills are used in other courses.

For further information, see the University's relevant course catalogue entry (www.abdn.ac.uk/registry/courses/display.php?Subject=PX#level3) and the Centre for Learning and Teaching's website (www.abdn.ac.uk/clt/page.php?id=45&sub=12&top=3)

3.4 Communicating science

Snapshot: Communicating Physics

SCQF level 10; on average 20 students studying the class; 10 credits

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The aim of this class is to introduce the techniques of communicating and popularising physics. Individually and in groups students perform a number of exercises linked to some or all of the following topics: scientific journalism; physics in art and literature; physics web pages and discussion forum; science festivals and science centres.

There are four elements to the class. One centres on presenting science to the general public, and covers how to apply for Public Understanding of Science funding. A second element is directed at communicating science to school children under the 5-14 curriculum. As part of this exercise, students are expected to help out at National Science Week events (this part of the course is delivered in conjunction with the Glasgow Science Centre). The third element looks at how various art forms such as poetry or painting can be used to convey a concept in physics. The final part of the course is concerned with use of the internet to communicate science to the general public. It covers scientific writing for the lay person and the development of internet media such as web pages or simulations.

Details of each component can be found at http://phys.strath.ac.uk/12-490/

3.5 Learning through case studies

Case study: Case Studies in Physics

This case study describes an SQCF level 11 course of 15 credits (one-eighth of year four) entitled Case Studies in Physics. It must be taken by all fourth-year single honours physics students. The course is optional for those on joint or combined degrees, although the majority takes this class (8-16 students).

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Discipline area: physics

Brief description of course

The aims of this course are to:

- introduce aspects of physics used in industry
- improve understanding of methods used in industry
- develop the skill of interpreting technical articles and summarising their contents intelligibly for less knowledgeable people
- develop problem-solving and analytical skills
- improve interpersonal and teamworking skills
- develop communication skills.

The course follows a tutored self-learning approach, with the class working in groups of four to five students. After an initial 'expert' presentation (often given by someone external to the Department), the groups are given a real-world problem to work on and research. There are two tutor-led meetings per week, but the tutor acts as a facilitator not a teacher. The tutor also observes the dynamics of each group and can intervene where there are evident problems. Each of the three case studies in the course lasts four weeks, although we are presently trialling two studies lasting five weeks each, to allow more initial time on teamwork skills, and avoid too many deadlines clashing in the final week of the term.

At the start of the course there is a session on group working, with two exercises (Belbin team roles and desert survival problem). This allows time to explore the advantages and disadvantages of teamwork before the assessed parts begin. Teams are rotated between studies, and feedback on the previous task is given before the next one begins.

The material covered in the case studies is easily varied from year to year. Topics have included:

- paper whiteness (with Arjo Wiggins paper mill)
- subsea remotely operated underwater vehicles (with Subsea Offshore Ltd)
- fibre optics (with British Telecom)
- positron emission tomography (PET) scanners (with Department of Biomedical Physics)

- solid oxide fuel cells (with University of St Andrews)
- applications of superconductors (with University of Cambridge)
- giant magnetoresistance materials (with University of Leeds)
- biomedical materials (with School of Medical Sciences)
- portable nuclear magnetic resonance (with School of Medicine/Medical Physics).

Once a case study is set up, it is easily reusable.

Linkages between teaching and research

The course tackles the concept of research in two ways. First, students are for the most part researching open-ended problems. This complements the type of research they encounter during their (concurrently running) honours project. Also, whereas the project is individual, the tasks in this course are tackled as part of a team, giving students a different view and experience of research as a concept. It also links into research as something that is not just academic. The course emphasises the role of research within industry, and looks at 'real-life' problems rather than artificial exercises often encountered during lecture courses.

The second aspect is the link to academic research. This is much easier for an academic department to control, and we can encourage members of staff - both within the Department and from cognate disciplines or other universities - to lead appropriate studies as the 'expert' and also the assessor of the final product. This not only exposes students to what is going on within 'Physics at Aberdeen', but also makes them think of physics as a broader principle, often in a multidisciplinary field, and find out what may be happening at other universities/institutions. This latter point can further help those thinking about applying for postgraduate research positions.

Course history

The course has been running since 1997 and has allowed flexibility of input, depending on staff interests and contacts. The course builds on elements of previous knowledge from lecture courses and labs, but specifically enhances those skills developed in the level 3 course Research Skills in Physics (see snapshot in section 3.3); where presentation, library and computing skills are developed together with project management, teamwork and a mini-project.

Subject-specific links can be seen between, for example:

- fibre optics case study - Light Science (year two) and Applied Optics (year four)
- PET case study - Electricity and Magnetism (year three) and Nuclear Physics and Medical Applications (year three/four)
- solid oxide fuel cells - Energy and Matter (year three).

The skills gained also feed into the full-year (year four) honours project.

Course assessment

The introductory teamworking workshop involves exercises (as mentioned above), but these are formative in nature. The case studies are assessed by some type of presentation; poster, oral, webpage presentations are normally used for the three studies. In addition, a technical 'summing-up' document is required from each group, and marks for teamwork and individual contributions are also incorporated. These assessments are both summative and formative, as quick feedback is essential to help in subsequent studies.

The tutor/facilitator marks the technical documents and contributes to the presentation assessment and other marks, using the experience of observing group dynamics to inform the individual marks. Peer and self-assessments are used (confidentially) to aid in informing the individual marks and to identify any problems that may not have been obvious to the tutor. Presentations are assessed by a panel of at least three members, which can include staff and postgraduate students. Each presentation normally takes 20 minutes and is marked under the headings of content, presentation and answering questions. All team members must contribute to the presentation in some way. A typical distribution of marks might be: team mark (20 per cent), individual contribution (20 per cent), presentation (25 per cent), technical content (35 per cent).

Course evaluation

Feedback is received from the students on each study, as well as through official university mechanisms such as the Student and Staff Liaison Committee halfway through the course and the Student Course Evaluation Forms near the end of the course. This feedback is used to make improvements to course delivery in subsequent years - hence our current trial of two studies rather than three.

The course is also continually under scrutiny within the Department, but the flexibility of the course allows alterations to be made easily in response to changing needs, changing expertise or topical physics problems. The course has also been evaluated as part of the institutional teaching review and as part of our IoP accreditation.

Key aspects and transferability

The course design is easily transferable and has been looked at by other disciplines; the only change would naturally be the subjects for the case studies. The skills developed are transferable in terms of disciplines, but also for future employment/research; many students have commented that this course has helped hugely in interview situations. The numbers of students on our course are small, but this is not a hindrance to transferring it elsewhere to larger cohorts - it would simply require an additional number of tutors/facilitators. The groups generally comprise four or five students; any more becomes too difficult for task distribution and assessment.

Course development and delivery issues

This type of open-ended problem-solving, together with teamwork, can lead to problems - hence the twice-weekly meeting with a facilitator or tutor. 'Loners' are quickly spotted and usually do not do well in the course if they insist on going it alone and refusing to interact, but this is rarely a problem. By assigning a team leader and secretary for each study, and ensuring that meetings are minuted and work-logged, we have a record of not only what was done but also how it was achieved. Peer assessment is also very important in this respect. Dominant students can similarly upset the group dynamic, but careful tutor management can quickly resolve this situation. Issues can also arise with students only learning a small area of the work. However, it is repeatedly emphasised to students that they should be aware of the whole area, and thus they must share information.

Further details

For further information see www.abdn.ac.uk/physics/case/

Case study: Contemporary Forensic Practice and Techniques

This case study focuses on a case exercise delivered as part of a compulsory fourth-year module running over two semesters, entitled Contemporary Forensic Practice and Techniques, which provides 30 credits out of a total of 120 for the year. Student numbers for the whole BSc (Hons) Forensic Sciences programme are 196 in total: 65 in the first year, 52 in the second, 44 in the third and 35 in the fourth year.

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Brief description of course

This is an overview of a case exercise which is part of an honours-year module in our programme. FS1001A is a double module running over two semesters. It encompasses three interconnected strands:

- contemporary forensic practice, which stretches students and encourages them to think about the modern and future practice of forensic science on a wide front
- advanced forensic techniques, which introduces students to new and potential techniques for forensic examination and analysis
- a major case exercise, which allows students to apply the skills and knowledge they have acquired earlier in the course, extend and develop those skills and acquire new skills and knowledge, analyse, interpret and evaluate evidence and develop a range of transferable skills not readily fostered by any other means.

The case exercise allows students to work on a major crime (simulation) in five groups (group size depends on total student numbers for the year; this year the groups were of six or seven), applying their skills and knowledge in a real-time exercise. It proceeds from acquisition of evidence at the crime scene through analysis and evaluation of evidence and its presentation under hostile cross-examination in court.

