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Enhancing practice

Research-Teaching Linkages: enhancing graduate attributes

Information and Mathematical Sciences

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Research-Teaching Linkages: enhancing graduate attributes

Information and Mathematical 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 until June 2009 by Professor Kenneth Miller, Vice-Principal, University of Strathclyde and now by Professor Andrea Nolan, Senior Vice-Principal and Deputy Vice-Chancellor, University of Glasgow, 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.

Bill Harvey

Dr Bill Harvey
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
Senior Vice-Principal and Deputy Vice-Chancellor, University of Glasgow

1 Executive summary

This report examines the experiences of academic staff and students within the information and mathematical sciences subject areas. Experiences of staff and students have been summarised in the form of case studies and snapshots of current practice that demonstrate how the student experience and graduate attributes can be enhanced by activities that link research and teaching.

Key findings from the investigation were drawn from the questionnaire responses, surveys, published literature, workshops, case studies and interviews. Three themes were identified, and we make six recommendations:

1.1 Themes

- One key benefit of linking research and teaching is to enthuse a future generation about the excitement of exploration; understanding the research process itself is as important as comprehending the detail of the discipline's current cutting-edge research, which may be either too dynamic to keep up with, or too cumulative in nature.
- It is important to demystify research at an early stage and this can be done through exposure to what excites teachers about their research from day one. Direct student participation in research projects is most common at final-year undergraduate and taught postgraduate levels. It is particularly appropriate to applied subjects.
- Students are particularly excited by research that can be related to an application or real world problem. It can be inspirational and aspirational for some, with less tangible but still valuable benefits to others, even where it is not directly motivating for all students.

1.2 Recommendations

- Learning and teaching directors and programme coordinators could examine the range of identified graduate attributes to consider how programmes should be designed to enhance a richer set of attributes than those most commonly quoted (for example, critical understanding and ability to analyse problems).
- Students at all levels should encounter research processes and practices, even if the subject content itself is not related to contemporary research.
- Students should have a broader understanding of the academic community they inhabit, to ensure that they understand the nature of research and to help make informed decisions about their future careers.
- Where possible, teaching content should be related to 'real world' examples, to assist students to relate concepts to their everyday experiences and to excite them with the prospect of research involvement and gaining research skills. Such examples should be genuinely and proportionately integrated within programmes.

- Departments should emphasise to their students the importance of being able to stay at and to contribute to the forefront of knowledge. This corresponds to the need to demystify research to students; that is, to convey to them that not all research is concerned with obtaining a PhD, but is regularly expected within most working environments.
- Ensure teaching staff are aware that introducing research or research methods into their teaching practice does not necessarily mean introducing their own specialist area of knowledge and should include subject-relevant research skills.

1.3 The way forward

Research is clearly seen by most staff and students as an important part of the learning experience if it is appropriately placed. Academics in some fields and teaching at some levels have pointed out that research linkages are sometimes neither appropriate nor practicable, but they universally acknowledge the motivational potential where they are. We hope that our recommendations will prove helpful in the future development of effective research-teaching linkages in the subject areas covered. There will never be 'one size fits all' rule solutions, and it will always be likely that at least some teachers will be teaching outside their research field. We believe that a pragmatic, but systematic approach to thinking through where and how research and teaching can be most appropriately linked is the best way forward. The will and demand is clearly there, and by and large the practice base isn't broken; the main aim therefore should be to raise awareness of the issues and to provide support for innovative developments at department as well as individual level. It is interesting to speculate about the extent to which the perceived status of teaching in relation to research might change as linkages become tighter and clearer to academic staff and management. The next Enhancement Theme, Graduates for the 21st Century: Integrating the Enhancement Themes, will no doubt prompt yet more developments in this area.

1.4 Conclusions

It is clear from our brief study that research is alive and well around Scotland as a component, exemplar and even driver for teaching. The diversity of opinions and practices which has emerged is healthy and to be encouraged and we see no need to promote a uniformity of approach. We would, however, suggest that where this has not already happened, departments should give careful and systematic consideration to the roles that research can play in their teaching and learning, and to strategies they might adopt to further enhance related graduate attributes throughout the degree. What is clear is that where research is appropriately and effectively embedded in the curriculum, its effects are overwhelmingly positive, contributing significantly to enhancing the student experience and to the breadth and depth of student learning.

