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Research-Teaching Linkages: enhancing graduate attributes

Life Sciences

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Research-Teaching Linkages: enhancing graduate attributes

Life 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
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1 Executive summary

A diverse array of activities linking research with teaching to enhance graduate attributes are taking place in the life sciences discipline across Scotland, as evidenced by the 10 universities and higher education institutions that took part in this Enhancement Theme discipline project. These research-teaching enhancements are informed by collaborative events, conferences and workshops promoted by bodies such as the Bioscience Subject Centre, Higher Education Academy, learned societies and professional bodies.

Higher education institutions are being encouraged to adopt formal mechanisms to systematically stimulate and monitor research-teaching linkage enhancements, at both departmental and institutional levels, as current practice appears too reliant on purely informal, individual academic-led and to some extent chance developments. Institutions are also encouraged to further contacts with the Higher Education Academy and Centres for Excellence in Teaching and Learning. The latter, despite not being funded by the Scottish higher education sector, remain a rich source of materials for enhancing teaching and learning.

This project has brought together a large number of case studies demonstrating how the student experience and future graduate attributes can be enhanced by activities including group-based exercises; early level inquiry-based activities; field-based, placement or project work designed to provide a flavour of the research-based scientific process; or immersion in life sciences research environments. Senior academic staff involved in structured interviews indicated that these types of activities would contribute to the enhancement of 16 different graduate attributes, closely related to those identified by the Research-Teaching Linkages: enhancing graduate attributes Theme steering committee Quality.

Senior staff considered the most important research-related graduate attributes at undergraduate level to be: an ability to critically appraise and synthesise novel concepts; developing self-confident achievers; and an ability to work flexibly, independently and as part of a team. Key master's-level graduate attributes included greater understanding of concepts, advanced research methods and technical and project management skills. Senior staff believed that 40-60 per cent of graduates would become practising life scientists.

Following the project's survey work with 43 academic or academic-related staff and 263 students, broad agreement existed regarding the value of enhancing research-teaching linkages. Academic staff and students who had undertaken extended projects were strongly convinced of the value these would bring for future employability and development in the life sciences or other careers. Life sciences students believed that their learning activities provided them with a good understanding of the scientific process, the provisionality of knowledge, and the importance of ethical and professional studies as part of their programmes. Developing research-type skills, including a sense of inquiry, better prepares students for research project or placement experiences as a capstone to life sciences programmes. Life sciences students were believed to be well prepared for the world of work or further study, and to make an important contribution to the development of the economy and society in general.

Following partnership working with the Bioscience Subject Centre, Biochemical Society, Physiological Society and Pharmacological Society, three external events were held to test opinion and obtain feedback. Deriving from these events, structured interviews with senior staff and survey work with over 300 academics and students, a number of recommendations to further enhance research-teaching linkages in the life sciences have been made. These recommendations are intended to increase the appropriateness and quality of the student experience.

Key recommendations include:

- Departments and institutions should encourage systematic engagement in linking research and teaching, for example through revised policies and periodic reviews, to involve greater numbers of staff and enhance productivity.
- Stimulate student learning from research practitioners by having researchers in residence sharing study space with students, perhaps as drop-in centres or shared discussion spaces.
- Systematically promote a wide range of research-teaching linkages over time to enhance student experience-based rewards, increase employability and reputation.
- Encourage key researchers to engage in early years teaching, bringing a flavour of international research excellence and stronger sense of enquiry to all students.
- Encourage new academic staff to conduct research skills audits for key programmes and share their findings with fellow staff and students.
- Stimulate a sense of enquiry in students through the use of innovative problem and field-based learning in early years modules, to foster a questioning attitude through out the student learning experience.
- Involve students in designing and constructing their own experiments and knowledge base, including use of inherited protocols from previous cohorts, to reinforce valuable independent learning.
- Instigate competitive research internships for students in the pre-final year summer vacation, requiring detailed written applications including details of how the student believes they will benefit from immersion in a research laboratory environment. Successful interns should share their experiences with succeeding cohorts at a mini conference, with a substantial prize for the best peer reviewed research-internship communication.

2 Introduction

2.1 The life sciences discipline

A wide range of biological and natural sciences are encompassed within the life sciences discipline group for the purposes of this report. Within Scotland, this discipline ranges from ecology to pharmacology and from molecular biology to sports science. The life sciences are a major feature of Scotland's higher education provision, with at least 17 universities and higher education institutions offering relevant programmes (see table 1).

Increasing numbers of life sciences graduates from Scottish higher education institutions are needed to service the skilled employee needs of the life sciences sector. This sector has experienced extensive growth, at rates exceeding 8 per cent per annum - four times faster than the Scottish economy as a whole - adding £2.8 billion to the economy (Life Sciences Scotland, 2007). More than 30,500 employees work in the Scottish life sciences sector, which has been recognised as a leading engine for high-value economic growth. There are 600 organisations and companies within the Scottish life sciences sector, including 57 universities and research institutes, with 17,000 research staff attracting £410 million of external research funding annually. This represents 13 per cent of total UK funding from a 9 per cent population base (Life Sciences Scotland, 2007). Within this, pharma-related business activity alone adds £600 million to the Scottish economy, and creates or safeguards 12,500 jobs (EP Associates, 2007).

Institution	Example programme
University of Aberdeen	BSc Hons Agriculture
Robert Gordon University	BSc Hons Biosciences
University of Abertay Dundee (UAD)	BSc Hons Biotechnology
University of Dundee	BSc Hons Biochemistry
St Andrews University	BSc Hons Evolutionary Biology
Adam Smith College	BSc Sport and Fitness
University of the Highlands and Islands Millennium Institute	BSc Hons Marine Science
University of Stirling	BSc Hons Aquaculture
University of Edinburgh	BSc Hons Ecological Science
Napier University (NU)	BSc Hons Biological Sciences
Queen Margaret University	BSc Hons Human Biology
Heriot-Watt University	BSc Hons Brewing and Distilling
Scottish Agricultural College	BSc Hons Horticulture
Glasgow Caledonian University (GCU)	BSc Hons Biomedical Science
University of Strathclyde	BSc Hons Forensic Biology
University of Glasgow	BSc Hons Molecular and Cellular Biology
University of the West of Scotland	BSc Hons Biology

Table 1: Scottish higher education life sciences programmes

2.2 Discipline range

For the purposes of this project report, the life sciences may be defined as encompassing anatomy, aquatic bioscience, biochemistry, biomedical sciences, biotechnology, genetics, immunology, microbiology, molecular and cellular biology, neuroscience, parasitology, pharmacology, physiology, sports science, zoology and related areas. A particular feature of life sciences provision, at both undergraduate and master's levels, is the extensive sharing of modules between several different programmes. This means that quite large proportions of programmes can be common, often within a rigidly or occasionally loosely defined framework. Choices of key modules in later years, or practical project topics, frequently determine degree award titles. Scotland is fortunate in having high levels of university research expertise in all of the life sciences sub-disciplines, as evidenced by Research Assessment Exercise (RAE) performance. Seven universities achieved 5 or 5* grades in the last RAE (in 2001).

The life sciences discipline is essentially experimental: virtually all knowledge within the discipline is related to observation or experiment. Significant research effort is concentrated on practical tools and technologies to aid the testing of hypotheses (Sears and Wood, 2005). Families of experimental methods are established around the investigation of life processes (from birth to death), which are being studied in a wide range of organisms - from viruses to bacteria, and from plants to humans. Such methods also include consideration of the inter-relationships among processes, among organisms and between processes and organisms. Bioinformatics and synthetic biology are recognised as becoming increasingly valued as tools for future life sciences developments.

Much life sciences content is driven by current hypotheses, as our best understanding of a process, rather than being based on certainty. It is a rapidly changing discipline, with the sheer volume of data emerging globally creating problems of data warehousing, distribution, access and compatibility. The practical nature of the life sciences requires graduates to develop fundamental and higher order skills to develop new understandings - essential for the Scottish life sciences sector to remain competitive (Life Sciences Scotland, 2007). These skills and understandings relate well to generic graduate attributes, at both undergraduate and master's levels, while also requiring increasing levels of discipline-specific knowledge, understanding and skills as the life sciences continue to develop rapidly. Understanding how to encourage and achieve high-quality innovative learning in the life sciences (Roach et al, 2000; Hounsell, 2005) is, of course, key to keeping Scotland's higher education sector globally competitive.

3 Research-teaching linkages and graduate attributes

3.1 The tradition of research-teaching linkages in the life sciences

There has been a tradition of teaching about research within both the school and the university curriculum for at least 50 years. Students are taught the 'facts', but are also taught how the facts are obtained - that is, how research experimentation and observation produces information which is then interpreted to produce the 'facts' that are in textbooks. This is not only about planning and interpreting experiments, but also about the technical details of instrumentation, including its sensitivity and precision - what can and cannot be measured with current technology. Any future practising life scientist needs to understand all this information in order to be successful (Scottish Science Advisory Committee, 2003).

A glance at any school textbook reveals pictures of experimental set-ups by which life sciences information can be obtained (Bell et al, 2003). Even at the simplest level of the microscope there is information about magnification and resolution: what can and what cannot be seen, and the effects of fixation and staining procedures. This starts to give students a view of the process of criticising the data that are obtained, and moves on to consider biological variability, the use of statistics and need for repeating experiments and observations, the need for appropriate controls, and so forth. This is all built on in the university years, when more sophisticated experiments may be carried out in practical classes (Coker and Davies, 2002).

Evaluating how students develop this understanding of the scientific process and the scientific method is a complex and difficult problem. The essential cognitive processes underlying the creation of new concepts cannot routinely be turned on and off (Carey, 2004). The constructivist epistemology of knowledge being based on and enhanced by experimentation, so that scientific theories can be created, tested, interpreted and revised, may evolve gradually during a student's development while at university, based on collective practical experience (McCune and Hounsell, 2005; Carey and Smith, 1993).

Scottish students' evolving ways of thinking, of practising their subject-based skills and developing their sense of enquiry are typically brought to a pinnacle through the research project (Ryder et al, 1999; MacKenzie and Ruxton, 2006). Final-year research projects encourage students to obtain experience of 'real' research - in other words, planning and doing experiments in which the result is unknown (Bio 2010 Committee, 2003; Lopatto, 2003). This contrasts with the experience of German university students (Thoermer and Sodian, 2002), where little evidence of this evolving understanding through intense student engagement in science environments is observed.

This may all be summed up in terms of encouraging students to understand **the process of science** (Leach et al, 1998; Mabrouk and Peters, 2000). The QAA subject benchmark statements for both biosciences and agriculture mention research projects as an indispensable part of the science training, when it is expected that students will indeed learn about the process of science at first hand (QAA 2002, 2007a).

Many life scientists have written about the importance of students learning about research as the only way in which information is obtained, with the accompanying issues of hypothesis generation, making testable predictions and designing experiments to test such predictions, using the instrumentation and technology available at the time (Rutledge, 2001; Saunders and Sievert, 2002). The views of Nobel Prize winners Popper and Krebs on testing hypotheses and teaching in an atmosphere of research, and more recently Hunt on teaching about **how** information is obtained being just as - or even more - important than the actual information obtained, eloquently illustrate this point.

Emergence from this learning environment and gaining of practical experience aims to generate life sciences graduates who can critically appraise published research. This again is a vital ability for the successful practising scientist, and one that students find difficult to develop. It takes time to garner this experience alongside extensive critical reading (Garett and Overton, 1996), and to develop the understanding that the 'facts' can change as technology improves and new types of experiment are devised, making new interpretations possible (LaPorte et al, 2002). This provisionality of knowledge can sometimes be overlooked, but is very important for lifelong learning by graduates in all disciplines, and especially so for the rapidly changing life sciences.

Life sciences programmes aim to produce the practising scientists of the future. That many students graduating from such courses will not in fact end up as 'bench scientists' undervalues the skills learned, since understanding experimentation and controls, understanding numerical data and how it is presented, being critical, making comparisons, and so on, are all important skills whatever profession a graduate ultimately chooses. These skills are also valuable in the context of having a good understanding of social aspects of scientific issues (eg genetically modified foods, stems cells and cloning) and being able to comment on them in various fora, including political ones, so that the life sciences graduate can make a rounded contribution to citizenship and society.

3.2 The role of Higher Education Academy Subject Centres

The learning and teaching needs of the life sciences disciplines are significantly served by the Bioscience Subject Centre of the Higher Education Academy, based at the University of Leeds. Previously the Learning and Teaching Subject Network Bioscience Centre, this body has made a substantial and important contribution to the development and promotion of research-teaching linkages in the life sciences.