The case exercise integrates very well with students' developing knowledge of contemporary forensic practice and techniques being taught in the rest of the module. Students are expected to use not only the skills learnt in previous years, but must also apply the new skills being acquired in the honours year. The case exercise is a major study involving nine linked scenes and some 80 pieces of evidence in the major areas of trace and contact evidence, physical fit (physical matching together of component parts, such as a page torn from a book) substances of abuse and DNA. The teams have to address logistical, organisational, problem-solving and time-management issues.

Linkages between teaching and research

At Abertay we are conducting research in the emerging field of Bayes Theorem applied to evidence evaluation and interpretation. We are also interested in novel fingerprint-enhancement techniques: the acquisition of DNA from treated fingerprints and new methods for recovering marks at crime scenes. These and other research interests integrate well with the case exercise as key parts in the development of students' knowledge and expertise in forensic science.

Course history

The programme is in its sixth year, and this year sees our third cohort graduate. The programme is essentially stand-alone, focusing on chemistry, biology and forensic science, although it has input from important supporting disciplines such as law and statistics. Some other courses at the University also take several forensic modules as a core part of their programme.

Course assessment

Assessment of the crime scene exercise falls into three main areas: crime scene investigation, analysis and interpretation of evidence, and court appearance.

Crime scene investigation is subdivided into five areas:

- team performance, based on staff evaluation during the exercise (formative)
- self-evaluation by the teams during the crime scene part of the exercise (formative and summative)
- creation of a team report by each team. In our experience, these reports have been comprehensive and students recorded their views with honesty and humour. The scene logs have been filled in thoroughly, and care and thought have gone into justifying the recovery of evidence. Team meeting notes have been instructive and have paralleled staff views of team performance. Those teams which held regular, serious meetings with full complements of members have tended to perform better as teams (formative and summative)
- team effectiveness in evidence identification, recovery and packaging, assessed by staff (summative)
- an individual report evaluating critically and from the perspective of each student their own performance and that of their team during the progress of the exercise (summative).

In the forensic analysis and interpretation phase, each student is interviewed on an individual basis. This has proved to be extremely discriminatory, with clear differences emerging among students. The more able students defend their decisions comprehensively, but some students need a little prompting and others find great difficulty in justifying their decisions (formative and summative). Evaluation and interpretation of the evidence are carried out on a team basis. Students are expected to critically apply their knowledge of evidence evaluation, gained in the lectures in the contemporary practice part of the module. Each individual team member prepares a case file with witness statements for court (summative).

For the court appearance, a room is set up to simulate a court and two members of staff act as prosecution and defence councils. The prosecuting council leads the students through their evidence and the defence council then cross-examines them. This tests students' communication skills in a pressurised courtroom setting. Similar questions are used for each student, but those who stand up well to cross-examination are asked increasingly difficult questions (formative and summative).

Course evaluation

To ascertain whether the case exercise element of the module is operating successfully, the views and thoughts of students have been sought both formally (as their own self-assessment of teamworking in the form of a short questionnaire) and informally (asking questions at every opportunity to get their opinion of the module). This has allowed us to gauge the effectiveness of the exercise and the assessment instruments used. As a consequence of such evaluation, the exercise has evolved. New scenes have been developed to improve the scope of the types of evidence students are required to examine and broaden the range of techniques they employ.

The following is a sample of the type of comments and thoughts students have given over the last three years.

- They appreciate the high level of planning which has of necessity gone into the exercise.
- They like being able to both apply and develop skills techniques and practice learnt throughout the course.
- They appreciate working with others in their teams whom they would not normally work with or did not know well, and feel that they learn a great deal from this. Students have commented that this has created a number of new friendships and fostered a tremendous unity in the year cohort.
- They welcome the need to develop teamworking and leadership skills.
- They appreciate the opportunity to examine a wide range of inside and outside crime scenes and the ability to work in difficult weather conditions.
- They appreciate the opportunity to look at real (simulated) road traffic accidents (scenes involving cars which have been deliberately crashed into each other).
- The teams feel under considerable pressure at times - particularly when, as they perceive it, last-minute information is fed in, or a bundle of witness statements is provided when they are in the middle of a scene examination, or the senior investigation officer (a member of staff) is breathing down their necks demanding answers. Concerning this last, the crime scene manager (a designated student of the team) quickly learns to be ready with their own questions to the senior investigation officer to get him off their back.
- Some evidence is difficult to find or is easily missed; teams omitting it can find this frustrating yet a stimulus to do better next time.
- A competitive spirit rapidly builds up, with each team wanting to be the best. This is reflected in the intensity of team meetings and the developing team spirit.
- Students feel that they are in a real situation and develop their teamworking skills appropriately. In some cases, stronger team members compensate for weaker ones.
- The importance of the managerial effectiveness of the crime scene manager rapidly becomes apparent to the team members. The most successful teams are those that have effective crime scene managers and work closely together.

Key aspects and transferability

The exercise provides students with:

- the opportunity, indeed necessity, to work in teams - they gain valuable insight and skills in teamworking, team development and planning, and it is instructive to see how the teams develop as the exercise progresses and how students are able to critically evaluate their respective team roles
- the opportunity to develop managerial skills - the team members gain an insight into managing and being managed, and the range of adaptable management styles required to supervise highly qualified technical people and successfully work together to produce a high-performing team
- formative feedback - a spin-off of the exercise is that staff members are able to schedule meetings to provide students with general feedback on how they can improve their performance
- the opportunity to work in a competitive environment - there is considerable competitive, self-generated pressure on the teams to outperform each other
- further input from staff during scene and evidence examination - this encourages the teams to apply their skills and knowledge rigorously, further develop little-used skills, and bring into play knowledge being learnt on other parts of this and other honours-level modules
- the opportunity to examine a wide range of crime scenes both inside and outside and to be able to cope effectively with the vagaries of the weather
- the requirement to respond to unexpected developments (last-minute additions are made to each scene exercise to simulate real-life situations)
- the experience of working under pressure - a member of staff takes the role of a senior investigation officer constantly demanding results.

Overall, this module integrates and reinforces the University's graduate attributes, not always explicitly but certainly implicitly. It encourages students to reflect on their development as confident thinkers, determined creators, flexible collaborators and drivers of change.

Course development and delivery issues

A definite positive for the continued development of this module has been the appointment of experienced forensic practitioners as lecturers on the Forensic Science programme. Their knowledge and experience in a wide range of forensic techniques and applications have enhanced the content and delivery of the module.

Preparation, delivery and assessment of this module are time-consuming and labour-intensive and provide a considerable challenge to staff. The issue of physical resources represents a further challenge, although a recent allocation of additional rooms adjacent to our crime scene facility has provided the opportunity to create a dedicated evidence storage area.

3.6 Research opportunities

Snapshot: Astronomy field trip

Level 2 Astronomy, approximately 30 students, part of the 30-credit level 2 course Astronomy 2Z.

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The Astronomy 2 field trip was introduced more than 10 years ago. Its principal function is to give early undergraduates experience of observing from a real dark-sky location, far from the city. It would be impractical to offer dark-sky observing to all of Astronomy 1 (although those students are offered an optional, free visit to the Glasgow Science Centre planetarium), so the field trip is primarily targeted at the smaller Astronomy 2 class. As well as naked-eye observing (which in itself has motivational value for students who have grown up in a light-polluted city) students have the opportunity to use reasonably large optical telescopes equipped with modern charge-coupled device (CCD) detectors.

The field trip venue is now Burn House in Edzell, near Forfar. The field trip usually runs over a weekend (Friday lunchtime until Sunday evening) in mid-February. As well as offering excellent dark skies, Burn House provides a comfortable, isolated and entirely self-contained environment. This helps to build strong camaraderie within the class and between students and staff. It is in the latter that the research-teaching linkages are most apparent.

For many in Astronomy 2, the field trip is the first real chance to talk to the academic staff about their research - which means what they do when they are not teaching. Discussions on a wide range of hot and/or controversial research topics (for example gamma ray bursts, extra-solar planets, dark matter and dark energy, gravitational wave detection) arise naturally, often prompted by observing a related object in the sky. Similarly, daytime observing of the sun (for example solar flares and prominences via an H-alpha filter) might stimulate discussion of the latest solar physics research. The staff's goal is always to underline the excitement and challenge of current research, while emphasising how it links to physics that students already know and phenomena in the sky they can see for themselves.

There appears to be much added value in discussing research with students outside of the classroom (the level 1 Frontiers of Physics lectures - see section 3.1 - are very successful, but a much more formal and traditional mode of teaching). Firstly, there are no exam questions to worry about, which permits students to ask about what really interests them, rather than what they think they need to know. Secondly, it encourages students to really think about the physics - observing under the stars there are no PowerPoint slides to distract them, or even pieces of paper to scribble on. Thirdly, it lets students see, perhaps more readily than via formal lectures, the passion and enthusiasm with which staff pursue their research. Finally, it gives staff much additional information about the students: what motivates them and how they interact together and work as a team. This is very helpful for identifying students who have strong potential for undergraduate research and/or postgraduate study.