2 Introduction

Throughout the world, research and teaching are the main activities of higher education; to that extent, research and teaching are inextricably linked and many institutions, particularly in the UK, claim that research drives their teaching as well as informing it. The extent to which this is true varies widely between institutions and between disciplines, and depends on the level at which the teaching is taking place. For example, a postgraduate course in computer vision is much more likely to have significant opportunities for research-teaching linkages than an undergraduate module in discrete mathematics.

Whatever the reality in any given discipline in any given university, it is generally accepted that teaching benefits from being carried out by people who have a strong interest and an active engagement in the topic in question. This is universally true across education and training, where the value of practical experience is recognised as a strong driver for teaching quality and learner engagement.

In this study, for the Research-Teaching Linkages Enhancement Theme, we set out to examine the extent and nature of research-teaching linkages in information and mathematical sciences in higher education in Scotland, with a view to mapping the area and disseminating best practice in line with Scotland's Enhancement Themes.

2.1 Background

Theme

The overall aim of the Enhancement Themes is to provide a means of identifying and building on 'good practice' to improve the student experience in Scottish higher education. The Enhancement Themes are intended to encourage academic and support staff and students to share current good practice and collectively to generate ideas and models for innovation in learning and teaching.

The aim of the Research-Teaching Linkages: enhancing graduate attributes Enhancement Theme is to look at how links between research strategies and activities can best support the student learning experience in ways that can enhance learner achievement of research-type attributes. Examples of the type of attributes and skills to be considered included:

At undergraduate level

- Critical understanding.
- Informed by current developments in the subject.
- An awareness of the provisional nature of knowledge, how knowledge is created, advanced and renewed, and the excitement of changing knowledge.
- The ability to identify and analyse problems and issues and to formulate, evaluate and apply evidence-based solutions and arguments.
- An ability to apply a systematic and critical assessment of complex problems and issues.

- An ability to deploy techniques of analysis and enquiry.
- Familiarity with advanced techniques and skills.
- Originality and creativity in formulating, evaluating and applying evidence-based solutions and arguments.
- An understanding of the need for a high level of ethical, social, cultural, environmental and wider professional conduct.

At master's level

- Conceptual understanding that enables critical evaluation of current research and advanced scholarship.
- Originality in the application of knowledge.
- The ability to deal with complex issues and make sound judgements in the absence of complete data.

One sector-wide project and nine disciplinary projects were commissioned. This report is one product of the project in the area of information and mathematical sciences, including the subject areas of computing science, mathematics, statistics and related areas. It describes a set of effective and practical ways in which research-teaching linkages can be used to support the enhancement of learner achievement of 'research-type' skills and attributes. It is hoped to also consider rather more: how research content and inspiration can lead to better learning across the board, for example, through bringing students to the boundaries of knowledge, encouraging teacher enthusiasm for the subject, and identifying first-class examples and exemplars of engagement.

2.2 Approach and methodology

The aim of the Information and Mathematical Sciences project was to identify, share and build on good and innovative practice in utilising research-teaching linkages to enhance the achievement of graduate attributes. This included identification of:

- the graduate-type attributes valued at discipline level
- approaches taken to make best use of research to enhance the achievement of such graduate attributes
- how best to use research-teaching linkages within programmes
- how best to use research-teaching linkages to inform the process of learning about research-type processes.

Information for this report was gathered from a range of sources using a number of methods, principally literature review, desk survey, workshop, staff and student questionnaire, and interview.

Published literature

Published literature provided a rich source of information about national and international initiatives to promote research-teaching linkages. Nationally, the work of Jenkins (for example 2005, 2006, 2007, and 2008) and Healey (2005) prompted further investigation of what is meant by 'research-teaching nexus', and provided excellent examples of case studies across other disciplines. Internationally, the work in Australia by Professor Kerri-Lee Krause of Griffith Institute for Higher Education has been inspirational. The associated work of the Teaching Research Nexus project (TRN) is recommended in particular.[1]

Issues raised and/or being addressed by the Higher Education Academy (HEA) Subject Centres - Information and Computer Sciences (ICS) and Mathematics, Statistics and Operational Research (MSOR) - were directly relevant: HEA-ICS and HEA-MSOR were very supportive of the team's efforts to gathering information and explore related issues.