Life sciences teachers have benefited greatly from an extensive range of high-quality Bioscience Subject Centre resources, and discipline and topic-based events held around the UK. These have been uniformly praised by attendees for their informative and imaginative content and subsequently widely used, for example via web-based event reports, case studies, presentations and quarterly e-bulletins. The Bioscience Subject Centre was among the first discipline-based bodies to consider the research-teaching interface in detail, and an excellent and expanding set of resources is available from the Centre's website (see Wood, 1990; Sears and Wood, 2005; Bioscience Subject Centre, 2008).

The Bioscience Subject Centre participated in the delivery of this project through partnership working, including co-hosting several research-teaching linkages events and co-authorship of this report by a former Centre Co-Director. Many of the case studies presented here as examples of good practice were identified, enhanced or documented with the support and assistance of the Bioscience Subject Centre team.

Topics closely related to health sciences and the allied health professions are similarly dealt with by the Health Sciences and Practice Subject Centre, based at the Waterloo campus of King's College, London (Health Sciences and Practice Subject Centre, 2008). All the Subject Centres relevant to the life sciences aim to assist teachers in further and higher education to develop the achievement of desirable attributes among their graduates. More generic advice on promoting research-teaching linkages is also available from the Generic Centre of the Higher Education Academy.

3.3 Generic graduate attributes

The Research-Teaching Linkages: enhancing graduate attributes theme steering committee identified a range of graduate attributes - generic to any subject or discipline - which are applicable at undergraduate or master's levels (see table 2). These generic graduate attributes anticipate increasing levels of conceptual, analytical and appraisal skills from undergraduates and master's-level students, while recognising the provisionality of knowledge at master's level. Specific disciplines have the potential to add or expand on these graduate attributes, for example through the use of subject benchmarks.

Undergraduate level	• critical understanding • informed by current developments • awareness of knowledge properties • ability to identify and analyse problems, evaluate and apply evidence-based solutions • ability to systematically and critically assess complex issues • ability to deploy techniques of analysis and enquiry • familiarity with advanced techniques and skills • originality and creativity • understanding of need for high level of ethical, social, cultural, environmental and wider professional conduct
Master's level	• conceptual understanding enabling critical evaluation of current research and advanced scholarship • originality in application of knowledge • ability to deal with complex issues and make sound judgements in absence of complete data

Table 2: Generic graduate attributes. Source: Enhancement Themes (2008)

3.4 Discipline-based attributes

QAA subject benchmarks for life sciences subjects were first published in 2001, including biosciences, biomedical science and agriculture, forestry, food and consumer sciences. Revisions of the benchmarks for biosciences and biomedical science, among others, have recently been undertaken (QAA, 2007, 2007a). A range of discipline-specific graduate attributes can be identified from subject benchmarks, which provide details of particular skills, abilities or competences which might be expected to be demonstrated.

Tables 3 and 4 describe typical discipline-specific attributes for biosciences and biomedical science graduates, respectively. The life sciences subject benchmarks which were revised in 2007 exemplify the rapid advancement of knowledge and the impact of key breakthroughs, such as the sequencing of the human genome.

Biosciences subject benchmark statement - graduate attributes

3 Subject knowledge, understanding and skills

3.1 The range of courses covered by individual programmes of study will depend on the specific degree offered and the institutional context. No provider has the resources or time to cover everything that is encompassed by the biosciences and the rich diversity of curricula provides students with abundant choice. Whatever the subject discipline, students should expect to be confronted by some of the scientific, moral and ethical questions raised by their study discipline, to consider viewpoints other than their own, and to engage in critical assessment and intellectual argument.

Subject knowledge and understanding

3.2 Approaches to study and forms of subject knowledge likely to be common to all biosciences degree programmes will include:

- a broadly based core covering the major elements defined by the particular programme and providing the wider context required for the subject area, together with specialised in-depth study (often career-related) of some aspects of the discipline or subject area. Whatever the degree programme, there is a need for an interdisciplinary and (where appropriate) a multidisciplinary approach in advancing knowledge and understanding of the processes and mechanisms of life, from molecular to cellular, and from organism to community
- engagement with the essential facts, major concepts, principles and theories associated with the chosen discipline. Knowledge of the processes and mechanisms that have shaped the natural world in terms, for example, of the spread of time from the geological to the present and of complexity from the environmental to the cellular. The influence on living systems of human activities (and the converse) could also be considered
- competence in the basic experimental skills appropriate to the discipline under study
- understanding of information and data, and their setting within a theoretical framework, accompanied by critical analysis and assessment to enable understanding of the subject area as a coherent whole
- familiarity with the terminology, nomenclature and classification systems, as appropriate
- methods of acquiring, interpreting and analysing biological information with a critical understanding of the appropriate contexts for their use through the study of texts, original papers, reports and data sets
- awareness of the contribution of their subject to the development of knowledge about the diversity of life and its evolution
- knowledge of a range of communication techniques and methodologies relevant to the particular discipline, including data analysis and the use of statistics (where this is appropriate)

- engagement with some of the current developments in the biosciences and their applications, and the philosophical and ethical issues involved. Awareness of the contribution of biosciences to debate and controversies, and how this knowledge and understanding forms the basis for informed concern about the quality and sustainability of life
- understanding the applicability of the biosciences to the careers to which graduates will be progressing.

Subject-specific skills

3.3 Learners working to acquire the qualities of mind appropriate to the biosciences should recognise much of what they are taught is contested and provisional, particularly in the light of continuing scientific advances. The actual qualities include:

- an appreciation of the complexity and diversity of life processes through the study of organisms, their molecular, cellular and physiological processes, their genetics and evolution, and the interrelationships between them and their environment
- the ability to read and use appropriate literature with a full and critical understanding, while addressing such questions as content, context, aims, objectives, quality of information, and its interpretation and application
- the capacity to give a clear and accurate account of a subject, marshal arguments in a mature way and engage in debate and dialogue both with specialists and non-specialists, using appropriate scientific language
- critical and analytical skills: a recognition that statements should be tested and that evidence is subject to assessment and critical evaluation
- the ability to employ a variety of methods of study in investigating, recording and analysing material
- the ability to think independently, set tasks and solve problems.

Graduate and transferable skills

3.4 …The specific graduate and transferable skills that should be developed in bioscience degree programmes are subdivided into the following headings and described in the following paragraphs:

- intellectual skills
- practical skills
- numeracy skills
- communication, presentation and information technology skills
- interpersonal and teamwork skills
- self-management and professional development skills.

Intellectual skills

3.5 Bioscience degree programme students should be able to:

- recognise and apply subject-specific theories, paradigms, concepts or principles. For example, the relationship between genes and proteins, or the nature of essential nutrients in microbes, cells, plants and animals

- analyse, synthesise and summarise information critically, including published research or reports
- obtain and integrate several lines of subject-specific evidence to formulate and test hypotheses
- apply subject knowledge and understanding to address familiar and unfamiliar problems
- recognise the moral and ethical issues of investigations and appreciate the need for ethical standards and professional codes of conduct.

Practical skills

3.6 Bioscience degree programme students should be able to:

- undertake sufficient practical work to ensure competence in the basic experimental skills appropriate to the discipline under study
- design, plan, conduct and report on investigations, which may involve primary or secondary data (eg from a survey database). These data may be obtained through individual or group projects
- obtain, record, collate and analyse data using appropriate techniques in the field and/or laboratory, working individually or in a group, as is most appropriate for the discipline under study
- undertake field and/or laboratory investigations of living systems in a responsible, safe and ethical manner. For example, students must pay due attention to risk assessment, relevant health and safety regulations, issues relating to animal welfare and procedures for obtaining informed consent. In some biosciences, students will show that they respect the rights of access, for example, in fieldwork or in order to map the genes of a community, family or group of plants or animals, including humans. They should show sensitivity to the impact of investigations on the environment, on the organisms or subjects under investigation, and on other stakeholders.

Numeracy skills

3.7 Bioscience degree programme students should be able to:

- receive and respond to a variety of sources of information: textual, numerical, verbal, graphical
- carry out sample selection; record and analyse data in the field and/or the laboratory; ensure validity, accuracy, calibration, precision, replicability and highlight uncertainty during collection
- prepare, process, interpret and present data, using appropriate qualitative and quantitative techniques, statistical programmes, spreadsheets and programs for presenting data visually
- solve problems by a variety of methods, including the use of computers.

Communication, presentation and information technology skills

3.8 Bioscience degree programme students should be able to:

- communicate about their subject appropriately to a variety of audiences using a range of formats and approaches, using appropriate scientific language

- cite and reference work in an appropriate manner, including the avoidance of plagiarism
- use the internet and other electronic sources critically as a means of communication and a source of information.

Interpersonal and teamwork skills

3.9 Bioscience degree programme students should be able to:

- identify individual and collective goals and responsibilities and perform in a manner appropriate to these roles, in particular those being developed through practical, laboratory and/or field studies
- recognise and respect the views and opinions of other team members; negotiating skills
- evaluate performance as an individual and a team member; evaluate the performance of others
- develop an appreciation of the interdisciplinary nature of science and of the validity of different points of view.

Self-management and professional development skills

3.10 Bioscience degree programme students should be able to:

- develop the skills necessary for self-managed and lifelong learning (eg working independently, time management, organisational, enterprise and knowledge transfer skills)
- identify and work towards targets for personal, academic and career development
- develop an adaptable, flexible and effective approach to study and work.

Table 3: Biosciences subject benchmark graduate attributes. Source: Biosciences subject benchmark statement, revised 2007 (QAA, 2007a)

Biomedical science subject benchmark statement - graduate attributes

4 Subject knowledge and understanding

4.1 Biomedical science graduates acquire knowledge in the subject areas indicated below. The sub-headings are not intended to imply module titles and the subject matter is not intended to constrain module content.

Basic knowledge

i **Human anatomy and physiology** refers to the structure, function and control of the human body, its component parts and major systems.

ii **Cell biology** is the study of the structure and function of cells (and the organelles they contain) and includes their life cycle, division, self-replication and eventual death.

iii **Biochemistry** is the study of chemical processes which support life. It requires knowledge of key chemical principles which are relevant to biological systems and includes the structure and function of biological molecules and cellular metabolism and its control.

iv **Genetics** is the study of the structure and function of genes (including their role in human disease) and inheritance.

v Molecular biology is that branch of biology that deals with the manipulation of nucleic acids (deoxyribonucleic acid (DNA) and ribonucleic acid (RNA)) so that genes can be isolated, sequenced or mutated. It covers methods which allow the insertion of new genes into the genome or the deletion of genes from the genome of an organism. It allows the effects of genes and genetic factors to be investigated in health and disease.

vi **Immunology** is the study of components of the immune system, their structure, function and mechanisms of action. It includes innate and acquired immunity.

vii **Microbiology** is the study of the structure, physiology, biochemistry, classification and control of micro-organisms, including the role of normal flora.

Clinical laboratory specialities

4.2 These subjects [NB: the traditional disciplines of cellular pathology, clinical biochemistry, clinical immunology, haematology, transfusion science, clinical genetics and medical microbiology are increasingly being reconfigured into blood science, cellular science and infections in major pathology service units in the NHS. This subject benchmark statement presents the essential topics in traditional style] specifically address the knowledge and understanding of disease processes in the context of laboratory investigation and include the following.

i **Cellular pathology** is the microscopic examination of normal and abnormal cells (cytopathology), and tissues (histopathology) for indicators of disease. A biomedical science graduate will have a knowledge of:

- the preparation of cells and tissues for microscopic examination
- microscopy and its applications
- the gross structure and ultrastructure of normal cells and tissues and the structural changes which may occur during disease
- the principles and applications of visualisation and imaging techniques.

ii **Clinical biochemistry** is the evaluation of analytes to aid the screening, diagnosis and monitoring of disease. A biomedical science graduate will have knowledge of:

- the principles and applications of routine methods used in clinical biochemistry
- the investigation of the function and dysfunction of organs and systems and of the biochemical changes in disease
- the principles of the biochemical investigations used in the diagnosis, treatment and monitoring of disease
- therapeutic drug monitoring and investigation of substance abuse.

iii **Clinical immunology** is the study of immunopathological conditions and abnormal immune function. A biomedical science graduate will have knowledge of:

- the causes and consequences of abnormal immune function, neoplastic diseases and transplantation reactions together with their detection, diagnosis, treatment and monitoring
- immunological techniques used in clinical and research laboratories
- the principles of the function and measurement of effectors of the immune response

- prophylaxis and immunotherapy
- the causes and consequences of abnormal immune function, neoplastic diseases and transplantation reactions together with their detection, diagnosis, treatment and monitoring.

iv **Haematology** is the study and investigation of the different elements that constitute blood in normal and diseased states. A biomedical science graduate will have knowledge of:

- the structure, function and production of blood cells
- the nature and diagnosis of anaemias
- haemoglobinopathies and thalassaemias
- haematological malignancy
- haemostasis and thrombosis.

v **Transfusion science** is the identification of blood group antigens and antibodies which ensures a safe supply of blood and blood components. A biomedical science graduate will have knowledge of:

- the genetics, inheritance, structure and role of red cell antigens
- the preparation, storage and use of blood components
- the selection of appropriate blood components for transfusion and possible adverse effects
- immune mediated destruction of blood cells.

vi **Clinical genetics** is the identification of genetic mutations and polymorphisms and their influence on disease processes. A biomedical science graduate will have knowledge of:

- the principles of the methods used to study human chromosomes and DNA
- epigenetics
- the identification of genes for Mendelian diseases
- testing and screening for genetic susceptibility.

vii **Medical microbiology** is the study and investigation of pathogenic microorganisms. A biomedical science graduate will have knowledge of:

- the pathogenic mechanisms of a range of microorganisms
- the laboratory investigation and the epidemiology of infectious diseases
- food, water and environmental microbiology
- anti-microbial and anti-viral therapy (including drug resistance)
- infection control.