Usually (especially if the skies are cloudy), staff and postgraduates give some more formal presentations highlighting current research topics. Students are particularly interested to learn about the role of large, international collaborations in many projects and the opportunities for travel this affords. Talks mixing discussion of research with 'travelogue' always go down well with students and help to boost the image of a research career as stimulating and exciting, on intellectual and social and cultural levels.

Snapshot: Use of the St Andrews observatory in teaching

Observatory-related components of Second-Year AstroPhysics, Observational AstroPhysics (Honours) and honours projects. Student numbers: 18, 18 and three, respectively, per year.

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Our observatory, which has been used predominantly for research, has been upgraded to be better integrated into teaching activities. A PC classroom has been installed and extra equipment purchased (for example binoculars) to complement the existing telescopes.

Second-year astrophysics

Students can take an Observer Training Programme, consisting of four one-hour modules using the observatory PC classroom, coupled with training on our two teaching telescopes. These optional classes run in the evenings. After two or three practical training sessions, students are required to demonstrate proficiency with the telescopes, after which they can be loaned keys to allow them access to the telescopes and PC classroom.

The course provides students with information on how to plan and conduct scientific astronomical observations and hands-on experience in navigating the skies. During the course, students are encouraged to write telescope proposals for the main research telescopes. The objective is to provide students with the facilities and skills to make the most of the observatory outside their formal courses, and to develop a sense of association and ownership of the observatory. This has proved popular with students.

Observational astrophysics

Students use our two research telescopes to conduct astronomical observations, including planning, execution and reduction of data in a similar manner and using similar software to that used by the professional astronomers in the School. This provides a unique insight into what it is like to be a professional astronomer as well as a chance to consolidate classwork from earlier courses. The goal is to produce publication-quality figures of astronomical data that students have obtained themselves. The aim is to provide an idea of the research life of an astronomer.

Honours projects

Honours projects frequently bring students into ongoing research programmes at the observatory to conduct practical on-site fieldwork. The aim is to provide students with a detailed insight into an active and world-class research programme.

An overview of the observatory facilities is at:
www.st-andrews.ac.uk/physics/pandaweb/newtour/teachf/obs.htm

Details of the astronomy courses are available via:
www.st-andrews.ac.uk/physics/Staff_Stud.shtml

Case study: Use of the Liverpool Telescope in first-year undergraduate education

This case study is concerned with use of the Liverpool Telescope (LT) to enhance the learning experience in a suite of level 1 Certificate of Professional Development (12-24 credits) and Certificate of Higher Education (120 credits) programmes taught part-time by distance learning. Two to three staff have a significant involvement, with up to 10 others acting as tutors. Total student numbers are typically 200 per year over all the courses.

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Brief description of course

These courses are intended to bring the latest in astronomical knowledge and research to a non-specialist audience. The courses are taught by distance learning, with students allocated a tutor (who is a researcher) to interact with via email, phone, letter and video-conference. Entry requirements are minimal since courses can be tailored by the tutors to match the needs of each student. This gives us a very varied cohort, from students who left formal education at a very young age, to those with PhDs.

Each course covers a different aspect of astronomy, plus an introductory general course. Some concentrate on a research area (for example stars or planetary atmospheres), while others have a more practical emphasis (for example the use of personal telescopes to carry out simple experiments, or projects involving mining professional data archives).

Although these are level 1 courses, we find that our students are highly motivated and often produce work of a very high standard. This has led us to look for ways to stretch them, whether as an integral part of the course or through extension activities. In particular, we are now making considerable use of the Liverpool Telescope (LT), which is the world's largest fully robotic telescope and is owned and operated by the University. Such usage comes in several areas:

- motivation for students (for example prizes of telescope time)
- providing real data for experiments
- giving access to the experience of doing research.

This facility is also widely used for final-year project work.

Linkages between teaching and research

By using the LT we can bring students closer to research in three main ways:

- actually taking part in research projects

- using the same instrument that is carrying out (often well-publicised) research
- providing access to the telescope in the same way as for professional astronomers, to give an accurate 'feel' for the day-to-day realities of research.

All three are currently being tried within the courses, as in the examples below.

- One piece of assessed work involves writing a proposal for a simple experiment, in a similar way to applications to a professional panel for the allocation of telescope time. To give the process maximum reality, and as a motivating factor, the best proposals are carried out on the telescope.
- When studying Hertzsprung-Russell diagrams, students create their own from data taken for them. Not only is this far more interesting than simulations or archive data, it also introduces students to the vagaries of real data.
- When developing or updating courses, current research from the telescope is included, with short video-clip interviews with the scientists involved where appropriate.
- Some practical projects involving the use of home telescopes are enhanced (and made a bit more 'weather-proof') by supplementing students' own observations with ones from the LT.
- The best students each year are given their own allocation of telescope time to do with as they wish.

Course history

The distance learning courses have been running for about 10 years, but use of the LT has only really been an integral part of them for about 18 months. That use is increasing all the time, however, as we develop new courses and update old ones. The motivation for inclusion of the LT is largely to maximise the stimulation for students, but also to bring our own research and teaching as close as possible, to allow each to feed off the other.

Course assessment

Each course is assessed in a range of ways, from practical projects to multiple-choice tests. All work is marked by the tutor, with second-marking by the Programme Leader to ensure consistency. The tutors are a mixture of research/lecturing staff and PhD students; one of the motivations for running the courses is the excellent experience it gives to the tutors. Overall, dealing with assessment is a large proportion of the workload for the courses once they have been developed. The majority of assessment is summative, with extensive feedback provided for each piece of work.

Course evaluation

All courses go through the standard validation process within the University, and we have an external examiner who is responsible only for the distance learning courses. The courses are also endorsed by the Royal Astronomical Society. The specific aspects relating to use of the LT have been particularly scrutinised by our external examiners, who have been very positive. Another, slightly out of the ordinary 'evaluation' was the award to the University of a Queens' Anniversary Prize for Higher and Further Education in part for this work with the LT and our distance learning courses.

Key aspects and transferability

Obviously, without access to a similar instrument, the details of what we are doing cannot be reproduced. However, the most important aspect is the value of getting cutting-edge research into courses right at level 1. This is where the motivational effect is most strongly seen, particularly (as here) if the research is included in a practical way - which means students actually 'getting their hands dirty' with the data.

Course development and delivery issues

The biggest challenge has been to ensure that we retain the complexity and intricacy of the research while still making it accessible to level-1 students, especially those with little previous experience of formal education. However, by looking at all stages in the process (for example planning, collecting data, reduction and analysis) rather than just the final result, the full flavour of the research comes across, together with a sense of ownership.

Effect on student experience

So far, we have collected little formal student feedback specifically about use of the LT in the courses. However, unsolicited responses from students have been very encouraging ('a super job', 'breathtaking'). We have also seen an increase in completion rates for those assignments where LT data are used to support and supplement students' own observations. As a general observation, it is impressive how students have grasped even quite complicated procedures and concepts when we have been able to provide direct, practical, real examples using the LT. We suspect that this is mainly because of the additional motivation of making use of a professional instrument, and therefore working alongside professional astronomers.

3.7 Internships and placements

Case study: Industrial Placements

This case study describes a level 10 course of 90 credits (three-quarters of year four) entitled Industrial Placement. It is taken by all MSci students (and a similar experience is taken by some BSc Hons students); numbers in the 2007-08 academic session were 82 (71 MSci and 11 BSc students).

A core team of five staff interview all students and agree the area of chemistry in which they would like to work. Each member of staff has a set of companies they deal with exclusively in terms of setting up interviews etc. A further five members of staff are involved in this activity. Finally, almost all academic staff (up to 40) are involved in placements as academic supervisors.

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Brief description of course

Our Department has been supportive of industrial training for many years, in the firm belief that it ultimately enhances our students' ability to obtain employment, broadens their outlook on chemistry, improves their personal and transferable skills, and helps them to discover how the courses we teach them knit together in the real world. Even if students are not considering a career in chemistry, this is an opportunity for them to work as part of a team in real-world situations.

The Industrial Placement has been seen to benefit students by:

- increasing their scientific knowledge and understanding
- developing their intellectual skills in, for example, analysing problems, proposing solutions to them, organising work and writing scientific reports
- improving manual skills associated with scientific and technological operations
- developing their personality and their understanding of individuals and groups in work situations
- providing background information and experience which will help career choice
- providing future career opportunities.

Linkages between teaching and research

The Industrial Placement encourages links between teaching and research on many fronts. One task placement students must complete is the literature review. It takes the form of a critical review of the literature pertinent to an area of science in which they are working, or some relevant area of special interest to their industrial supervisor. This task gives students training for the preparation of their research thesis, which they complete in their final year of study. In the past, some high-quality literature reviews have led to publications in the scientific literature.

Students are also required to submit a final report focusing on some research aspect of the work they have carried out as part of their industrial placement period. This also provides invaluable experience for the preparation of the thesis on the final-year research project. General development in areas such as increased scientific knowledge, improved critical and analytical thinking skills, improved manual skills and ability to work as part of a team also prepares students for the rigours of research.