Publications from professional bodies and societies were reviewed to identify discipline-specific graduate attributes already recognised formally: the British Computer Society and the Institute of Mathematics and its Applications. QAA's subject benchmark statements for *Computing* (QAA, 2007a) and *Mathematics, statistics and operational research* (QAA, 2007b) were consulted to identify particular skills and understanding which might be expected to be demonstrated at undergraduate and master's postgraduate levels.

Desk study

A desk study was performed to identify programmes and teams to be contacted separately to gain examples of practice. Reviews were made of web-based public information about undergraduate and taught postgraduate programmes offered by institutions in Scotland: prospectuses, websites, course descriptions and module descriptions were examined. Nuffield undergraduate student research bursary awards and Biotechnology and Biological Sciences Research Council (BBSRC) student vacation bursary awards were reviewed.

Questionnaires and interviews

The project team contacted heads of departments and deans/assistant deans teaching and learning across Scotland to inform them of the project. Survey questionnaires were then emailed to departments to discover which graduate-type attributes were valued, and gain insights into approaches being used, and the success thereof, that linked research and teaching in ways that might enhance these attributes. Separate questionnaires were issued to students and to staff for online completion (see Appendices 7.1 and 7.2). The former was based upon the survey developed at the University of Gloucestershire in 2002 by Mick Healey, Fiona Jordan and Chris Short. The latter was based upon a questionnaire originally developed by Mick Healey and subsequently adapted by Maria Fasli (University of Essex) and Su White (University of Southampton). In each case, respondents were asked if they would agree to a follow-up contact, either by email, telephone or face-to-face interview. Those staff and students who responded positively to this request were contacted again, and a set of interviews conducted to probe elements of their questionnaire answers further.

The framework for student interviews was based upon work by Healey and by Robertson and Blackler (2006). It probed what students think research is, how visible it is to them (where it is located, who engages in it), how much they knew about the research in their department, if research is for **all** students or only for some, and what opportunities they have for their own research. Appendices 7.1 and 7.2 provide links to the survey instruments.

[1] Available at: http://trnexus.edu.au

Workshop

Delegates who attended the Research-Teaching Linkages: Enhancing Graduate Attributes Theme Outcomes Event, held in Edinburgh on 6 November 2008, participated in a mini workshop to discuss and debate the Enhancement Theme. This provided useful confirmation for the project team of one emerging theme for the discipline, as summarised by one delegate: '[the workshop] set out very clearly the tensions between an orientation of enquiry as an approach to student learning and research-led teaching of mathematics'.

Case studies

The project team gathered information as described above, making every effort to use as wide a net as possible to catch as much information as possible. The information here reflects the responses received, originating from many higher education institutions and including a number from Scotland. The team selected a number of examples from which case studies were developed and these are presented in section 4. The selection represents different categories of research-teaching linkages, different subject areas, and different levels of undergraduate and postgraduate study. Where possible, a common format was adopted for the case studies, including contact details for the source, course details, a summary of how research and teaching are linked, identification of relevant graduate attributes developed, and feedback obtained. These case studies and others are also available on the project website[2] and typically include more detail than could be presented here.

2.3 Outline of the report

Section 3 of this report addresses the fundamental issues:

- definitions of 'research' in this context
- what 'research-teaching nexus' applies to information and mathematical sciences
- which graduate attributes are relevant to these disciplines.

Section 4 outlines main findings from the project in terms of the student experience and the academic experience. It concludes with a set of case studies that illustrates a range of different approaches identified to link research and teaching to enhance graduate attributes. The case studies are categorized according to their focus (learning through research content, learning about research processes, and sponsored research studentships) and level (undergraduate to postgraduate).

Section 5 considers issues identified in the project, giving particular attention to the challenges to enhancing graduate attributes further. Section 5 concludes with the team's recommendations for the subject disciplines and suggestions for next steps.

[2] www.computing.dundee.ac.uk/rtl

3 Research-teaching nexus and graduate attributes

Information gathered from the various higher education institutions, the Higher Education Academy, and other bodies such as the Nuffield Foundation show that a most stimulating diversity of research and teaching connections exists across the UK. Accompanying the healthy diversity of practice is a matching range of opinions relating to possibilities, benefits and constraints. This section introduces further background as context for the findings presented later in section 4.