Integrated studies

4.3 Programmes should contain a reflective, integrated component (pathobiology) in which these clinical laboratory specialities are represented in a system-led approach to the study of disease and its treatment.

5 Subject-specific skills and other skills

5.1 A biomedical science graduate will practice professionally and ethically and be aware of the need for compliance with health and safety policies, good laboratory practice, risk and control of substances hazardous to health assessments, the Human Tissue Act (2004), and the importance of quality control and quality assurance. Students who graduate from integrated programmes have the opportunity to demonstrate competence in these and other skills in a clinical laboratory environment.

5.2 There are a range of skills which a biomedical science graduate will have the opportunity to acquire during the programme of study:

- discipline and subject-specific skills associated with laboratory practice, including safe handling of specimens, sample preparations, aseptic techniques, liquid handling, use of relevant instrumentation taking into account such factors as accuracy, calibration, precision and replicability, accurate interpretation of patient data and problem solving
- research skills, including ethics, governance, audit, experimental design, statistical analysis, literature searching, critical appraisal of literature and scientific communication
- key transferable skills, including communication, information technology (including the use of the internet and other electronic devices as sources of information and means of communication), numeracy (including the preparation, processing, interpretation and presentation of data), data analysis and negotiating skills.

Table 4: Biomedical science subject benchmark graduate attributes. Source: Biomedical science subject benchmark, revised 2007 (QAA, 2007)

These two subject benchmarks take contrasting approaches to subject-specific graduate attributes, since they are intended for slightly different audiences. While the biosciences benchmark is highly generic, the biomedical science benchmark relates to a highly specific group of programmes, many of which will be accredited or registered with the Health Professions Council (HPC) and Institute of Biomedical Science (IBMS). Such programmes are intended to produce graduates suitable for employment within the analytical biomedical science and hospital laboratory industry, with accredited programme graduates able to proceed to full registration on a fast-track route compared to graduates of other programmes. In some instances, such as NHS hospital laboratories, graduate entrants are normally only accepted from HPC/IBMS-approved programmes. Graduates of other life sciences degrees frequently need to undertake supplementary postgraduate conversion programmes prior to full registration and becoming licensed to practise.

3.5 Role of employers, employment and professional statutory bodies

Life sciences graduates are frequently in demand from a wide range of employers, including private and public sector bodies, small and medium-sized enterprises (SMEs) and the voluntary sector. Certain sub-disciplines within the life sciences, including those biomedically or pharmaceutically relevant, are also subject to constraints from regulatory bodies on programme content and many aspects of skills development.

The proportions of life sciences graduates becoming scientific practitioners in their first employment are mixed. For example, 35 per cent of University of Durham biology graduates in 2002-04 pursued postgraduate study, with a further 10 per cent each entering teacher training and biology-related employment (Przyborski, 2005; Cowie, 2005). Of 870 University of Leeds bioscience graduates between 200 and 2002 in employment six months after graduation, only 44 per cent entered science, education, healthcare or information technology (Newton, 2008). Among University of Leeds pharmacology graduates, no more than 50 per cent became practitioners or regulators in pharmaceutically relevant employment (Hughes, 2002, 2003). Anecdotal data repeatedly suggest that these destinations are not atypical across the life sciences as a whole, although variation among sub-disciplines is apparent.

A frequently received comment from academics was that employers are not consistent in indicating which skills and graduate attributes they need most. To some extent, this is borne out by available evidence. Life sciences employers in the late 1990s were adamant that graduates lacked skills in biotechnology and genetics, leading to shortages of highly skilled practitioners. By the early 2000s, however, similar employers were convinced of the need for much greater experience in in vivo skills (Hughes, 2003, 2005). Hughes (2002, 2003) also showed that employers rated communication skills, being a self-motivated team player and an ability to solve problems by designing and carrying out tasks as the three most important graduate attributes, while at all times expecting academic excellence.

The diversity of employment and further training routes undertaken by life sciences graduates is further illustrated by a survey of 841 students graduating from pharmacology programmes at 26 UK institutions in 2003 (Hollingsworth and Markham, 2006). Excluding intercalating medical, dental and veterinary students, 36 per cent of BSc, 34 per cent of MSc and 4 per cent of PhD graduates pursued further training six months after graduation. Employed BSc graduates were as likely to be in non-pharmacological as pharmacological posts (18 per cent each), while MSc graduates were six times more likely to be in pharmacologically relevant employment than not (18 per cent versus 3 per cent), and 67 per cent of PhD graduates were in employment requiring pharmacological knowledge (Hollingsworth and Markham, 2006). These data suggest that the further students progress with pharmacological studies, the more likely pharmacologically relevant employment becomes. Even so, there is still an apparent shortage of UK graduates in the pharmaceutical industry (Pagnamenta, 2007).

The influence of professional and statutory bodies on the curricula in biomedically and health relevant sub-disciplines is highlighted by the tightly controlled manner of the biomedical science benchmark sampled in this report (see table 4). These professional and statutory bodies are charged with helping to protect public safety. This is frequently done by a combination of bodies. For example, the IBMS works with the HPC to regulate biomedical science degrees leading to entry into the hospital lab-based professions, and they require a high degree of curricular content in clinical laboratory specialities specifically addressing knowledge and understanding of laboratory investigations of disease processes. That potential students sometimes misinterpret the more variable content of more generic biomedical sciences degrees as providing suitable graduate attributes for direct entry into hospital lab-based professions is perhaps unsurprising, without perusal of the relevant subject benchmarks. The difference in experience and subject-specific graduate attributes gained between the two types of degree, however, seems certain to be increased, as many biomedical science students in

Scotland take advantage of NHS Education Scotland bursaries linked to a semester-long placement experience in an IBMS-approved hospital laboratory (from 2008 onwards).

One slight concern relating to the role of professional and statutory bodies is the risk of curricular creep due to overcrowding of fact-based materials at the expense of developing conceptual understanding and enquiry-based learning skills. While such bodies need to do all they can to protect patient safety, as the applications of technology become ever more numerous and complex it may become necessary to guard against this tendency becoming too prescriptive.

3.6 Influence of learned societies

Within the life sciences there is a long tradition of many, generally quite specialised learned societies promoting education, research and development in their chosen subjects. The Biochemical Society, Physiological Society and Pharmacological Society all contributed to this project, through co-hosting of events for example. Through their charitable aims, many such learned societies have a strong commitment to promoting the life sciences by means of a variety of initiatives such as summer studentships, careers conferences, graduate surveys (Biochemical Society, 2004) and the development of innovative resources (Biochemical Society, 2008). More than 60 life sciences learned and professional societies are working together to promote the discipline in a coordinated way through the Biosciences Federation (www.biosciencesfederation.org). This body is likely to have an increasingly important role in influencing educational policy, resource development and practice.

3.7 International clientele

As the life sciences higher education market in Scotland has matured and become more competitive, universities and other higher education institutions have recruited increasing numbers of students from other European Union (EU) Member States and international students (from non-EU countries). These trends enrich the international student culture of campuses, while allowing recruitment of additional student numbers generating higher fee levels than for EU fee band students. In the life sciences, such recruitment has tended to be to the final (honours) level of undergraduate programmes, and predominantly to master's level programmes. The growth in international master's students is a particular feature of Scottish life sciences programmes, because of the relative excellence of programmes available and, at least in part, the residency advantages available to migrant workers wanting to remain in Scotland (Scottish Executive, 2004, Fresh Talent Initiative).

4 The importance of research-teaching linkages

Developing highly skilled graduates with detailed understanding of life sciences subjects is an important factor in realising the Scottish Government's lifelong learning and skills strategy (*Skills for Scotland,* Scottish Government, 2007). Within universities, anecdotal and experiential evidence clearly demonstrates that tensions can frequently exist between research and teaching imperatives. Structured interviews carried out for this project supported this contention, while also emphasising that all universities have a strong commitment to enhancing the student learning experience - by providing (among other things) some elements of immersion in a practical research-led or research-informed environment.

4.1 Structured interview findings

To investigate the nature of research-teaching linkages in the life sciences, the project carried out structured interviews with 10 senior staff from teaching delivery units: four pre-1992 (older), five post-1992 (modern) universities and one specialist higher education institution. Such units in Scotland have a wide variety of organisational structures, with no common format. Findings from these interviews have been grouped together, with commonalities identified together with elements of innovative or good practice. The interviews included details of provision, scale and individual roles, together with 24 questions, the majority with open-ended responses relating to the current status of research-teaching linkages and ways in which they enhance graduate attributes at undergraduate or master's level.

4.1.1 Roles and scale of teaching activity

Respondents ranged in formal title from Dean of Faculty, Head of School, Head of Department, Director of Academic Programmes or Professor to Teaching Organiser, Head of Division or Head of Subject Group. Areas of main professional interest were evenly distributed between teaching/administration and teaching/research, although all those in the latter group admitted that most of their time was spent on teaching and administration. Estimates of earned full-time equivalent (FTE) students taught within the teaching units surveyed ranged from 450 to almost 2,000. Staff FTEs ranged from 20 to more than 130, although there was considerable variation in the working definition of a teaching staff FTE among the institutions.

4.1.2 Type of curriculum

When asked for their views on the type of life sciences curriculum operating in their unit - whether research informed, research led or mixed mode - a wide range of responses were obtained. Respondents identified their curricula as spanning the full gamut, from research informed (with little direct exposure to conducting research), through mixed mode (where increasing amounts of contact with active researchers and their latest findings became commonplace, especially in later years of undergraduate programmes) to research led (with a high proportion of student time spent in original investigations).

The most commonly expressed view from senior staff, however, was of mixed-mode activities, with an increasing taper towards research-led in honours and master's years. In discussing the reasons behind their curricular choices, staff identified the inevitable limitations of resources, including access to increasingly expensive and specialised equipment, consumables costs, and available staff time for laboratory supervision of (for example) honours and master's-level projects.

An increasing problem for universities with biomedically relevant programmes was the extent of delays in obtaining ethical approval from NHS bodies for clinically relevant projects. Delays of six months or more were reported, perhaps due to regionalised consideration of ethical approval requests. Such delay caused problems for the allocation, design and conduct of research projects within taught programmes.

4.1.3 Influence of research activity levels

The percentage of staff time devoted to research activity among the life sciences units varied widely, from 20 to 90 per cent, with most of the remaining time devoted to teaching activities. Individual senior staff time was predictably much more heavily focused on teaching and administration, with only a single respondent maintaining a research focus for a majority of the time. Typical research time was 20-30 per cent of the working week.

All interviewees recognised the importance of some senior staff devoting their time to teaching and teaching administration, so that other staff could devote more of their time to research activities. None of the respondents identified staff concentrating on fostering research-teaching linkages specifically. Units may wish to consider this possibility, as a way to encourage closer linkages between research and teaching to provide a higher quality student experience.

4.1.4 Linking research and teaching to inform graduate attributes

All the institutions believed that research-teaching linkages were incrementally informing graduate attributes at levels 3, 4 and 5, while few considered that anything other than an occasional keynote was offered for students at levels 1 and 2. Most institutions encouraged senior students to attend research seminars, although actual attendance was frequently sparse. In some universities, physical restrictions on access to particular zones or buildings were considered to discourage student attendance at seminars and some guest lectures by invited visitors.

Little evidence emerged of systematic attempts to foster research-teaching linkages, although this view must be placed in the context of a highly research-intensive discipline, in which Scotland strives to be internationally competitive. This absence of any formal mechanism is perhaps surprising, given Scotland's competitiveness in the life sciences and the increasing numbers of international students who are coming to Scotland (particularly for master's-level programmes) and are actively seeking PhD and research career opportunities, often as a result of learning about the Fresh Talent Initiative (Scottish Executive, 2004).

4.1.5 Identifying research-related graduate attributes

Interviewees identified a wide range of research-related attributes that could be expected from life sciences graduates. While none of the personal suggestions completely matched either the undergraduate or master's-level attributes used as a backdrop to this project, the majority of those attributes were identified across all interviewees. Research-related attributes identified by two or more respondents are shown in table 5.