As most academic members of staff are involved in visiting students while out on placement, it has allowed many staff to form collaborative links with partners in industry. Through these links a number of collaborative research projects have been established, and certain members of staff regularly go out into industry to teach on new aspects of chemistry and the research being carried out in the Department. A number of companies also offer financial support for final-year projects. Additionally, these links with industrialists assist with attracting more students to study chemistry. The Department runs the RSC-funded chemistry at Work event, when industrialists are invited to present interactive lectures to school pupils to emphasise the importance of chemistry in everyday life and to encourage them to consider chemistry as a career.

Course history

The Department began the placement scheme over 20 years ago in the firm belief that industrial training ultimately enhances students' ability to obtain employment, broadens their outlook on chemistry and improves their ability to carry out practical work both independently and as part of a team. Initially, placements were only of five months' duration and for a small number of students. As industry became aware of the pool of talent available, the scheme grew and all students were given the opportunity to go on placement. Industry began to recognise, however, that in a five-month period students were probably only 'useful' towards the last two months. So the placement is now of 12 months' duration, to allow industry to take full advantage of the efforts invested in training students.

Preparation for the placement begins in the second year, when students attend a compulsory class provided by the Science Adviser from the University Careers Service on how to prepare a CV. Students must submit their CV at the end of the second year. At the start of the third year an updated CV is submitted, including any new experiences gained over the summer months. Students receive instruction on interview techniques, and one-to-one training is provided by the Careers Service for those who wish to take advantage of this facility. During the third year, students are interviewed by various companies and industrial bodies until they secure a placement. The number of interviews an individual student has varies from student to student, but is typically two or three.

While on placement, students are expected to complete a distance-learning assignment, which ensures an academic link with students while they are off-site. This assignment must be completed outside the working hours of the placement. The activities of the placement (practical work, literature review and final report) clearly feed into the research project in the final year of study.

Course assessment

Students are visited by their academic supervisor twice during the industrial placement period, for discussions with the industrial supervisor and a general assessment of their work and performance. At the first visit (normally within the first three months of employment), the discussion includes a check on any safety-related details and ensures that students have understood their duties and other general aspects of their work. A first-visit form is completed and assessment is discussed. Students are advised that their literature review should be submitted to their academic supervisor at least two months before their placement ends. There is a marking scheme and the academic supervisor marks the review (out of 50), using criteria such as technical presentation, scope and evaluation, with some input from the industrial supervisor.

The second visit usually occurs in the last month of the placement period. During this visit, the industrial and academic supervisors discuss and mark the final report and complete the skills matrix. This focuses on the skills acquired by students while on placement, including chemistry skills and ability to manage time, work independently, etc. The skills matrix is mainly completed by the industrial supervisor, with moderation by the academic supervisor, and carries 100 marks. The final report is marked by the academic supervisor, with some input from the industrial supervisor. It is marked out of 50, based on the criteria of technical presentation, introduction and methods, evaluation of results and discussion. The final mark is then scaled to a percentage. A second-visit form is also completed.

Course evaluation

The development of this class in its current form has evolved over the last six or seven years with the introduction of the MSci degrees (five-year courses) alongside the BSc Hons degrees (four-year courses). The class is compulsory for all MSci students, but not for BSc students. However, any BSc students who are successful in securing a placement complete a 'sandwich year' before returning to their final year of study. The placement carries no credits for BSc students, but it provides them with invaluable experience. The placement has been evaluated by the RSC as part of our application for accreditation of courses. All four of our MSci degrees are accredited by the RSC.

Students are requested to complete evaluation forms for every individual class they undertake, and the feedback for the placement has always been extremely positive. At the last faculty review of the Department the placement experience was highly commended as an important tool in terms of employability and enhancing the graduate attributes of our students.

Key aspects and transferability

The Industrial Placement is useful in a number of different ways. It increases students' employability since they graduate not only with their qualification but also with experience. It widens students' experience in terms of the application of their science and exposes them to research as performed in an industrial setting. Students augment their transferable skills (such as oral and written communication, group working), as these are regularly put into practice during the course of the placement. We find that students mature during the 12 months they are out in industry. The placement experience could be adapted to any scientific discipline.

Course development and delivery issues

The Department's increasingly strong links with its industrial partners have certainly helped the development of the Industrial Placement, as has the deployment of more staff to assist in this area. Many companies have very small 'windows of opportunity', so staff and students need to be prepared to act very quickly to requests for CVs, interview appointments, etc. The increasing numbers of students looking for placements have caused the Department concern, and the 'in-house' placement option has been introduced as a fall-back position if required. Competition from other universities is clearly a factor in placement operation as more departments recognise the value of this activity.

Effect on student experience

The placement changes the student experience inasmuch as our students graduate with not only a qualification but also real industrial experience. This improves their employability; a recent poll by *The Guardian* suggested that our students have the best graduate employment prospects in Scotland. Many of our students return to the company where they carried out their placement once they have graduated. Even those students who do not plan to go into the chemical industry learn many skills during their placement, which will stand them in good stead in their future careers, regardless of discipline.

Further details

The course will continue to evolve, as the University has taken the decision to move all classes to 20 credits (or multiples thereof). Our next challenge is to address how we will continue to operate within the new framework. Additionally, in the national context, the introduction of the new subject benchmark statement may impact upon these placements.

Snapshot: Summer vacation research project

Summer vacation research projects between the second and third years, 10-15 students each year, not credit bearing.

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Discipline area: chemistry

Each year, students in the second year of our five-year MChem or four-year BSc degrees are circulated in February/March with a list of available summer vacation projects. The top one or two (who are eligible) are put forward for and usually receive a Carnegie Vacation Scholarship; others are funded by supervisors, usually for a period of six weeks at a mutually agreed time between June and September.

During the project, students carry out full-time research, typically assisted by PhD students and post-docs as well as the academic supervisor. Although they will have covered the basic skills in first and second-year laboratories, full-time lab work is a new experience, as is carrying out experiments for which the outcome is unpredictable. Students have to keep an accurate record of their work in a format suitable for use by other research group members and ultimately for publication. Undergraduates on this type of project have quite commonly got their names on papers in the primary literature. During the vacation project, students are also encouraged to participate in relevant colloquia and seminars and get the feeling of belonging to the Research School.

3.8 Project skills preparation, learning what research is

Case study: Training in Research Methods

This case study describes a compulsory 40-credit SCQF level 10 course undertaken by fourth-year MChem students not spending the year away from the University on industrial placement. The course is typically undertaken by 20 students and involves up to 20 staff.

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Brief description of course

In addition to their lecture courses, those MChem students choosing to remain in Edinburgh for their fourth year undertake a 40-credit Training in Research Methods course, building on the year-three transferable-skills activities (see section 3.3) and providing preparation for the final-year research project. The various components of this course emphasise practical, technical, literature survey, presentation, scientific writing and teamworking skills.

Early in the year students prepare a literature survey on a given topic, guided by a member of staff. The experience gained and feedback provided through this written exercise are then used in the subsequent writing of a literature survey in preparation for the final-year research project.

A major component of this course comprises three research methods exercises, each of six weeks' duration. These exercises are designed to develop students' practical research skills and provide an introduction to the methods, techniques and instrumentation in different areas of chemistry. Each exercise is undertaken by groups of four to six students, who are encouraged to divide their effort to most effectively achieve the exercise aims. The groups are changed between each exercise to encourage practice in team-building.

After the initial week of the exercise, during which students define their aims and methods within the given area with reference to the literature and supervisor guidance, the groups undertake their chosen mini project, often within the supervisor's research group laboratories. Each student group has control of the budget for the exercise (£50 per student) and is free to explore the given area and decide on the activities undertaken, with guidance from the supervisor(s). The final week of each exercise is devoted to preparing a report, which has a different format for each of the three exercises: oral presentation, poster, and written (paper format) report. An introductory lecture on the preparation of the written report is provided.

Students often achieve a surprising amount during the exercises, and the quality of the outcomes is reflected by the fact that the results of some of the exercises have been published (for example *Journal of Inorganic BioChemistry*, 2006, vol. 100, 7, p.1260-1264). Fifteen exercises are currently available in such diverse areas as computational chemistry; heterocyclic chemistry; supramolecular chemistry; inorganic mass spectrometry; microwave chemistry; solar cells; coordination chemistry; high Tc superconductors; metal-carbon multiple bonds; and combinatorial chemistry.

Linkages between teaching and research

As its title suggests, the course is intended to train students in the methods of research - use of the literature; scientific writing; oral and poster presentation skills; practical skills; instrumentation; and methodology. As such, the entire focus is on linking research and teaching. The intention is to bridge the gap between the conventional level 9 laboratory courses/transferable-skills activities undertaken in the third year and the final-year research project, and thus provide the skills and understanding required for the successful completion of a master's (level 11) research project.