1	Enquiring, gathering and analysing information
2	Understanding science controversies and the provisionality of knowledge
3	Hypothesis design, testing and experimental skills
4	Evaluation, critical appraisal and synthesis of novel concepts
5	Understanding risk, health and safety
6	Understanding science structures
7	Managing resources
8	Understanding ethics and professional behaviours
9	Developing lifelong learning skills
10	Communication and presentation skills
11	Numeracy, accuracy and precision skills
12	Employability skills
13	Integrity and open-mindedness
14	Ability to work flexibly, independently and as part of a team
15	Developing self-confident achievers
16	Project management skills

Table 5: Research-related life sciences graduate attributes

These life sciences graduate attributes can be mapped onto the research-teaching linkages attributes and skills on which this project focused.

Undergraduate level:

- critical understanding 1, 2, 4
- informed by current developments 1, 2, 10
- awareness of knowledge properties 2, 3, 10, 11, 16
- ability to identify and analyse problems, evaluate and apply evidence-based solutions 1, 3, 4, 10, 11, 13, 15, 16
- ability to systematically and critically assess complex issues 2, 4, 6, 8, 12, 13, 15, 16
- ability to deploy techniques of analysis and enquiry 1, 3, 4, 7, 8, 11, 13, 15, 16
- familiarity with advanced techniques and skills 1, 3, 5, 7, 11, 15, 16
- originality and creativity 3, 13, 14, 15
- understanding of the need for a high level of ethical, social, cultural, environmental and wider professional conduct 2, 4, 5, 6, 8, 12, 13, 15, 16.

Master's level:

- conceptual understanding enabling critical evaluation of current research and advanced scholarship 1, 2, 4, 6, 11, 15
- originality in application of knowledge 1, 4, 5, 13, 15
- ability to deal with complex issues and make sound judgements in absence of complete data 1, 2, 3, 4, 11, 15.

When asked to identify the three most important research-related graduate attributes, the most frequently cited were:

- evaluation, critical appraisal and synthesis of novel concepts
- developing self-confident achievers
- ability to work flexibly, independently and as part of a team.

These were followed closely by developing a sense of enquiry. Perhaps the most surprising aspect was the relatively low priority accorded to lifelong learning skills and to overt employability skills. This may reflect the range of employability skills embedded within other cited attributes, or the wide range of employment options open to these graduates, as senior staff agree that approximately 50 per cent of graduates become practising life scientists during their careers (Bioscience Subject Centre, 2008a, 2008b). Specific attributes for master's graduates were only rarely suggested, with greater expectations of conceptual understanding, advanced research methods and technical and project management skills being widely expected.

4.1.6 Building research linkages into curricula

While all the higher education institutions surveyed were aware of the range of relevant subject benchmarks, the extent to which these informed curricular design varied considerably. All institutions claimed that research-teaching linkages were built into their programmes, but none of them had any formal mechanism for ensuring that this was the case, or for monitoring the effectiveness of the research linkages which were established.

The most common approach was to rely on informal linkage mechanisms, frequently involving guest lectures, access to research seminars, and modules or units with emphasis on contemporary research-relevant issues. In some instances, little more than reliance on using active researchers to deliver lectures was expected. Such an approach could risk becoming piecemeal or fragmentary if not appropriately monitored. In other cases, the proportions of research-relevant staff could be improved, leading to a greater frequency of actual contact with researchers, who might otherwise never meet students on taught programmes. Clear evidence emerged of detailed engagement with research-related concepts, methods, technologies and skills during projects at both undergraduate and master's levels. Here, immersion in active research groups became possible for periods ranging from a few weeks to five months, typically for master's students.

Accreditation or recognition by professional and statutory bodies was an important factor for modern universities, but not for older institutions. While the HPC and IBMS were frequently reported as an accrediting or recognising body, a range of others - including the Forensic Institute, Royal Society of Chemistry and British Dietetic Association - were also important. The insistence of professional and statutory bodies on adequate research and contemporary issue content was viewed as a positive feature in helping teaching units to safeguard resources against competing institutional demands.

The need to have programmes accredited or recognised by professional and statutory bodies was not considered important by older universities, citing potential constraints on academic freedom and the selective nature of admission to their programmes, which were frequently less vocational than those found in modern universities.

All the higher education institutions reported that informal mechanisms involved in curricular design, together with module performance reporting procedures, were able to ensure that research linkages into teaching were adequately considered - for example, through subject development teams, bespoke modules devoted to research skills or project preparation, or research-relevant activities embedded within a wide range of different modules. In several universities, a series of modules developed research skills incrementally, with cross-linking to (for example) particular laboratory sessions or activities in other modules providing opportunities for reinforcing or extending these skills. A tapered approach with increasing opportunities to build in research linkages was common to many universities. Annual programme monitoring and periodic revalidation or internal subject review activities were believed to provide additional safeguards to ensure that research linkages were satisfactorily built into and maintained within delivered programmes.

4.1.7 Role of research projects and placement experience

All of the senior staff interviewed believed that undertaking some form of extended project - preferably of a practical, hypothesis-testing nature - was a central and essential feature of life sciences programmes at undergraduate or master's level. Pressure from increasing student numbers and reduced consumables resource budgets were frequently mentioned as constraining some aspects of research project delivery, as were time delays associated with obtaining ethical approval for clinically relevant projects in areas such as dietetics, nutrition, physiology, pharmacology and biomedical science.

Several programmes built in research skills or project preparation modules, while some were able to go further and offer mini-projects which were either formative or carried few credits. Most institutions recognised that it may no longer be possible to always offer all students 'wet' lab research projects, depending on student and staff numbers. An increasing number of projects with significant IT-based content, in areas such as bioinformatics, were being undertaken. These were seen as a natural extension of wet lab projects, since an ability to use biological databases, modelling or 3-D structure tools is likely to be required of almost all practising life sciences graduates in the coming decades. This recognition chimes well with the need to develop lifelong learning skills, to develop a sense of enquiry, and to gather, analyse and evaluate information as defined in the generic graduate attributes.

The importance of research projects, of whatever type, in life sciences programmes is reflected in the 20-50 per cent of honours credits associated with them, and the extended nature of lab or bioinformatics-based projects at master's level typically undertaken for 40-50 per cent of available credits.

Evidence of increasing importance and value associated with gaining placement experience emerged from at least six of the interviews. Opportunities for undertaking semester-long industrial or hospital lab placements were viewed as providing additional immersion in a research-informed working environment and benefiting graduates' understanding of professional practice and their employment prospects.
The introduction of bursaries funded by NHS Education Scotland for up to 100 Scottish

biomedical science students from 2007-08 was viewed as a significant enhancement for future graduates, who were considered likely to be more employable and highly prized as a result of this immersion.

In many programmes related to ecological, conservation or other environmental aspects of the life sciences, extensive use was made of fieldwork-based exercises. These were often real-world research immersion projects, with students able to contribute to original investigations of organisms, ecosystems or interactions in natural settings. Such fieldwork exercises, whether as fieldwork training courses, research projects or a combination of both, were viewed as excellent tools for developing flexible approaches, teamworking and data analysis skills highlighted in both generic and life sciences discipline-specific graduate attributes. Where wet lab, fieldwork or bioinformatics projects were not undertaken, extended dissertations or literature analyses were sometimes used, alongside extended interpretation exercises based on previously obtained data, for example from clinical trials, public health or nutrition information sets.

4.1.8 Developing specific graduate attributes

Critical thinking was developed among life sciences students by a variety of means in the different higher education institutions. The plethora of approaches probably reflects the varying pace of learning between selecting and recruiting institutions, but a number of common elements emerged. Students at every institution were encouraged to develop critical factors such as appraisal and evaluative skills gradually, beginning from a base of 'what is written is true', through series of graded tasks such as précis, verification, evaluation, authoring draft manuscripts and problem-solving exercises involving data interpretation. Interviews with senior teaching staff obtained a clear sense of gradual increase of these critical appraisal skills.

Alongside these skills several universities developed students as 'enquiring minds' able to formulate and ask critical questions to aid analysis, evaluation and understanding, as part of developing their knowledge. Most programmes included an element of research ethos, providing several opportunities for students to exercise their critical appraisal skills and hone these attributes to graduate level. At master's level, these attributes were developed further, with an expectation of synthesis of new ideas and concept formation as part of knowledge development. Typically, this culminated in an extended research project, drawing on the higher order skills developed at undergraduate level and during the master's taught programme.

Few, if any, of the senior teaching staff interviewed were aware of formal institutional policies or mechanisms to specifically develop life sciences students as lifelong learners. Informal mechanisms and in a few cases bespoke tools were, however, beginning to be deployed for life sciences students. These included the development of lifelong learning training to encourage confidence in students' abilities to access, harvest, collate and present information at all levels of taught programmes, alongside recognition of the provisionality of knowledge by accepting firstly what we do not know and using curiosity to drive the need for new knowledge. In some sub-disciplines in the modern universities, such as nutrition, dietetics and biomedical science, developing students were required to keep portfolios outlining (among other things) their learning skills activities, as part of their path to registration and obtaining a licence to practice.

Research methods modules also provided some elements of preparation for lifelong learning, particularly where toolkits for analysing complex data sets were developed. Among research-intensive universities, part of the drive to encourage students to become capable lifelong learners came from the very speed of advancing knowledge within the life sciences. Students, particularly at advanced levels, were required to continuously update their knowledge in response to newly created knowledge, arising in many cases from leading-edge technological advances. Those particularly adept at this attribute could place themselves at competitive advantage in the graduate jobs or PhD studentship marketplace, as well as being better prepared for professional life.

All in all, although informal rather than formal mechanisms were generally used, each higher education institution was engaged in some form of activities to prepare students to be able to continue learning after graduation. This could best be summed up by the comment from one interviewee that: 'Learning skills are for life, not just for Christmas!'.

An appreciation of the need for appropriate standards of ethical and professional behaviour was developed in a wide variety of different ways. In some programmes, professional and statutory bodies encouraged specific modules or part modules on professional ethics and ethical issues, often in the early years of undergraduate curricula. In other instances, series of embedded activities were used at all levels. A common feature was the embedding of activities on ethics and professional standards of behaviour within several modules during a programme, especially where no standalone ethics module existed.

As the numbers of scientific controversies receiving high levels of media publicity continue to rise, an interesting array of potential new examples for group activities on ethics, professional behaviour and scientific uncertainty are emerging. Examples include examining the science behind the recent court judgement on Al Gore's documentary film *An Inconvenient Truth*, debates around intelligent design and the appropriateness or otherwise of certain types of biofuels. These types of activities also serve to reinforce the concept of knowledge being uncertain, or at least incomplete and subject to change over time.

Each higher education institution employed a diversity of approaches to highlight local cutting-edge research expertise in their taught programmes. These included guest lectures by local life sciences industrialists open to all students, seminars given by staff from local research institutes, hot topics modules, use of extended local case studies, and the deliberate inclusion of lectures by in-house star researchers within units at each level of a programme. These measures were designed to encourage a greater sense of research enquiry among students, and were regarded as sufficiently important to take up a major component of scheduled classes at honours and master's levels in some universities. Every institution shared a commitment to fostering greater knowledge of local research successes, regarding this as good publicity likely to encourage further student applications and contribute to the advancement of knowledge by helping to hone the inquisitive minds of future scientists.

When asked to indicate where the balance of research-teaching linkages lay within the Healey quadrants of research-tutored, based, oriented or led activities (Healey, 2005), interviewees ranked research-based teaching highest, in which the curriculum emphasises students undertaking enquiry-based learning as most important. This was followed by research-led teaching, in which students learn about research findings alongside the teaching of subject content. Research-tutored teaching, in which the curriculum emphasises learning which focuses on students writing and discussing papers or essays, was ranked third. This was followed by research-oriented teaching, in which the curriculum emphasises teaching processes of knowledge construction within the life sciences. No higher education institution concentrated solely on any one or two of these types of research-teaching linkages. Instead, they varied their expectations and delivery according to the most appropriate type of linkage for particular modules or programme stages.

4.1.9 Sharing good practice in research-teaching linkages

The majority of staff interviewed were aware of the Scottish higher education Enhancement Themes and had had some dealings with their institutional contact. Activities to share good practice included collaborative development of research-teaching linkages with international collaborators, exposure to other universities' quality assurance systems (including in the role of external examiners), and through the use of module reflection groups.

Good practice internally was identified by scrutiny of student feedback questionnaires, through formal and informal teaching observation sessions, from student-staff consultative committees, through the use of virtual learning environments and discussion boards, by word of mouth, and through cross-unit activities such as university-wide Enhancement Theme groups and university-wide awards for innovations in teaching and learning or small research projects with outcomes linked to teaching activities. Subjects covered ranged from forensic biology to developing practical skills in preparation for research projects, and from molecular biology techniques workshops to adding value to fieldwork exercises. In each of these examples, students were expected to develop skills and competences suitable for workplace or research scholarship environments, which were considered desirable graduate attributes.

While all the higher education institutions were aware of the Higher Education Academy's Bioscience Subject Centre, the majority of senior staff interviewed felt that stronger links would be welcome, especially for sharing best practice. Conflicting priorities, pressure of work and information overload were all cited as holding back further development of interactions with subject centres. It should be noted, however, that several of these interviews were carried out around the time of RAE narrative submission, which frequently appeared to be occupying minds greatly.

Disappointingly, little knowledge of the Centres for Excellence in Teaching and Learning (CETLs) was evident, despite several of these centres being highly relevant to the Enhancement Theme, including the CETL for Applied Undergraduate Research Skills at the University of Reading. To some extent, lack of knowledge of the centres was unsurprising, since the 74 CETLs are funded solely by the Higher Education Funding Council for England (HEFCE); they were founded following the 2003 White Paper *The Future of Higher Education*. Each CETL is highly relevant to the enhancement of graduate attributes via research-teaching linkages and has much web-based material for enhancing teaching delivery. To further aid the enhancement of research-teaching linkages through increased knowledge of the Bioscience Subject Centre and CETLs, promotional information was provided to all senior staff interviewed, including a leaflet on the 12 CETLs with close links to the life sciences (table 6).

Host university	CETL title and website link
Aston, Liverpool Hope, London Metropolitan	Write Now for Scientific Literacy www.writenow.ac.uk
Bristol	Applied and Integrated Medical Sciences - AIMS www.bris.ac.uk/cetl/aims
Reading	Applied Undergraduate Research Skills - AURS www.reading.ac.uk/cetl-aurs
Bristol	Bristol ChemLabS www.chm.bris.ac.uk/bristolchemlabs
Gloucestershire	Centre for Active Learning in Geography, Environment and Related Disciplines - CeAL www.glos.ac.uk/ceal
Harper Adams University College	Advancing Skills for Professionals in the Rural Economy - ASPIRE www.harper-adams.ac.uk/aspire
Nottingham Trent	Centre for Effective Learning in Science - CELS www.ntu.ac.uk/cels
Liverpool John Moores	Centre for Excellence in Leadership and Professional Learning www.ljmu.ac.uk/CETL/index.htm
Open	Centre for Open Learning of Mathematics, Science, Computing and Technology - COLMSCT www.open.ac.uk/colmsct/
Plymouth	Experiential Learning in Environmental and Natural Sciences - EL CETL www.plymouth.ac.uk/cetl/el
Leicester	Genetics Education Networking for Innovation and Excellence - GENIE www.le.ac.uk/genetics/genie
Leeds	Inter-Disciplinary Ethics Applied - IDEA www.idea.leeds.ac.uk

Table 6: Life sciences-related CETLs. Source: Bioscience Subject Centre, 2007

4.2 Case studies

Many higher education institutions and the Higher Education Academy's Bioscience Subject Centre provided examples of case studies in which research-teaching linkages enhance life sciences graduate attributes. This report briefly discusses a number of examples in relation to the graduate attributes likely to be enhanced by their delivery. The case studies have been loosely grouped around scientific method, fieldwork, projects, learning environments and international examples. These groupings contain a high degree of overlap, and frequently relate to more than one graduate attribute.

4.2.1 Scientific method

Understanding scientific thought processes
Morven Shearer and Charles Paxton, University of St Andrews

Encourages student identification of appropriate hypotheses by introducing knowledge skills and principles of ethics and enhancing scientific reasoning skills. Widely applicable across all scientific disciplines.

Using data to promote scientific thinking
Maria Jackson, University of Glasgow

Uses original research data to encourage critical analysis and develop confidence and communication skills for undergraduate students. At master's level, students work to decide on and use suitable research tools to investigate research problems in, for example, medical genetics or cancer biology. Encourages student discussion of the meaning of scientific data and the application of problem-solving skills.

Student indignation: a strategic tool for progressive skills development
Lorna Sibbett, University of St Andrews

Students are encouraged to use debate and scientific argument as part of communications and scientific skills development in critical appraisal, experimental design and use of appropriate statistical tests. Creates learning partnerships and empowered individuals able to assume responsibility for their own learning.

Research and employability skills toolbox
Emma Creighton, University of Chester

A layered approach to encouraging development of research and problem-solving skills is used in toolbox modules at HEFCE levels 1-3. Gradual development of investigative, communications and problem-solving skills allows extensive opportunities for repetition and reinforcement of prior learning. In later levels the skills toolbox is directly linked to research projects and preparation for future careers.

Fostering a questioning attitude in first-year students
Maria Chamberlain, University of Edinburgh

A questioning and critical approach to learning, reflection and data acquisition is generated by promoting enquiry among small teams of new students asked to consider novel problems, frequently in a field setting. Emphasis is placed on promoting enquiry among students by encouraging and rewarding the design of good questions. This is reinforced by enquiry-based tutorial sessions and examination of controversial topics such as the nine potentially flawed assertions in Al Gore's documentary film *An Inconvenient Truth* and a recent High Court judgement on balanced views needed before it can be shown in schools (www.teachernet.gov.uk).

Engage! Online science research process information source
AURS CETL, University of Reading

A structured environment providing interactive resources for life sciences students explaining scientific method, the need for systematic appraisal of previous findings, experimental design, user-friendly statistical analysis, science communications and publishing findings. Through simple explanations and examples, the resources help any student to develop research skills and become confident questioners of others' findings, in preparation for professional science careers.

Introducing undergraduates to scientific reports and investigations
Chris Willmott, University of Leicester

Provides a series of exercises for HEFCE level 1 medical biochemists and medical genetics students to read, consider the structure of, précis and evaluate individual research papers during three sessions spread over two months. The findings are used to encourage students to imagine their future roles as investigators (for example in honours projects), to design experiments to investigate a selected problem further and to write individual reports based on supplied data. Innovative opportunities for buzz groups, formative assessments, individual and small-group presentations and feedback sessions are used in a non-threatening way, to encourage critical thinking and problem-solving among students (Willmott et al, 2003). Valuable preparation for experimental design is provided with a variable degree of challenge for students of all abilities as an initial stage in preparations for honours projects.

4.2.2 Fieldwork

Crossing continents on field courses: preparation for life
David Paterson, University of St Andrews

An Icelandic field course is used to develop group-work and communications skills in a highly original setting. The activities encourage integration of previous learning while enhancing self-expression and critical faculties in a problem-solving manner, including accumulation of original research data. This provides excellent preparation for, and in some cases contributes to, honours projects by bringing together and applying much of previous learning.

Taking learning into the field
Julian Park, University of Reading

Provides immersion in and experience of landscape-based research and data-gathering activities from fieldwork. Introduces students to the uncertainty and variability of real data, the influence of environment on research strategies and provides taster preparation for a variety of landscape-based careers. Students' experience, feedback and results can be used as part of justifications for continuing to devote resources to field studies for any life scientist.

Managing, executing and communicating marine field research projects
Mark Davies, University of Sunderland

Experience is gained in formulating and costing an application for research funding to support a marine field study, planning the trip, carrying out the research, preparing an oral presentation and producing a scientific paper on the results of the study. Honours students gain a strong sense of purpose, and independent and team working, alongside an enhanced appreciation of the scientific method, the competitive nature of research funding and scientific writing.

4.2.3 Projects

Research for Real
Mark Huxham, Napier University

An extended module used as the capstone for honours students investigating research-related problems and developing scientific writing and communications skills, which frequently leads to peer-reviewed publications. Conference-style format encourages dissemination skills and prepares students for the world of work or further study. Previous cohorts' outputs are used in preparatory sessions each year to encourage a sense of ambition.

Students as research proposers, funders and practitioners
Phil Collier, University of Abertay Dundee

Through a series of structured techniques and skills modules, thematically developed over several years, biotechnology students are instilled with a 'research ethic', developing a clear understanding of the role that research plays in solving scientific problems and enquiry-based learning skills. Having undertaken extensive lab skills development exercises, students write their own grant proposals for a medical or life sciences project, individually present their case for support and participate in group assessment of peer proposals. The thematic development culminates in the honours research project, acting as the learning capstone throughout the final semester of studies, in which students demonstrate their practical and communications skills through self-defined goals in the design, operation, completion and presentation of a research project.

This gradual development of research-led graduate attributes develops confident thinkers with excellent planning, development and problem-solving skills alongside the critical awareness to address specific problems. A similar, although more concentrated approach is adopted with master's students in biotechnology or bioinformatics, where the frequently self-funded international students benefit from additional training to challenge assumptions and received wisdom, demonstrating the provisionality of knowledge, together with a strong sense of self-motivation and commitment to problem-solving.

Undergraduate research opportunities scheme
Gillian Fraser, AURS CETL, University of Reading

Short-term opportunities are provided for undergraduates to become involved in real research projects. Students are encouraged to consider which sub-discipline they may wish to follow. Their employability skills are enhanced by requiring competitive CVs for successful students.

Learned society summer studentships

The larger life sciences learned societies frequently offer short-term studentships, including the Biochemical Society, Society for General Microbiology and science-supporting bodies such as the Wellcome Trust and Nuffield Foundation. Typically, students are immersed in an active research group to experience a competitive research environment. They are expected to address a clearly identifiable research problem and assemble solutions involving hands-on experience of a wide range of high-tech equipment which might be available in scheduled laboratory settings. Such studentships develop confidence, independent and team working skills, and communications and employability skills. Typically, 120+ such studentships are offered each summer, frequently to students prior to entry into honours year.

***Bioscience Horizons:* a national journal for undergraduate research**
Celia Knight, University of Leeds

Horizons is one of a number of scientific journal outlets for peer-reviewed papers from bioscience honours research projects. Participating higher education institutions are asked to propose their best honours projects for possible inclusion. Students author papers from selected projects, developing a sense of enquiry and problem-solving, writing and employability skills. The journal is a joint development by the Universities of Leeds, Nottingham, Reading, Chester and Trinity College Dublin. See also *Origin*, a journal published by the University of Chester for findings from undergraduate research projects in the life sciences (Potter, 2002; www.chester.ac.uk/origin).

Encouraging Research-Teaching Symbiosis
Kay Yeoman, University of East Anglia

Students are encouraged to develop their experimental design, data analysis, scientific writing and presentation skills through a HEFCE level 2 dedicated research skills module which aims to bridge the gap between lab abilities developed in conventionally taught modules and the honours research project. Enhanced manipulative and analytical skills are developed, together with a strong sense of enquiry, in a manner which impacts positively on project performance. Student feedback suggests that an emotional connection between students and a research ethos is generated, establishing a strong sense of ownership of a problem and pride in achievements made and communicated to others.

Students and staff: research in tandem
Mark Langan, Manchester Metropolitan University

Students from diverse institutions and learning backgrounds come together on a field course to experience aspects of scientific research alongside staff undertaking subject or pedagogic research in environmental sciences, biological sciences or agriculture. Students are involved in negotiated scientific process design, data acquisition, analysis, presentation of results and discussion of referees' comments with other, initially unfamiliar students and staff from other universities. The experience of networking, group work, participation in research and critical discussions provides an excellent filter for students to decide whether a research-based career is for them, prior to choosing honours-year projects, while encouraging self-confidence and better communication skills.

4.2.4 Learning environments

Whitespace knowledge environment
University of Abertay Dundee

A unique way of organising learning spaces and implementing learning methodologies to encourage students' immersion in a researcher and practitioner environment not constrained by disciplinary boundaries. Students, teaching staff, researchers, industrial practitioners and staff from SMEs are all encouraged to work and learn in new ways to solve problems innovatively. Encourages student self-confidence, inter and multidisciplinarity and thinking outside the box, and enhances employability (www.abertay.ac.uk/About/WhiteSpace.cfm).

Veni, vidi, wiki (vici?): experimenting with student authoring
Paul McLaughlin, University of Edinburgh

An innovative teaching studio setting is used to develop desirable graduate attributes such as team skills and problem-solving and communications abilities by using computer modelling and simulations to investigate systems biology questions.

Moodle discussion forums to enhance small-group skills
Andrea Brown, University of Glasgow

Moderated discussion for a on the university's virtual learning environment Moodle introduce students to small-group working in a study comparing different countries' lifestyles for humans and other species. Through their small groups, students receive an introduction to teamworking and presentation skills, but are also encouraged to undertake independent research on topics they come across during the Moodle discussions and find interesting, thereby encouraging reflection. Developed as part of the Re-Engineering Assessment Practices (REAP) project (www.reap.ac.uk).