The three research methods exercises enable students to gain a hands-on insight into a range of chemical research fields, which gives valuable breadth to their understanding of the challenges offered by the different areas of chemistry. Students are encouraged to set their own targets, think about chemical problems for themselves and as a group, and make use of the available resources to achieve results that may often be regarded truly as research - which is reflected in the occasional journal publication of results. In this way, qualities of initiative, independence, creativity and teamworking are fostered, in addition to chemistry-specific knowledge and skills, thus providing training in the full range of intellectual and practical qualities and skills required of a successful researcher. The written exercise and the project literature survey involve one-to-one supervision by a member of academic staff, allowing students to benefit directly from the expertise available within the School.

Course history

The original motivation for the course arose in 1999 from the introduction of new MChem degree programmes complementing the existing BSc degrees. This process was a response to the UK-wide updating of undergraduate chemistry degrees prompted by industry and RSC reviews of industry's requirements of chemistry graduates. The intention of the new MChem was to provide degrees better suited to students intending to progress to careers as professional chemists within industry.

Being five-year programmes, distinct from the existing four-year BSc degrees, the content of the new fourth and fifth years were considered in detail. A particular requirement was for students to undertake a master's (level 11) research project in the fifth year, distinct from the level 10 project undertaken by BSc students. Training in research methods during the fourth year was therefore clearly required for MChem students to perform at this level in research.

Course assessment

The written exercise contributes 25 per cent to the course mark and is assessed by the staff member who assigned the topic. Formative written and oral feedback is provided by the supervisor on the basis of a draft of the exercise before final submission.

The research project literature survey contributes 25 per cent to the course mark and is assessed by the final-year research project supervisor, who is assigned early in semester 2 of the fourth year. The timing of this exercise following the completion and assessment of the preceding written exercise enables students to make use of the feedback received when writing the literature survey. The feedback provided on both exercises provides preparation for writing the research project report in the fifth year.

The research methods exercises collectively contribute 50 per cent to the course mark. The exercises are generally supervised by one or two members of academic staff along with a postgraduate demonstrator. Each exercise is assessed on the basis of individual effort, attainment and output, and a proportion of the marks is also awarded for the group's effectiveness in the exercise and output (oral, paper, poster) activities. Given the day-to-day involvement of the postgraduate demonstrators in supervising the exercises, their views are sought during the assessment process.

Assessment of each component of the course is structured by forms listing characteristic levels of performance in the various assessed areas consistent with numerical marks (0-20). In this way, consistency of assessment by different markers is ensured.

Course evaluation

The MChem degrees were subject to RSC accreditation in 2003; the next accreditation exercise is due in 2008. A detailed quality assurance assessment of the course is conducted each year and formally reported. Student feedback is solicited every year in the form of a questionnaire. The responses are considered by the Years 4/5 Committee in detail, and written responses are included in the minutes. Replies are notified back to students at Staff-Student Liaison Committee meetings. Students generally find the course a useful exercise and particularly like the range of experience they can gain from the research methods exercises.

Key aspects and transferability

In terms of transferable skills, the training in scientific writing and use of the chemical literature achieved by the written exercise and subsequent project-literature survey (which build on each other) is probably the most useful outcome. This is certainly reflected in the quality of students' final-year project reports. The practice provided in oral and poster presentation skills is also valuable. Many of the components of the course build on transferable skills activities undertaken in the preceding (third) year and are subsequently practiced in the final-year project.

As highlighted above, the Training in Research Methods course may therefore be regarded as one which upgrades students' abilities in various aspects of chemical research to enable them to undertake a master's-level research project in their final year. Many of these skills are of course directly relevant to students' subsequent careers, within both the chemical and other industries.

Course development and delivery issues

While the written exercises and project-literature surveys are not particularly staff-time intensive, and are well distributed among staff, the research methods exercises are more demanding in this respect. As students undertake three exercises in relatively small groups, a rather large number of exercises is required if repetition within a year is to be avoided (for example 15 exercises are required for 20 students in groups of four). However, staff generally recognise the value of the exercises and are willing to devote the necessary time to their set-up, administration and supervision.

Effect on student experience

Evidence of student performance in final-year research projects indicates that students develop substantially in confidence and ability in the various skills and qualities required for chemistry research. In comparison with their BSc colleagues they generally demonstrate significantly greater maturity, independence and initiative in their work - features common among those students returning from industrial placements.

Further details

Details of the course have not previously been disseminated. Although other chemistry schools have no doubt addressed in various other ways the issues that prompted the development of our course, evidence suggests that this course is particularly effective. Publication of an account in the chemical education literature may be considered.

Case study: Project Training

This case study describes a 10-credit SCQF level 9 course with approximately 40 students. It is a compulsory class for most BSc and MSci programmes, but optional for others. Two staff members are involved in delivering the class: one lecturer and one tutor (currently an EPSRC Advanced Fellow). Other academic staff are involved in research laboratory tours and six advanced fellows/early career researchers in talk assessments.

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Brief description of course

The aim of the course is to develop the skills necessary for project work in an academic or industrial setting. These include:

- literature skills - awareness and use of different referencing schemes
- communication skills - oral, poster and interpersonal
- scientific and report-writing skills - abstract writing, summarising, coherent technical reporting within a given word limit
- critical analysis - development and appreciation of research strategies, project planning and time management.

Teaching and learning are through interactive lectures and coursework. The interactive lectures comprise 12 one-hour sessions over the semester in 'flat-floored' seminar rooms. Lectures have a small component of formal teaching, outlining the aim of the lecture and defining its context with respect to the course. The majority of the lecture time is spent on group work (five to six students per group). Students are assigned randomly to a group at the start of the course and remain in that group. Each student must act as spokesperson for the group at least once during the course. Students are given the topic for each lecture beforehand and are often required to undertake preparatory work, literature reviews or research in advance of the subsequent lecture discussion. The lecturer facilitates and guides the group work part of the lecture, and keeps the groups on track with the aid of the tutor.

The coursework element comprises three written assignments - explanation of literature review techniques/scientific writing, experimental methods analysis and an overview of departmental research, based on material covered in the formal part of lectures - as well as poster and oral presentations. Summative mark sheets are provided for all the assignments in advance of the hand-in date, with clear learning outcomes and requirements and mark breakdown. In the talk, a peer assessment exercise is undertaken and the class decides the final marking scheme.

Library skills are supported by a lecture provided by University of Strathclyde library staff and include an online tutorial that students must complete. The course also includes research laboratory tours, whereby all students visit staff research facilities. These tours are organised outside of lecture times. They take place in the middle two weeks of the course and last two hours each.

Linkages between teaching and research

The course provides direct practical exposure to the skills students need to acquire to be successful researchers, as well as a broad range of transferable skills. It also fosters relationships between research and teaching, as the laboratory tours provide students with a detailed insight into the research carried out by the various members of staff in the Department.

Following this course, several students have approached some of the research groups looking for summer placements (paid or unpaid, depending on the finances of the research group). Furthermore, this heightened awareness becomes very apparent in the following year when students select their final-year project, as they are much more focused on the research area they wish to follow.

Course history

The course has been running for 10 years and was originally designed to prepare students for their external placement between the third and fourth year and the final-year project. The course provides groundwork for the following courses: Physical Science I; BSc level 10 project; Industrial Project (level 10); Research Skills (level 10); Communicating Physics (level 10); MSci level 11 project.

Course assessment

Assessment for the course is on a continuous basis, with credit divided equally between the written coursework and evaluation of communication skills. The written coursework credit comprises 20 per cent for literature review/scientific writing, 15 per cent for experimental methods analysis and 15 per cent for overview of the Department's research activity. The academic who delivers the course does all the assignment marking; this is cross-checked by the tutor to ensure fair and equal marking across the board. The marking scheme in the summative assessment sheets is strictly adhered to. Formative assessment is also given, during group work in the lectures and on an individual basis by use of the comment sheet on the back of the summative form. Assignments cannot be returned to students as the course is continually assessed, so all work needs to be available to hand (if requested) to an external examiner at the final honours board. In practice, students who attend lectures regularly and do the work requested get a good mark.

Communication skills contribute the other 50 per cent of the marks for the course. Within this, 10 per cent come from lecture attendance, group participation, preparatory work and acting as spokesperson for the group in presentations to the rest of the class. The remainder of the mark comes from the poster and talk components. The poster is provided in template format. Students in each group are assigned one science article at the start of term on which to base their talk, poster and literature assignment. The talk is peer assessed, based on the marking scheme developed by the students, with 60 per cent of the final mark weighted to the academics and 40 per cent to the students. Techniques for delivering talks and preparing posters are described extensively before either assignment is completed.

The preparation and assessment for this course are obviously very labour intensive for the academic staff member. Every two weeks there are 40+ scripts to be marked, and staff also have to be coordinated to undertake the talk assessments and project tours. This probably takes about one day a week during the semester in which the course runs.

Course evaluation

The lecturer has developed a questionnaire, which is given out to students at the end of the course for feedback on the course. The questionnaire is designed to encourage students to think about specific aspects of the course, rather than simply commenting on whether lectures were well prepared etc. The academic running the course has done so for three years, and the course content and material have evolved over that time to account for comments from students. Feedback has now been sought from the first cohort of fourth and fifth-year students (now undertaking their projects), who also undertook this course with the current lecturer.

Topics likely to be included in future include further writing skills, time-management skills and planning skills - areas undergraduates have felt they were lacking in. Consistently, students enjoy learning the literature skills, realising that 'lecturers don't just teach but do interesting research in the Department', and practising talk skills. Less popular is always the workload. Two other comments often arise: 'top-flight' students often do well and do not complain about the workload, but they often do not enjoy the group work. The course is also assessed through the standard university questionnaire that students complete once the semester has finished. The IoP Accreditation Panel reviewed the course in 2005.

Key aspects and transferability

This course is aimed at the development of generic skills relevant to anyone working in an academic or industrial environment (be it research or service-based). As such, with the choice of appropriate examples, this course is applicable to any discipline, from chemistry to law.

Course development and delivery issues

The biggest issues facing the course are availability of suitable flat-floored teaching space and the time and effort involved in preparing, organising teaching, and assessing the course. The Department assists the teaching and group assessment during classes by allowing research staff (for example the current EPSRC Advanced Fellow) to be involved in the course.

Effect on student experience

The laboratory tours serve two purposes: firstly, they allow students to identify possible areas of study for final-year projects and, secondly, they let students see the research environment of staff, leading to post-tour comments like 'I did not know that Professor XXX worked on that'. Students now appreciate the complexity of literature and the issues around reviewing it, and tend to produce pieces of scientific writing that are not just 'cut and paste' from the internet.

Further details

The course has been disseminated by the lecturer as part of a university teacher training course. The University has changed its credit structure such that all classes will have a minimum weighting of 20 credits. The Department values the Project Training class and has identified a suitable approach to ensure that it remains an integral part of a student's curriculum.

3.9 Group research project

Case study: Frontiers of Crystallography

This case study describes an SCQF level 9 Frontiers of Crystallography course (part of the Frontiers of Chemistry afternoon series) taken by around 20-30 students per year. Frontiers of Chemistry overall is a non-assessed compulsory part of the supplementary course for MSci students; the individual modules are commonly regarded as 'semi-optional'.

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Brief description of course

In two afternoon sessions students are introduced to the ideas and methods of research in structural chemistry. They then endeavour to determine the structure of crystals grown in the research lab. These analyses can result in publication.

Session I (1.5 hours)

The first session of Frontiers of Crystallography introduces the importance of structural chemistry in one or more key science areas (for example hydrogen bonding or polymorphism). This allows not only a full contextual development of the course material, but also helps to emphasise from the start the very strong research driver for the Frontiers of Crystallography course. The particular materials (or range of materials) chosen for study on the research component of the course are introduced in this context. Specifically, it is made clear that the materials to be studied fit into ongoing research programmes; indeed, they often form part of the project of a PDRA or PhD student who will be involved in the hands-on research sessions.

Throughout Session I it is emphasised that the Frontiers of Crystallography course includes a real research programme. As such, the possibility of 'failure' is emphasised. We may not grow good-quality crystals, there may be problems in obtaining data, or there may be problems in solving and refining the crystal structure. It is stressed that those involved in tutoring also do not know the answer. Sometimes we obtain crystals of the individual components, sometimes we produce new forms (polymorphs) of the individual components, sometimes we produce more than one form of the desired complex, and sometimes we produce crystals so horrible there is little we can do with them. All of these are genuine exposures to the real research experience.

Session II (3 hours)

Session II provides the practical, hands-on data collection, structure solution and refinement component of Frontiers of Crystallography. It is founded on determining an unknown crystal structure, based on crystallisations observed by students in Session I. As with the previous session, Session II is led by two academics, assisted by four to five PDRAs/PhD students from the session leaders' research groups.

The set-up is for students to work in typically four or five groups (of four to five), analysing the structure of one (or more) crystal(s) for which full data set(s) have been collected on the previous day/overnight, using the suite of research-level X-ray single-crystal diffractometers available in the Chemistry Department. The data analysis involves using the data collected to solve and refine the unknown crystal structure, and to make relevant observations on the structure, its packing and hydrogen bonding, etc. This work is carried out in small groups, each around a PC/laptop with research-level software installed. In order to expedite the process in the time available for this procedure, the structure solution and refinement are based on a template provided to the groups. Each group is mentored by a PhD student. The course organisers take a back seat and adopt a purely advisory role, including asking relevant questions to ensure a degree of understanding of the procedures.

Linkages between teaching and research

Frontiers of Crystallography uses a research-led form of teaching that results in students' exposure, in a relatively short course, to a range of vital principles of the nature of research. These include:

- awareness of the research process
- experience of practical crystallography in a research environment
- familiarity with modern structural Chemistry techniques and research drivers
- ability to adapt to a problem with a genuinely unknown solution and 'no right answer'
- experience of recording results and conclusions in a manner consistent with publication of original research
- hopefully, a published short paper.

It is stressed throughout the practical aspects of the course that no-one knows the 'correct' structure, so it is a full research-based experience. This is frequently manifest in the fact that different groups often take different paths through the process, depending on the practice of the facilitator. It is also possible that some groups end up with a 'better' solution than others, which leads to discussion of the reasons why and what could be done to ensure that both solutions represent the true situation (usually meaning that one or more groups are encouraged to revisit their conclusion).

Course history

The Frontiers of Crystallography course, which has been running in its present form since 2005, is part of a series of themed 'Frontiers' afternoons delivered to level-3 chemistry undergraduates at the University of Glasgow. Originally anticipated to be a lecture-based course, the idea of doing something different rapidly evolved when the present organisers inherited the Frontiers slots.

Frontiers of Crystallography takes place over 4.5-5 hours over two Friday afternoons, deliberately set to be two to three weeks apart. The typical attendance is 20-30 MSci students, reflecting the non-assessed nature of the course. The course builds on and uses as important background the level-3 course in diffraction that is timetabled more or less in parallel with the Frontiers sessions.

Course assessment

Frontiers of Crystallography is regarded as a supplementary course for level-3 MSci students. While formally compulsory, it is not assessed directly as part of the coursework. However, the course has strong spin-offs into course assessment, in that several (assessed) essay choices usually emerge from within the cohort attending the Frontiers course, supervised by one of the academics involved.

If all works out, a short paper is written up for one of the crystallographic structure reporting journals such as *Acta Crystallographica Section E*, or *Zeitschrift für Kristallografie: New Crystal Structures*, with those in the class who worked on the publishable new structure included as co-authors. In general, we find that editors are pleased to receive these papers and fully understand the extensive author list.

Course evaluation

A very high return rate for Session II is anticipated and usually delivered. Indeed, word of mouth can yield attendees at Session II who were not present at Session I. It is rewarding that many of the students who participate in the course carry on (after two further years of study for their MSci degrees) to take up PhD positions in the Department and elsewhere, including a fair proportion in the research groups of the course organisers. It is to be hoped that participation in the Frontiers of Crystallography course helps to fuel students' enthusiasm for a research career.

Key aspects and transferability

The research-led learning outcomes are generic, and do not apply solely to the area of research explored; this is emphasised to students. The format of this course could be applied to other topics in the Physical Sciences.

Course development and delivery issues

The relaxed nature of these sessions has been a contributory factor to the development of the course. The willingness of the Chemistry Department to allow these afternoons to be given over to (formally) non-assessed research-led teaching has allowed us to explore this idea in an environment in which the students are very relaxed. The enthusiasm of students who have participated in the course to date has been rewarding, and very helpful to the course ethos. The willingness of members of the organisers' research groups to participate in delivering this teaching has also hugely aided in the learning experience.

Effect on student experience

An important aspect of a course such as this - and one that is easily neglected - is the chance for the class to meet the 'true persona' of the academic staff. Rather than someone standing at the front of the class, lecturing on what may be rather dry subject matter, in Session I the students get to see the academic in their natural environment, talking about research in a relaxed and interactive way. For the majority of students, this is their first exposure to a research environment, and it can come as a surprise to find the staff so passionate about their work.

We find that students are responsive to this environment, and after the usual ice-breaking they welcome the opportunity to 'just ask anything' in this general area; this is particularly emphasised in the mini forums for debate, modelled on Café

Scientifique discussion groups. It is also illuminating for students to ask questions to which the academics simply do not know the answer, stimulating further discussion.

Further details

Though the instructional design itself has not been published, the student output often has, attracting several citations (for example Parkin et al, 2005).

Snapshot: Chemistry mini project

SCQF level 9, module CH3441, 48 students, 20 credits.

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Students are divided into (mixed-ability) groups of five to six, each allocated to an academic supervisor who assigns a topic for investigation. This topic requires some literature research, experimental planning, experimental work, analysis of results and their presentation. Students have no other class and are able to spend their full time on this module for four weeks at the end of semester two, although the laboratory is only open from 09.00 to 13.00 each day.