Promoting creative potential among graduates
David J Adams, University of Leeds

Uses a wide variety of structured exercises designed to promote the development of creativity in students, to encourage the development of enquiring minds, unorthodox thinking and questioning attitudes. Students are encouraged to consider new perspectives and develop creative faculties at individual and group levels through brainstorming, mind-mapping, assumption challenging and simple analogy activities. Use of 'fridge magnets' to capture and sort ideas, along with different types of 'thinking hats' for small groups, has proven useful in encouraging curiosity and a sense of inspiration through creativity. Tried and tested examples of creativity-building exercises for students and teachers are available at: www.fbs.leeds.ac.uk/creativity

Immersion in an internationally competitive research race
Jean Assender, University of Birmingham

HEFCE level 2 students are asked to imagine themselves working in small teams in an internationally competitive research environment - as teaching laboratories racing to unravel the quaternary structure of a potentially valuable protein. Teams labelled as different countries become immersed in using research tools to find out things about their protein, hopefully before their competitors do, and to be the first to publish their complete findings at an international conference. Students gain experience in the competitive team environment of research groups, greater understanding of how international science works and a sense of fun, while preparing for the world of work.

Business in the biosciences
Mary Tatner and Anne Tierney, University of Glasgow

Honours students undertaking a commercially relevant research project are encouraged to participate in an intensive short course with preliminary training on entrepreneurial business techniques, with assistance from a sponsoring company or Scottish Enterprise. Skills needed for planning a research-based business - including teamwork, market research, financing, cash flows and exit strategies - are developed, and there is a visit to a life science company. Teams of students are expected to develop a business plan for a new product or service and present to a 'Dragon's Den' style panel of would-be investors. This approach is being extended to postgraduate students as part of their personal development planning.

4.2.5 International case studies

Scientific Training by Assignment for Research Students (STARS)
John A Finn and Anne C Crook, University College Cork, Ireland

Provides a web-based series of skills development resources for use by teachers and novice researchers. An easily accessible set of tools and exercises with examples of how research-type attributes can be developed through projects, including useful tips, short activities and extended case studies (www.ucc.ie/research/stars).

Research-based approaches to increasing meaningful learning of targeted concepts in microbiology
Ann C Smith et al, University of Maryland, USA

Microbiology teachers committed to applying a research-group approach to the development of student learning, after agreeing to build curricular content across seven separate modules ranging from Microbial Genetics to Immunology and from Microbial Pathogenesis to Epidemiology for the Study of Host-Pathogen Interactions (Marbach-Ad et al, 2007). Following group discussions, staff agreed to adopt two common approaches: relating student learning materials to six topics fundamental to understanding host-pathogen interactions, and choosing two 'anchor' organisms, the bacteria Escherichia coli and Streptococcus pneumoniae, as exemplars in all seven modules. The teaching team has trialled and tested a variety of methods, such as literature-based learning (Parent et al, 2005), to introduce a research-based style of learning to all seven modules, encouraging innovation among teachers and implementing a force concept inventory approach (Hestenes et al, 1992; Odom and Barrow, 1995; Anderson et al, 2002) to deliver deeper, longer term student learning (www.clfs.umd.edu/hpi).

The Stanford Research Communication Programme
Carolyn Gale, Stanford University, USA

An example of how to address the tensions between teaching and research imperatives by exposing first-year university students to scientific writing and communications needs. Students create a 750-word statement describing their research findings on a particular problem following a six-week mixture of online and face-to-face meetings to discuss progress with peers and reviewers from different disciplines. Critical appraisal skills are developed in improving initial statements to reach a suitable endpoint. This model has also been adopted in Swedish universities (Gale, 2002).

The research-teaching nexus project
University of New South Wales, Australia

Provides access to a wide range of institutional resources linking research and teaching. Includes consideration of research-teaching scholarship, case studies of good practice, and ways to involve students and conduct research into student learning (http://learningandteaching.unsw.edu.au/content/RandI/research_nexus/research_teaching.cfm?ss=5).

BioLogos
University of Rennes, France

Undergraduate research or review articles, published in French, on any aspect of biosciences or environmental science. Contains a useful archive of previous submissions. (www.biologos.univ-rennes1.fr/Fichiers/AfficheArchive.php).

Council on Undergraduate Research (CUR)
Washington DC, USA

CUR activities focus on inquiries or investigations conducted by undergraduate students that make an original intellectual or creative contribution in any discipline. A charitable educational organisation founded in 1978, CUR now has institutional and individual members from over 900 colleges and universities. Extensive and comprehensive support for academics, outreach tools, publications and events to encourage undergraduate involvement in research are provided (www.cur.org).

Journal of Young Investigators (JYI)
National Science Foundation and other international funders

JYI draws together online research articles written by undergraduate students globally, in an attractive magazine-style format. Examples include the science of allergies, why caffeine is a stimulant, and reducing recovery time and medical costs in operating rooms by using a DaVinci robot. JYI aids the development of self-confidence, communication and presentation skills among students internationally (www.jyi.org).

Undergraduate Biology Research Program
University of Arizona, USA

An educational programme designed to involve students in biosciences research. Students are funded for placements, while developing an enhanced understanding of scientific method and life sciences research. The experience helps students to develop research employability skills with support from, among others, the Howard Hughes Foundation (http://ubrp.arizona.edu).

Summer Undergraduate Research Fellowships Program (SURF)
Caltech, USA

Modelled on a typical grant-awarding process, SURF has been providing summer vacation studentships to undergraduates since 1979. Students are introduced to research processes under the guidance of research mentors at Caltech and associated laboratories. SURF typically supports approximately 575 students and mentors annually (www.surf.caltech.edu).

Undergraduate Research Opportunity Program
University of Michigan, USA

Collaborative research partnerships between first and second-year students and researchers at the University of Michigan are developed through team project approaches. The activities encourage development of a sense of enquiry, self-confidence and practical and presentational skills among peers, and have recently involved 900 students and 600 faculty researchers (www.lsa.umich.edu/urop).

Further details of many of these case studies, frequently including PowerPoint presentations, are available from the Centre for Bioscience, Higher Education Academy (http://bio.ltsn.ac.uk).

4.3 Life sciences student and staff surveys

Students at honours or master's level from six Scottish higher education institutions were asked to complete a simple Liekert scale survey consisting of 17 short statements relating to the role of research in teaching on their programmes. The institutions were: University of Abertay Dundee (UAD; 71 responses), Glasgow Caledonian University (GCU; 94 responses), Napier University (NU; 91 responses), and the Universities of Dundee and Edinburgh, together with the Scottish Agricultural College (a further seven responses in total). Attendees at the Biosciences 2007 Education Symposium 'Research-Teaching Linkages in the Biosciences' and the Life Sciences Research-Teaching Linkages Discipline event held in February 2008 as part of this project provided 43 survey responses from academic staff interested in teaching and learning, who were asked to comment on the programme they most identified with. In total, 263 students' responses were included in the analysis of 306 surveys. In one instance, surveys were undertaken with MSc student groups before and after extended research projects.

The Liekert scale used dealt with the extent to which the respondent agreed with a statement, ranging from 1 (strongly disagree) through 3 (neutral/not applicable) to 5 (strongly agree) with each statement. Respondents were asked to identify their higher education institution and programme. An information sheet giving details of the project, the terms under which the survey was being undertaken and the project director's contact details was provided. Surveys were carried out in accordance with British Educational Research Association *Ethical Guidelines* (2004), and the survey approach was ethically approved by GCU's School of Life Sciences Ethics Committee.

The responses were collated and analysed in a number of ways. Table 7 shows a comparison of responses by institution, student or staff source, plus combined students' response and overall response (students plus staff), as well as percentage data and modal and mean responses, for each of the 17 statements.

Key to student and staff research-teaching linkages survey data	
Staff:	Biosciences 2007 Education Symposium and Life Sciences Research-Teaching Linkages Discipline Event responses (n=43)
UAD students:	University of Abertay Dundee students summary data (n=71)
GCU students:	Glasgow Caledonian University students summary data (n=94)
NU students:	Napier University students summary data (n=91)
Other:	Scottish Agricultural College, University of Dundee, University of Edinburgh combined (n=7)
Student summary:	Overall students' summary data (n=263)
Overall summary:	Overall respondents' summary data (includes researchers; n=306)
% overall:	Percentage overall respondents data (n=306) rounded to nearest integer
Mode:	Most frequent response
Total:	Number of responses to individual question
Mean:	Average response value (on 1-5 scale)
Key to responses:	
1	Strongly disagree
2	Disagree
3	Neutral/not applicable
4	Agree
5	Strongly agree

Statement		**Options**					**Mode**	**Total**	**Mean**
	Choices	**1**	**2**	**3**	**4**	**5**			
1	From the lectures I have attended I understand how bioscience research is carried out.								
1	Staff	2	2	6	18	14	4	42	3.95
	Other	0	0	2	5	0	4	7	3.71
	UAD students	1	5	8	48	9	4	71	3.83
	GCU students	3	6	27	51	7	4	94	3.56
	NU students	1	4	17	50	19	4	91	3.90
	Students summary	5	15	54	154	35	4	263	3.76
	Overall summary	7	17	60	172	49	4	305	3.78
	% overall	**2%**	**6%**	**20%**	**56%**	**16%**		**100%**	

Statement		Options					Mode	Total	Mean
	Choices	**1**	**2**	**3**	**4**	**5**			
2	Lecturers on this programme explain how research is done.								
2	Staff	0	5	10	20	8	4	43	3.72
	Other	0	0	2	5	0	4	7	3.71
	UAD students	0	4	14	39	14	4	71	3.89
	GCU students	1	14	31	37	11	4	94	3.46
	NU students	0	4	16	49	22	4	91	3.98
	Students summary	1	22	63	130	47	4	263	3.76
	Overall summary	1	27	73	150	55	4	306	3.75
	% overall	**0%**	**9%**	**24%**	**49%**	**18%**		**100%**	
3	In the lectures I have attended so far the lecturers frequently illustrate the topics by examples from research that has been carried out.								
3	Staff	1	2	7	21	12	4	43	3.95
	Other	0	0	2	1	4	5	7	4.29
	UAD students	3	5	13	28	22	4	71	3.86
	GCU students	1	9	27	42	15	4	94	3.65
	NU students	1	0	13	40	37	4	91	4.23
	Students summary	5	14	55	111	78	4	263	3.92
	Overall summary	6	16	62	132	90	4	306	3.93
	% overall	**2%**	**5%**	**20%**	**43%**	**29%**		**100%**	
4	At this stage in my programme/after carrying out my research project I understand how bioscience research is carried out.								
4	Staff	0	4	4	12	22	5	42	4.24
	Other	0	0	3	4	0	4	7	3.57
	UAD students	2	2	20	37	10	4	71	3.72
	GCU students	2	11	33	31	17	3	94	3.53
	NU students	2	2	24	43	20	4	91	3.85
	Students summary	6	15	80	115	47	4	263	3.69
	Overall summary	6	19	84	127	69	4	305	3.77
	% overall	**2%**	**6%**	**28%**	**42%**	**23%**		**100%**	

Statement		Options					Mode	Total	Mean
	Choices	**1**	**2**	**3**	**4**	**5**			
5	From the work on the programme so far I understand what is meant by the word 'hypothesis'.								
5	Staff	1	0	4	18	18	4/5	41	4.27
	Other	0	1	1	2	3	5	7	4.00
	UAD students	1	6	8	32	24	4	71	4.01
	GCU students	2	4	16	40	32	4	94	4.02
	NU students	0	1	4	26	60	5	91	4.59
	Students summary	3	12	29	100	119	5	263	4.22
	Overall summary	4	12	33	118	137	5	304	4.22
	% overall	**1%**	**4%**	**11%**	**39%**	**45%**		**100%**	
6	I understand that when research has been done and results obtained, the conclusions are published in scientific journals or presented at conferences.								
6	Staff	1	0	2	11	28	5	42	4.55
	Other	0	0	1	1	5	5	7	4.57
	UAD students	3	3	4	30	31	5	71	4.17
	GCU students	0	3	12	37	42	5	94	4.26
	NU students	0	0	9	29	53	5	91	4.48
	Students summary	3	6	26	97	131	5	263	4.32
	Overall summary	4	6	28	108	159	5	305	4.35
	% overall	**1%**	**2%**	**9%**	**35%**	**52%**		**100%**	
7	My programme encourages me to read scientific papers about research (the so-called primary literature).								
7	Staff	0	2	3	15	23	5	43	4.37
	Other	0	1	0	1	5	5	7	4.43
	UAD students	3	0	1	17	50	5	71	4.56
	GCU students	5	5	17	35	32	4	94	3.89
	NU students	0	1	4	17	69	5	91	4.69
	Students summary	8	7	22	70	156	5	263	4.37
	Overall summary	8	9	25	85	179	5	306	4.37
	% overall	**3%**	**3%**	**8%**	**28%**	**58%**		**100%**	