The projects assigned vary, but generally fall somewhat short of original research while maintaining substantial scope for student input to the direction of the work and how to best achieve the goal set. In particular, the projects afford excellent experience in group work, discussion and allocation of tasks among group members. The assessment is based on an individual mark for the practical work from the supervisor, individual written reports, a group written report and a group oral presentation, all of which fall within the four-week period. Written reports are each assessed by two staff members and oral presentations by three staff members. The group marks are moderated by student peer assessment of the contribution made by each group member.

The module has run for the last five years and typically yields grades rather similar to conventional lab classes at this level. A consistent observation, however, is that this module really brings out the best in some otherwise weaker students who seem to be inspired by the idea of contributing to the team effort in a way that is not achieved in a more conventional class.

For further information, see http://ch-www.st-andrews.ac.uk/teaching/aims/Mod3441/a.pdf

3.10 Final-year research project

Case study: Final-year research project modules: an overview

This case study is written with knowledge of the St Andrews physics and astronomy versions of final-year projects, but tries to incorporate what is being done across many Physical Sciences departments.

The final-year project is usually a compulsory 'capstone' module for undergraduates' learning. At St Andrews, Physics BSc projects are 30 credits, and MPhys projects are 60 credits.

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Brief description of course

Most departments have a final-year project as the 'capstone' of the student learning experience. Students often work within research teams on a chosen topic of research, and can sometimes produce work that is published in the scientific literature. Indeed, some departments producing work of a quality suitable for publication is a stated goal of the project. This type of module often forms a major part of the final year, and is probably the most obvious example of the research-teaching linkage. Students can get to do discipline-based research first hand, gaining from the guidance and facilities available from within active research teams.

Some departments provide project-preparation or research-skills modules to prepare students for their projects; see, for example, the University of Strathclyde physics and University of Edinburgh chemistry case studies described in this report (section 3.8). Some departments provide a group-project experience before an individual final-year project; see, for example, the University of Glasgow chemistry case study and the University of St Andrews chemistry snapshot described in this report (sections 3.8 and 3.9). Most departments will already have provided students with training in working with the literature. Many of the skills developed in these pre-project modules are honed further in the final-year project module. Where such pre-project modules do not exist, these skills may be developed more explicitly in the project module.

In their final-year project, students work with the knowledge and skills acquired through their education so far, bringing many of these together to do 'real' research.

Heriot-Watt University's chemistry project learning outcomes suggest that on completion of the project modules, the learner will be able to:

- 'analyse, evaluate and interpret experimental evidence at the forefront of chemistry
- execute a defined research project and identify and implement relevant outcomes
- demonstrate a detailed background knowledge of a topic of original research

- demonstrate a knowledge of the concepts and theory underpinning the topic of original research
- apply specialist practical skills to a topic of original research
- make formal presentations on a specialised topic to an informed audience
- communicate effectively with professional-level colleagues and specialists
- interpret, use and evaluate a wide range of data to solve problems of both a familiar and unfamiliar nature
- use a range of software to support and enhance work at an advanced level
- undertake critical evaluation of a wide range of data
- deal with complex issues and make informed judgements in situations of incomplete or inconsistent data
- apply strategies for appropriate selection of relevant information from a wide source and large body of knowledge
- exercise initiative and independence in carrying out research and learning activities.'

(Quoted with permission from research project links through www.che.hw.ac.uk/modules/module_details.html)

The formal statement of aims for the University of St Andrews Physics BSc and MPhys modules is that the 'project aims to develop students' skills in searching the appropriate literature, in experimental and observational design, the evaluation and interpretation of data, and the presentation of a report'.

Physics students at St Andrews choose a topic from a list provided by academic staff, then preface their project by producing a review paper on the area. Students usually work within research teams on their chosen area of investigation. They develop independent learning and research skills as well as the interpersonal skills needed to function within a research environment. Through their discussions with their supervisor and direct experience in the lab, students develop their critical analysis, experimental design, data collection and interpretation skills, and in many cases the need for perseverance. Fortunately, most of our students also find the project to be a positive experience in which they can enjoy exploring a chosen topic within physics.

Students develop their own self-study skills to allow them to work with the literature, researchers and their own results to extend their knowledge of physics and its methods of enquiry. In some cases, they also extend our community's knowledge and understanding of a certain part of physics. In our School students write up a formal report on their project and present the main results to a panel, thus further developing their communication skills. Similar arrangements are in place in other physics and chemistry departments, though with variations. For example, in chemistry at the University of Glasgow project students present their work to their peers at a formal session. Theoretical or computational physics projects may not involve work in an experimental research lab, but nevertheless allows students to work in research mode in an independent manner with the guidance of a subject expert.

Linkages between teaching and research

The final-year project is perhaps our best example of students learning to think about and 'do' science like a scientist; indeed, each is being a research scientist. Frequently, the learning is done within a research environment. Students both do their own research and see experienced researchers doing their own research work. Students can become familiar with some of the skills, equipment, techniques, attitudes, pressures and opportunities available in research. They often value the fact that they can be doing something genuinely new.

The Boyer Commission on Educating Undergraduates in the Research University (1998) among other things called for degree courses to 'culminate with a capstone experience - the final semester(s) should focus on a major project and utilize to the full the research and communication skills learned in the previous years...'. This is what the final-year projects are aiming to do.

Course history

The final-year project module has been established in many departments for as long as can be remembered. This is as close to being an 'apprentice' in the professional conduct of the discipline as many students get during their undergraduate studies, and possibly mirrors the sort of master-scholar relationship that was present in universities centuries ago. It might be argued that the final-year project is the modern version of the revolutionary approach to undergraduate science teaching that was pioneered by Lord Kelvin in the late nineteenth century in Glasgow. He took undergraduates into his research laboratories to work on problems coming from his own research in the science and engineering associated with electrical phenomena.

The project module is usually the culmination of students' undergraduate studies, and as such many of their previous courses feed into it. The independent learning and professional execution of the work in a project can act as a springboard into employment or further study in the discipline, and is often the subject of discussion in interviews.

Course assessment

The work done by students in project modules tends to be assessed by a number of means, which may include the following:

- a written literature review before the experimental work is carried out, assessed by staff
- an oral presentation of the material in the literature review and the plans for the project work
- a written report on the main project work, assessed by staff
- an oral examination by an assessment panel of staff
- an oral presentation on the project outcomes by the student to staff and/or peers, assessed by staff
- an assessment by the supervisor of the student's performance during the project.

In physics at St Andrews we use all except the second of the above assessments, though the oral presentation is at the end of the project and is currently just to a staff panel. Looking at project guides from different departments, a great deal of work has gone into providing appropriate descriptors for learning achievements and ensuring that projects with different supervisors and in different areas can be judged fairly. The relative weightings given to the different sections varies among departments, as might be expected.

Course evaluation

Project provision is the subject of evaluation by external examiners, subject review teams and accrediting bodies such as the Institute of Physics and Royal Society of Chemistry.

Key aspects and transferability

The project module is already widely used across disciplines and institutions. The development of independent critical thinking skills, skills in working as part of a team and the determination to see a project through to completion are at the very core of what attributes we would like all graduates to have.

4 Discussion and recommendations

4.1 Discussion

The case studies and snapshots in this report have presented a huge breadth of experience and practice across disciplines and years of study as well as the methods used to link research and teaching more closely. These range from problem-based learning approaches all the way to doing research as part of (or occasionally outside of) formal project exercises.

In spite of very real pressures of time, space and finance, many interventions have been developed and introduced in the early years of the curriculum - despite this being when class sizes are typically largest, exacerbating such pressures. This is as it should be: we want to introduce our students to the research communities that exist within our schools and departments from an early stage in their undergraduate careers, and illustrate to them that this 'research ethos' or mindset is at the very heart of what it means to 'do' science. In some cases, these changes have been effected by relatively minor alterations that have been shown to have a big impact, such as rewriting laboratory guides in the form of a research paper (at an appropriate level) rather than as a recipe or set of instructions to be followed without the need for much independent thought. In others, they have involved a larger scale redevelopment and often upgrading of infrastructure (including teaching space and equipment).

It is clear from the case studies and snapshots presented in this report that a great deal of emphasis is placed on the final project as the capstone experience of research in the undergraduate curriculum. Most departments also offer preparatory skills courses to enable students to get as much out of the experience as possible, providing advance exposure to a wide range of skills further honed in the final-year project. The quality of what is learned and outputs produced from these projects are things the physical sciences sector can be justifiably proud of.

At the workshop we held in December 2007 as part of this project, groups of participants considered the questions of 'what's in it for them?' and 'what's in it for us?'. Placing ourselves in the students' shoes, the benefits seemed readily obvious. Enhanced graduate attributes point strongly towards better employability prospects as well as a more satisfying undergraduate experience, making the course material more relevant and in context. From the staff perspective, the general feeling was that closer linkages between teaching and research are not just desirable but imperative. Our students have changed dramatically in the last decade, in terms of their expectations and aspirations of what a degree in the Physical Sciences should equip them with. The point was made that improvements or modifications to more closely align research and teaching need not necessarily be labour intensive (but often can be). It often takes a good deal of time and space to redesign or realign courses or modules, and the odd half day spent here and there is not the most effective way to accomplish such things. Departments may want to consider 'teaching sabbaticals' for a semester to create the time and space needed to get such initiatives off the ground, managing the redistribution of effort in exactly the same way as is done for research sabbaticals.