Statement		Options					Mode	Total	Mean
	Choices	**1**	**2**	**3**	**4**	**5**			
8	On my programme I have been asked to summarise one or more scientific papers.								
8	Staff	2	2	5	11	22	5	42	4.17
	Other	1	1	0	2	3	5	7	3.71
	UAD students	3	6	17	17	28	5	71	3.86
	GCU students	7	13	9	34	31	4	94	3.73
	NU students	1	0	8	18	64	5	91	4.58
	Students summary	12	20	34	71	126	5	263	4.06
	Overall summary	14	22	39	82	148	5	305	4.08
	% overall	**5%**	**7%**	**13%**	**27%**	**49%**		**100%**	
9	On my programme it has been explained to me how scientific papers are written and formatted.								
9	Staff	2	6	6	12	16	5	42	3.81
	Other	1	0	0	3	3	4/5	7	4.00
	UAD students	2	8	17	27	17	4	71	3.69
	GCU students	5	12	27	26	24	3	94	3.55
	NU students	1	5	12	42	31	4	91	4.07
	Students summary	9	25	56	98	75	4	263	3.78
	Overall summary	11	31	62	110	91	4	305	3.78
	% overall	**4%**	**10%**	**20%**	**36%**	**30%**		**100%**	
10	I know that scientific papers are written in a standard format with sections like 'Materials and methods', 'Results' and 'Discussion'.								
10	Staff	1	1	0	11	30	5	43	4.58
	Other	1	0	0	0	6	5	7	4.43
	UAD students	3	2	1	30	35	5	71	4.30
	GCU students	1	2	9	34	48	5	94	4.34
	NU students	1	0	5	21	64	5	91	4.62
	Students summary	6	4	15	85	153	5	263	4.43
	Overall summary	7	5	15	96	183	5	306	4.45
	% overall	**2%**	**2%**	**5%**	**31%**	**60%**		**100%**	

Statement		Options					Mode	Total	Mean
	Choices	**1**	**2**	**3**	**4**	**5**			
11	I understand that the 'facts' in the textbook(s) I use represent conclusions based on actual research that has been done in the past.								
11	Staff	1	5	6	13	18	5	43	3.98
	Other	0	0	1	1	5	5	7	4.57
	UAD students	1	0	10	35	25	4	71	4.17
	GCU students	1	7	16	41	29	4	94	3.96
	NU students	0	1	11	31	48	5	91	4.38
	Students summary	2	8	38	108	107	4	263	4.18
	Overall summary	3	13	44	121	125	5	306	4.15
	% overall	**1%**	**4%**	**14%**	**40%**	**41%**		**100%**	
12	I am aware that the 'facts' in the textbook(s) I use may change with time.								
12	Staff	0	5	5	16	17	5	43	4.05
	Other	0	0	1	2	4	5	7	4.43
	UAD students	2	2	5	24	38	5	71	4.32
	GCU students	2	6	9	39	38	4	94	4.12
	NU students	0	0	6	31	54	5	91	4.53
	Students summary	4	8	21	96	134	5	263	4.32
	Overall summary	4	13	26	112	151	5	306	4.28
	% Overall	**1%**	**4%**	**8%**	**37%**	**49%**		**100%**	
13	In my practical classes the staff help me to understand how experiments are planned and how controls and statistics are used.								
13	Staff	3	4	6	15	12	4	40	3.73
	Other	0	0	2	3	2	4	7	4.00
	UAD students	2	2	8	32	27	4	71	4.13
	GCU students	4	11	23	34	22	4	94	3.63
	NU students	0	7	17	42	25	4	91	3.93
	Students summary	6	20	50	111	76	4	263	3.88
	Overall summary	9	24	56	126	88	4	303	3.86
	% overall	**3%**	**8%**	**18%**	**42%**	**29%**		**100%**	

Statement		Options					Mode	Total	Mean
	Choices	**1**	**2**	**3**	**4**	**5**			
14	After taking a year out to work in industry (or exchange etc) I have a much clearer idea of how research is done.								
14	Staff	1	0	8	8	23	5	40	4.30
	Other	0	0	5	1	1	3	7	3.43
	UAD students	1	1	35	20	14	3	71	3.63
	GCU students	2	2	64	11	15	3	94	3.37
	NU students	3	2	68	12	6	3	91	3.18
	Students summary	6	5	172	44	36	3	263	3.38
	Overall summary	7	5	180	52	59	3	303	3.50
	% overall	**2%**	**2%**	**59%**	**17%**	**19%**		**100%**	
15	I have a clear idea of why statistics are used in most bioscience research.								
15	Staff	1	6	8	15	13	4	43	3.77
	Other	0	1	2	1	3	5	7	3.86
	UAD students	1	6	14	42	8	4	71	3.70
	GCU students	2	10	16	49	17	4	94	3.73
	NU students	1	4	13	45	28	4	91	4.04
	Students summary	4	21	45	137	56	4	263	3.84
	Overall summary	5	27	53	152	69	4	306	3.83
	% overall	**2%**	**9%**	**17%**	**50%**	**23%**		**100%**	
16	I have a clear idea of why it is necessary to use controls in bioscience research.								
16	Staff	2	4	3	15	19	5	43	4.05
	Other	0	0	0	3	4	5	7	4.57
	UAD students	2	4	7	31	27	4	71	4.08
	GCU students	3	5	12	43	31	4	94	4.00
	NU students	2	1	10	27	51	5	91	4.36
	Students summary	7	10	29	104	113	5	263	4.16
	Overall summary	9	14	32	119	132	5	306	4.15
	% overall	**3%**	**5%**	**10%**	**39%**	**43%**		**100%**	

Statement		Options					Mode	Total	Mean
	Choices	**1**	**2**	**3**	**4**	**5**			
17	I have a clear idea of what 'ethical behaviour' means when applied to scientific research (eg honest reporting of data, no plagiarism, ethical behaviour when working with animals or human patients).								
17	Staff	1	4	5	17	15	4	42	3.98
	Other	0	0	0	2	5	5	7	4.71
	UAD students	3	2	6	28	32	5	71	4.18
	GCU students	2	5	8	36	43	5	94	4.20
	NU students	0	0	3	38	50	5	91	4.52
	Students summary	5	7	17	104	130	5	263	4.32
	Overall summary	6	11	22	121	145	5	305	4.27
	% overall	**2%**	**4%**	**7%**	**40%**	**48%**		**100%**	

Table 7: Student and staff research-teaching linkages survey data

The summary data indicate a high degree of uniformity generally among the universities and higher education institutions providing responses, and between students and an admittedly smaller sample of staff from the Biosciences 2007 Education Symposium and Life Sciences Research-Teaching Linkages Project Discipline event. The numbers of honours and master's students responding from the three universities engaging most fully ranged from 71 to 94, together with a small number from three other higher education institutions; this is believed to be a large enough sample size for conclusions to be drawn. Each of the questions had an approximately equivalent response rate across the survey groups.

All respondent groups agreed that lectures attended helped students to understand how bioscience research was carried out. This finding is reassuring from the point of view of introducing students to research methodologies and concepts, and encouraging for their further understanding of research findings and ability to develop critical evaluation skills. All groups agreed that lecturers explained to them how research was carried out. Modal student responses were identical. Similar findings also related to students' perceptions of lecturers' frequent use of research-based examples. The small 'other' group was, however, in strong agreement with this statement. Mean student response data indicated understanding of how bioscience research was carried out, although greater variation was found when modal responses were compared. Staff strongly agreed with this statement. All respondent groups agreed or strongly agreed that students understood the meaning of hypothesis, which is a positive statement with respect to abilities to design experiments and objectively report findings.

All groups strongly agreed with the research publication statement (6) and, overall, with students being encouraged to read primary scientific literature. The second highest percentage modal agreement response (58%) was obtained for this statement, and with being given opportunities to summarise scientific papers.

Respondents overall agreed that the process of writing and formatting scientific papers had been explained to them, although some student ambivalence was evident. There was uniformly strong agreement, however, on students having an appreciation of the sectionalised format of scientific papers. This may be a good surrogate indicator of their deeper understanding of the principles of scientific experimentation. This statement evoked the highest percentage modal response (60% 'strongly agreed') obtained in the survey. All groups of respondents clearly agreed with the use of the research base in textbooks and the notion of these 'facts' not being 'tablets of stone', aligning with the concept of all knowledge being provisional. All groups agreed that practical classes helped students to understand how to plan experiments and use statistics.

While researchers strongly agreed with industry placements or exchanges providing a clearer idea of how research is done, students were either not convinced or regarded the statement as not currently applicable to themselves.

All groups indicated by their modal responses a clear understanding of the need for and use of statistics and controls in bioscience research. All student groups strongly expressed an understanding of ethical behaviours, although the academics' sample was less certain of the extent to which students had fully developed this attribute.

Overall, the combined response data provide evidence for honours and master's students having developed graduate-type attributes relating to understanding the principles of scientific method, the mechanisms and need for appropriate communication methods to disseminate findings, having an appreciation of the provisionality of knowledge, and an understanding of ethical behaviours and approaches. The academics' sample was broadly in agreement with the student responses, although a little less certain of students' understanding of ethical behaviour.

The responses garnered from GCU students were sometimes less assertively in agreement with statements than those from UAD and NU students. The major GCU programme groups sampled concentrate very heavily on practical biomedical science, as part of training for the hospital laboratory and IBMS professionally recognised route, to a greater extent than either of the other two universities included in depth. When the very high practical loadings and technical content associated with the professional biomedical scientist preparatory programmes are borne in mind, the slightly lower extent of agreement for these students becomes less surprising.

Data from MSc Biomolecular and Biomedical Sciences and Pharmacology programmes at GCU taken before and after extended research projects - frequently undertaken in external industrial or research lab settings and lasting up to five months - identified three important changes in modal response to survey statements. After completing master's research projects (n=12), students strongly agreed that they understood how bioscience research was carried out, compared with previous neutrality (n=21). These students more strongly agreed that they understood how experiments were planned, and how controls and statistics should be used. Finally and perhaps most importantly, students having completed their master's research project strongly agreed that they had a much clearer idea of how bioscience research was done than students yet to undertake their project.

These data demonstrate student recognition of the value of an extended research project, and bring the student view into line with the expressed views of academic staff. An extended research project experience would seem to provide greater understanding of how research is done as well as developing other desirable graduate attributes, including employability, through immersion in a working laboratory environment.

4.3.1 Biosciences students and future intentions

Nuala Toman and Douglas Forbes from the Psychology Department in the School of Life Sciences at GCU have provided some interesting provisional findings from biosciences students participating in the Aiming University Learning at Work (AUL@W) partnership project, involving the University of Glasgow, University of St Andrews and GCU.

Biosciences students were the most likely of eight subject discipline groups to have definite employment or further study plans before graduation; they identified a number of aspects of their bioscience programmes which they believed were most useful to them on entering the world of employment (Toman, 2008). From both checklist and freeform comments, biosciences final-year undergraduates felt that their degree programme and the skills and attributes developed therein allowed them to consider specialist careers in their field or wider, more generic graduate-type jobs.

Specific skills or attributes that biosciences final-year undergraduates recognised as having developed included:

- analytical skills
- literature searching, critical appraisal and peer review
- communications and interpersonal skills
- laboratory skills and competences
- subject-specific and specialist bioscience knowledge
- report and academic writing skills
- confident presentation skills
- independent and team working abilities
- numerical skills
- ability to prioritise and work to deadlines
- sense of discipline
- science interests
- IT skills.

Of the biosciences graduates responding to the AUL@W survey, 77.5 per cent felt that their degree would be useful to them when they entered employment (compared with 69% of total participants), while 52 per cent of biosciences graduates felt their degree had prepared them well for entering the labour market (compared with 43% of total participants) (Toman, 2008; AUL@W, 2008).

Current provisional findings from the AUL@W partnership suggest that biosciences graduates face lower levels of uncertainty regarding their employment future than in other disciplines. Work-related learning activities have had a positive impact on biosciences graduates' skills development, assisting them in securing and performing well within employment and enhancing their understanding of the relevance and usefulness of their degree and the graduate attributes developed within it (Toman, 2008).

4.3.2 Destinations of life sciences graduates

A number of sources have reported extensive variation in data relating to the apparent destinations of life sciences graduates. The 2001-03 Biochemical Society surveys of programmes with a significant amount of biochemical content found that at least 58 per cent of first degree and 64 per cent of MSc graduates pursued a biochemically relevant career (Biochemical Society, 2004). The forthcoming National Subject Profile for Higher Education Programmes in Microbiology, and National Subject Profile for Higher Education Programmes in Biochemistry, using Higher Education Statistics Agency first graduates' destination data for 2004-05, suggest that 86 per cent of graduates' first destinations are in life sciences-relevant occupations (Bioscience Subject Centre, 2008a, 2008b). Regardless of their first or subsequent career destinations, however, it seems clear that life sciences graduates' exposure to research as part of their learning experience prepares them well for future employment.

5 Conclusions

5.1 Specific points about the research-teaching nexus

A wide range of activities linking research and teaching and leading to enhanced graduate attributes are being undertaken across the life sciences discipline in Scotland and further afield. There is much sharing of common practice across the sub-disciplines of the life sciences, including sharing of ideas through collaborative events, conferences and workshops at the level of individual practitioners. This is clearly enhanced by the work of Subject Centres of the Higher Education Academy (eg Bioscience Subject Centre, Health Sciences and Practice Subject Centre), learned societies and professional bodies within the Scottish higher education community. All of these sources, and many others, contribute to meeting the requirements of the life sciences relevant subject benchmarks.

However

There was little evidence of a systematic approach to developing research-teaching linkages among the Scottish higher education institutions contacted in this project, with the possible exception of an innovative learning space (Whitespace, University of Abertay Dundee) recently opened but not yet fully used by life scientists. Similarly, there was little evidence of any institution, department or programme systematically monitoring or developing research-teaching linkages to enhance graduate attributes. Informal mechanisms to enhance research-teaching linkages were commonly undertaken within a module, often driven by the interests of enthusiastic individuals. Feedback on the success of such enhancements tended to be anecdotal, with little systematic support for highlighting the effectiveness of these interventions.

There is a clear need for higher education institutions to consider formalising mechanisms to encourage wider spread of good practice in promoting research-teaching linkages to enhance the attributes of life sciences graduates. Such mechanisms might include giving named key staff responsibility for monitoring and encouraging the development of research-teaching linkages at departmental or institutional level.

Relatively little work appears to have been undertaken as yet on departmental or institutional research-teaching linkage strategies. This area requires further enhancement in the future.

Staff and students surveyed were generally in broad agreement about the value of research-teaching linkages in developing understanding of the research process, scientific method and professional behaviours.

5.2 General points

A considerable breadth of life sciences provision is available to students within Scotland. This diversity reflects differences in mission and aspects of economic need across the country.

The Scottish life sciences sector needs to continuously develop new knowledge and understanding to remain competitive in the global marketplace.

Life sciences programmes in Scotland consistently encourage students to understand the process of science, the provisionality of knowledge, and the potential economic and societal impacts of applying scientific knowledge in innovative and new ways. Scottish life sciences provision prepares graduates not just for research and discipline-based employment, but also for careers as global citizens in a wide range of sectors valuing a scientific approach and strong sense of enquiry.

Biosciences graduates surveyed believed that their degree would be useful to them in employment. Provisional AUL@W project data suggest that they are better prepared, in planning terms, than students of other disciplines.

Senior staff believed that approximately 40-60 per cent of Scottish life sciences graduates were likely to become practising life scientists.

Minor differences were observed in students' responses from different higher education institutions, which may reflect differing emphases in particular programme objectives.

The Scottish higher education institutions surveyed in this project linked research to teaching through a variety of mixed-mode activities. These included, in descending order of relative importance, research-based, research-led, research-tutored and research-oriented teaching, with an increasing amount of research-led activity in honours and master's years.

Senior life sciences teaching staff identified 16 research-related graduate attributes, which mapped closely onto the Theme identified graduate attributes. The three most important research-related attributes for life sciences graduates were considered to be: an ability to critically appraise and synthesise novel concepts; developing self-confident achievers; and ability to work flexibly, independently and as part of a team. Greater understanding of concepts, advanced research method, and technical and project management skills were generally expected of master's level graduates.

5.3 Contact with the Higher Education Academy

While most higher education institutions were aware of and had some contact with Higher Education Academy Subject Centres, senior staff surveyed believed that strengthening these interactions further was desirable. Little appreciation of the role of Centres of Excellence in Teaching and Learning was evident.

5.4 Practical work, projects and placements

There is considerable evidence of the value to all life sciences students of exposure to a range of team and/or group-based exercises with a research component, such as field courses, in preparation for further study or future employment. This aligns well with the recent revision by QAA of the biosciences benchmark statement, for example, and could be useful to departments wanting to accumulate evidence in support of retaining such exercises in resource-constrained times.

Senior staff considered that research projects and placements provided valuable experience and preparation for future employment. Most higher education institutions include research skills, project preparation or mini-project activities either embedded within programmes or as dedicated modules. Fieldwork opportunities were also considered desirable for future employability.

Regarding placements, staff were more strongly convinced of their value than students who were yet to undertake them. Students who had undertaken extended research projects were equally convinced of the value of placements or extended projects as staff respondents.

A wide range of innovative, exciting and stimulating case studies to enhance research-teaching linkages have been identified and promoted during this project. They are often highly imaginative and frequently engender a strong sense of enquiry in students.

Higher education institutions recruiting large numbers of international students should take care to ensure that adequate development of laboratory skills and experience, together with understanding of the scientific process, is built into programmes.

Senior life sciences staff recognised the 'Fresh Talent' initiative as an attractive feature for international students considering coming to Scotland to study.

6 Recommendations

A wide range of recommendations emerged or were amplified during the course of this project. While most are applicable to individual practitioners, selected ideas can be combined for integrated use at departmental or institutional level, perhaps as part of a formal mechanism to monitor and develop research-teaching linkages at these levels.

6.1 Recommendations for departments

Institutions should consider requiring the development of departmental-level strategies for linking research and teaching within programmes (Healey and Jenkins, 2006), including student understanding of the meaning of research and the practical competences to carry out research (Jenkins, 2004).

Encourage departments and institutions to systematically engage in linking research and teaching. Such a systematic approach is more likely to lead to enhanced productivity than a purely piecemeal approach with uptake left to chance by enthusiasts alone.

Integrate formal research-teaching linkages into policies and periodic reviews in your department or institution.

Remember that students benefit from and generally value learning opportunities in a research-based environment (Hunter et al, 2007). This can take many forms, including experience in research-group labs, fieldwork, simulations or modelling using research data in bioinformatics suites, research-based businesses or studio-based work with practitioners (see McLaughlin, Jackson, Paterson, Tatner and Whitespace case studies in section 4.2). Careful structuring of such opportunities can not only better prepare graduates for employment or further study, but also reinforce a departmental research-based culture (Wuetherick et al, 2007).

Conduct an informal review of current research-teaching linkages practice across a department or institution. Publicise the findings and celebrate examples of innovative or particularly effective practice. Follow up with periodic encouragement to engage more fully with the research-teaching linkage agenda, using for example the Enhancement Themes website and Bioscience Subject Centre/Health Sciences and Practice Subject Centre as sources of good practice examples to be tailored to individual needs.

For those departments with a comprehensive workload model, consider widening the definition - and workload model recognition - of what is research to include activities linking research into teaching.

For departments without a comprehensive workload model, consider introducing a simplified model using a matrix approach acknowledging time spent developing research-teaching linkages and activities (Healey and Jenkins, 2006).

Consider using some of Boyer's curricular-related interventions to promote research-teaching linkages, including:

- encouraging a research-based approach to learning among students
- inquiry-based learning in year one
- building on the successful foundations of early years linkages
- providing a research-based capstone experience, such as a practical project or immersive industrial experience (Boyer Commission, 1998).

Offer sabbaticals specifically for staff agreeing to develop innovative research-teaching linkages learning materials. Celebrate the new outputs and highlight student feedback to it.

Ask a local life sciences company to sponsor annual awards for innovative research-teaching advances.

Encourage your departmental contacts with the biosciences, health practice and other relevant Subject Centres, CETLs, learned societies and professional bodies with education groups to periodically report on research-teaching linkage enhancements at staff meetings, or via e-communications. For example, host a Subject Centre research-teaching linkages development event or one-day conference.

Stimulate student learning from research practitioners by having researchers in residence sharing study space with students, perhaps as drop-in centres or organised zones, such as Whitespace. Publicise these opportunities and make them available to students from other departments, or even the public too.

Sponsor a student society in your department to run a series of evening research seminars, café-style debates or discussion sessions bringing to life controversial or innovative research topics from outside your department.

Systematically promote a wide range of research-teaching linkage activities over an extended period in order to gain enhanced student experience-based rewards, increased employability and enhanced departmental reputation.

Persuade your department's technical staff to spend a few weeks during the summer months working with relatively inexperienced academic staff to develop innovative teaching materials bringing research ideas to teaching.

6.2 Recommendations relating to individual teaching staff

Consider encouraging greater engagement in the research-teaching linkage agenda by embracing a wider definition of advanced scholarship, as proposed by Brown (2003), in which critical re-evaluation and transfer of existing knowledge are valued alongside the creation of new knowledge, rather than more restrictive definitions (Boyer, 1990; Wood, 2003). Such an approach is likely to be favourably received by businesses seeking educational partners for knowledge transfer developments, and can also enhance income streams.

Encourage star researchers to engage in early years teaching, bringing a flavour of their internationally excellent research to all students. This can help students to develop a better appreciation of the significance of progress made, encouraging a sense of inquiry and the ability to assemble concepts and knowledge in new ways.

Encourage staff buy-in to enhancing research-teaching linkages by explaining why the topic is valuable and important to the desirable attributes needed by graduates in today's competitive marketplace.

Departments should consider increasing the use of research-based approaches to teaching, as used for example to gradually develop understanding and skills in microbiology by repeated reference to host-pathogen interactions within a series of modules (Marbach-Ad et al, 2007) over successive years.

Use your latest research findings in tutorials to verify your conclusions, or test alternative research hypotheses in real time. This approach can be especially useful for bioinformatics or systems biology students.

Write up your most successful research-teaching linkage innovations for publication in science education journals.

Run regional swap-shops for research-teaching innovations with other departments in your institution, or sister institutions regionally.

New academic staff should be encouraged to conduct research skills audits for key programmes, perhaps as part of work towards a higher education teaching award accredited by the Higher Education Academy.

6.3 Recommendations relating to students

Stimulate a positive sense of enquiry in students through the use of innovative problem and field-based learning in early years modules (see Chamberlain case study in section 4.2). Once acquired, this sense of enquiry can foster interest in research-type questions throughout the undergraduate learning experience, producing better graduates and enhancing an institution's reputation with prospective employers.

Develop students' scientific reading and critical analysis skills by encouraging early-years students to read, summarise and discuss recent topical scientific papers or reports (see Willmott case study in section 4.2, and Willmott et al, 2003).

Students should be encouraged to be independent learners (Hattie and Marsh, 1996), for example by involvement in constructing their own experiments and knowledge base, and by reinforcing the relationship between research and teaching further using inherited protocols, progress reports or data sets from previous sessions and mini-conference presentations with successive students (see Huxham and Langan case studies in section 4.2, and UCL case study in Jenkins et al, 2007).

Use the competitive nature of leading research to involve and motivate student learning, for example in research-based group mini-projects, to produce better scholars (Glassick et al, 1996, and see Assender case study in section 4.2).

Encourage research-based consultancy-type activity in groups, perhaps in research skills modules, as preparation for final-year research projects.

Instigate competitive research internships for students in the pre-final year summer vacation, along the lines of the learned society summer studentships. Insist on written applications from students highlighting why they believe they would benefit from immersion in a particular research group, and run a mini-conference of presentations or posters from the interns after the vacation, with a substantial prize for the best research-based communication as judged by peers (see learned society studentships and Fraser case studies in section 4.2).

Sponsor an afternoon of 'where are they now' talks from former students hand-picked for their research or industrial roles to present to final-year students on how they got their jobs and how their research experience has helped them in their career development.

Offer an annual prize for final-year students to nominate the academic staff member who has done most to foster a sense of enquiry in the learning experience. Ask the prize winner to present on their innovation linking research with teaching to a staff meeting.

Make more effort to encourage undergraduates' attendance at research seminars. Make space in a module for hot topics and student discussion groups based around recent research seminars.

Ask all staff to be available for two hours during student induction week for students to find out about three examples of innovative research progress and how it may influence a discipline in the future.

Bring forward careers advice, professional studies or research methods modules in your programmes.

Encourage final-year students to submit details of their projects for publication in undergraduate research project journals such as Origin or Bioscience Horizons (see Knight case study in section 4.2).

Involve students as paid field workers to gather data, input new information into databases or act as proto-consultants for analysis of new results.

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8 Appendix: Activities undertaken

- Developing Enquiring Minds - Napier University, Edinburgh, March 2007
- Scottish HE Biology Teachers Meeting - University of Glasgow, June, 2007
- Biosciences 2007 Education Symposium: Life Sciences Research-Teaching Linkages - Scottish Exhibition and Conference Centre, Glasgow, July, 2007
- Enhancing Life Sciences Graduate Attributes Using Research-Teaching Linkages - Glasgow Caledonian University, February 2008
- Structured interviews
- Student survey
- Project information sheet
- Consent confirmation
- Biosciences Subject Centre website on research-teaching linkages
- Enhancement Themes conference workshops (x5)
- Enhancement Theme update meetings (x6)

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