4.2 Recommendations

In making recommendations, we refer readers to the relevant section of Jenkins and Healey's (2005) report on institutional strategies to more closely link teaching and research. A departmental or institutional approach ensures that the self-nucleating islands of activity and innovation that naturally appear do not remain isolated but thrive as part of a coherent strategy. We are often concerned with examining programmes and activities horizontally (across a course, module or year of study), but it is harder to look vertically for themes that develop and progress through programmes.

Perhaps the strongest recommendation we would offer is to be aware of the expanding body of knowledge that represents the 'canon' of our discipline. The physical sciences are subjects whose core foundation knowledge dates back many centuries, and equally whose frontiers are expanding at a rapid pace. Not everything will fit in a degree of four or perhaps five years' duration, yet cutting material from a syllabus is something we all collectively find hard to do. Sufficient space must be made to allow for enhancing the links between teaching and research in the curriculum and fostering the skills and attributes we would wish our students to take with them after graduation.

In making specific recommendations to practitioners and course teams in the physical sciences, we would stress the importance of the following:

Supporting the final-year project

This is rightly the capstone experience for almost all undergraduates in the discipline, and a real taste of what research is like. For students and their supervisors to get the most out of the project experience, the skills required for it should be seeded at an earlier stage in the programme. These skills cover a broad range - from critical analysis of previously published work, through the practical skills, to presentation and communication of the work's findings. Courses introducing (elements of) these skills early in the undergraduate programme allows such skills to develop over time, with opportunities for feedback along the way.

Significant changes need not be prohibitively expensive

A combination of large class sizes and the linear way in which the subject develops in pre-honours classes often act as disincentives towards developing closer research-teaching linkages in the early years of programmes. However, we have demonstrated in some of the case studies presented here that relatively modest investments can yield a significant return if appropriately directed. Laboratory work offers excellent scope for this.

Catering for different aspirations

We should acknowledge the distinction between preparing a proportion of our graduates for research careers and equipping all of them with the graduate skills that are of value whatever they choose to do beyond their undergraduate study. The increasing percentages of school leavers entering higher education means that we need to be able to cater for the different career aspirations of students once they leave university. Joe Redish, a well-known physics education researcher in the USA, has expressed this issue as follows:

> 'It no longer suffices to reproduce ourselves. Society has a need not only for a few technically trained people, but for a large group of individuals who understand science.'

Ensure coherence and integration

It is necessary not simply to create course elements that 'tick off' episodes fostering the types of graduate attributes we have described. We must also ensure that such elements are integrated into a vertically coherent programme of study offering opportunities for advancement and development of these skills over time in different contexts. Curricula are normally stratified into horizontal layers; looking vertically can often illuminate areas where improvements could be made.

In taking things further, the well-established research pooling initiatives in Scotland (the Scottish Universities Physics Alliance and EastChem and WestChem) offer an ideal route for further developing closer integration between teaching and research, and should be exploited to their full potential.

5 References

Bates, S (2005) *Reshaping large-class undergraduate science courses: the weekly workshop* CAL-laborate, UniServe Science International Newsletter, 14, available at: http://science.uniserve.edu.au/pubs/callab/vol14/cal14_bates.pdf (accessed May 2008)

Bates, S (2007) *Collaborative Problem-Solving In First-Year Physics*

International Online Conference sponsored by the REAP Project: *Assessment design for learner responsibility*, 29-31 May 2007, available through case study library link (T1, Interaction of peer and tutor feedback) at: www.reap.ac.uk/reap07/Welcome/tabid/72/Default.html (accessed May 2008)

Bates, S, Howie, K and Murphy, A (2006) *The use of electronic voting systems in large group lectures: challenges and opportunities* New Directions: the Journal of the Higher Education Academy Physical Sciences Centre, issue 2, available at: www.heacademy.ac.uk/assets/ps/documents/new_directions/new_directions/ps0050_new_directions_issue2_dec_2006.pdf (accessed May 2008)

Boyer Commission on Educating Undergraduates in the Research University (1998) *Reinventing Undergraduate Education: A Blueprint for America's Research Universities* Stony Brook: State University of New York at Stony Brook, available at: http://naples.cc.sunysb.edu/pres/boyer.nsf/ (accessed May 2008)

Brew, A (2006) *Research and teaching: beyond the divide* London: Palgrave Macmillan

Chang, H (2005) *Turning an undergraduate class into a professional research community* Teaching in Higher Education, 10(3), pp 387-394.

Feynman, R (1986) *'Surely You're Joking Mr Feynman!' Adventures of a Curious Character* New York: Bantam Books

Grant, S, Freer, A, Winfield, J, Gray, C and Lennon, D (2005) Introducing *Undergraduates to Green Chemistry: An Interactive Teaching Exercise* Green Chemistry, 7, pp 121-128

Hattie, J and Marsh, H (1996) *The Relationship between Teaching and Research: A Meta-Analysis* Review of Educational Research, 66(4), pp 507-542

Heriot-Watt University, Chemistry Modules Information page see www.che.hw.ac.uk/modules/module_details.html (accessed May 2008)

Jenkins, A and Healey, M (2005) *Institutional strategies to link teaching and research* York: Higher Education Academy, available at: www.heacademy.ac.uk/assets/York/documents/resources/resourcedatabase/id585_institutional_strategies_to_link_teaching_and_research.pdf (accessed May 2008)

Kelly, G (2008) *We need those who can teach* Times Higher Education, 31 January, available at: www.timeshighereducation.co.uk/story.asp?sectioncode=26&storycode=400384&c=1 (accessed May 2008)

Parkin, A et al (2005) *Acta Crystallographica E61*, pp 2280-2282

Raine, D (2003) *Teaching Physics in an Internet Journal Group Project*. Higher Education Academy, Physical Sciences Centre, available at: www.heacademy.ac.uk/physsci/projects/detail/completed_projects/teaching_Physics_in_an_internet_journal_group_project (accessed May 2008)

Raine, D and Symons, S (eds) (2005) *PossiBiLities: a Practice Guide to Problem-based learning in Physics and Astronomy*. A Physical Sciences Practice Guide. Higher Education Academy, Physical Sciences Centre, available at: www.le.ac.uk/leap/pblguide.pdf (accessed May 2008)

Rammell B (2006), available at: www.dfes.gov.uk/speeches/media/documents/Rammell_speech_warwickrbl_25.10.06_internet.doc (accessed May 2008)

Redish, E, (1994) *The Implications of Cognitive Studies for Teaching Physics*, American Journal of Physics, 62(9), pp 796-804

Schatz, G, (2004) FEBS Letters 558 pp 1-2

Sneddon, P, (2007) *Renovating laboratory teaching: keeping the students' interest*. Proceedings of the Science Learning and Teaching Conference 2007, Keele University. York: Higher Education Academy, available at: www.sltc.heacademy.ac.uk/proceedings.htm (accessed May 2008).

University of Bath, Learning and Teaching Enhancement Office (2007) *Good practice Guide on Linking Research and Teaching*, available at: www.bath.ac.uk/learningandteaching/resources/outcomes/researchandteaching (accessed May 2008)

University of Edinburgh, School of Physics (2007) survey and responses available at: www.surveymonkey.com/sr.aspx?sm=weGA3hltX0j1kUTkJZrWfQyuPN7WXeUomBj69C7KuzA_3d (accessed May 2008)

Wieman, C (2004) *Professors Who are Scholars: Bringing the Act of Discovery to the Classroom*. Presentation from Integrating Research into Undergraduate Education: The Value Added. Stony Brook, Miami: Reinvention Center, available at: www.reinventioncenter.miami.edu/Conference_04/Wieman/Presentation.htm (accessed May 2008)

Websites

Bioscience Horizons. Available online at: www.oxfordjournals.org/our_journals/biohorizons (accessed May 2008)

EPSRC summer bursary scheme: www.epsrc.ac.uk/PostgraduateTraining/VacationBursaries/default.htm (accessed May 2008)

Physical Sciences Research-Teaching Linkages project. Talks and notes from the workshop available at: http://physci.rtl.googlepages.com/home (accessed May 2008)

Reinvention: a Journal of Undergraduate Research available at: www2.warwick.ac.uk/fac/soc/sociology/research/cetl/ejournal (accessed May 2008)

University of Leicester, Project LeAP: Problem-Based Learning in Astronomy and Physics www.le.ac.uk/leap/ (accessed May 2008)

University of Leicester, Department of Physics and Astronomy, Science Undergraduate Research Experience (SURE) summer programme available at: www.le.ac.uk/physics/sure.shtml (accessed May 2008)

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