3.1 What is meant by 'research'?

Three categories of research were identified by the Organisation for Economic Co-operation and Development (OECD) in 2002:

- basic (without any particular application or use in view)
- applied research (directed primarily towards a specific practical aim or objective)
- experimental development (directed to producing new materials, products or devices, to installing new processes, systems and services, or to improving substantially those already produced or installed).

Boyer (1990) describes four forms of scholarship: discovery, integration, application and teaching. The first of these is what is commonly considered research: 'knowledge for its own sake, to freedom of inquiry and to following in a disciplined fashion, an investigation wherever it may lead'. Integration is scholarship which transcends disciplinary boundaries. Application of knowledge relates to the interaction of theory and practice, as in a professional context. Teaching is judged to be a combination of intellectual stimulation in which the educators encourage 'graduate attributes' and in which educators are themselves learners.

Given the range of subject areas included in the project (computing, computing science, mathematics, statistics and related areas), the project team considered that a broad definition of research was appropriate in the circumstances of this project, encompassing the scope of both of these. Discussions with academics throughout the course of the project confirmed the validity of applying a broad definition. Interviews with students revealed a limited understanding of 'what is research'. Details of students' perceptions of research are summarized in section 4.2. More problematic than a definition of research is an understanding of the phrase 'research-teaching linkages'.

3.2 Research-teaching linkages

Figure 1 presents the model of the relationship between teaching and research by Healey (2005) which was used initially to prompt discussion about research-teaching linkages:

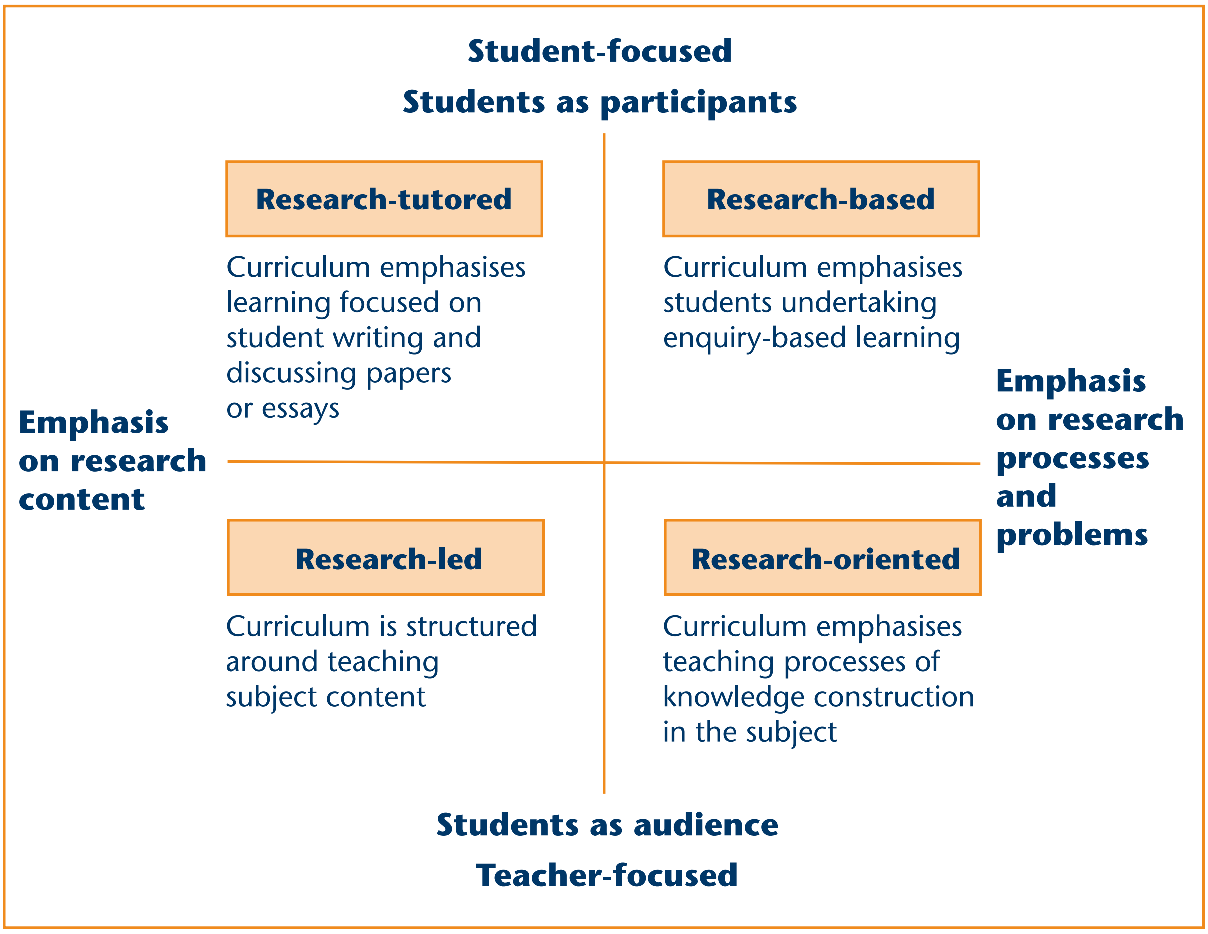

Figure 1: Curriculum design and the research-teaching nexus. Source: Healey (2005, p 70)

White and Irons (2007) were able to apply an analysis of Healey's different research perspectives to the computing disciplines:

Research-tutored eg: classic tutorial structure - typically realised as small group supervisions in the computing disciplines • Supervision class where students are taken through recent publication(s) and are invited to discuss/debate their understanding of the activity. • Possible at each level of study, but for organisational/management reasons may only apply in particular years of study.	**Research-based** eg: authentic research activities, inquiry/enquiry based learning • Students are given a task which requires them to use and develop skills (practice and understanding) which are equivalent to those used in authentic research. • May be practised at any level of study, but may be more typically found at advanced levels.
Research-led eg: curriculum follows current research • Most typically advanced-level options. • Can also be a component of teaching at any level, where students are exposed to leading-edge research concepts/developments in the field of study.	**Research-oriented** eg: teaching processes of knowledge construction • Typically found in capstone courses where students undertake some research activity, individually or as a group. • However, students at less advanced levels may practice this as part of research-based activities.

Figure 2: Healey's different research perspectives in the computing disciplines
Source: White and Irons (2007, p 5)

Nonetheless, a number of respondents to questionnaires and in interviews observed that they did not find the distinctions between these four categories intuitive. A number of alternative models were considered:

- the four categories originally identified by Griffiths (2004): research-**led** (subject content), research-**oriented** (inquiry skills and research ethos), research-**based** (curriculum based around inquiry-based activities) and research-**informed** (inquiry into the teaching and learning process itself)
- three categories identified by Brew (2006): research-**enhanced** teaching (teaching informed by staff research), research-**based** teaching (experience and conduct research and develop research skills) and **scholarship** of learning and teaching (research to understand learning and teaching)
- further elaboration by Jenkins (2007): learning **about** others' research, learning **to do** research (research methods), learning **in research mode** (enquiry-based learning) and **pedagogic** research (enquiring and reflecting on learning).

Jenkins' identification (2007) of the need for a 'language' to help us examine what we do ultimately led the project team to distil these categories into the most natural, simple grouping possible:

- teaching and learning through research content
- teaching and learning about research processes.

These categories form the basis of the groupings of case studies given in section 4.

3.3 Research-teaching nexus in information and mathematical sciences

Information gathered by the project team identified a quite fascinating range of examples of research-teaching linkages across the subject areas. Unsurprisingly, distinct variations in engagement with research were also found within subject areas. Different proportions of examples in section 4 were drawn from the different subject areas. Information and computing sciences proved to be a rich source of examples of teaching and learning about the subject through research (section 4.3). MSOR and ICS provided a broadly similar amount of case studies in the category of teaching about research processes (section 4.4). A final case study category is provided in section 4.5 - sponsored research studentships: here, the richest source of examples came from the subject area of mathematics.

One explanation for this relates to the position of the different subjects in a continuum from basic research through applied research to experimental research. At the 'pure' end of the continuum, research follows the very linear model of scientific discovery, technology development and subsequent commercialisation. Pure mathematics and pure computer science could be placed at the opposite end of the continuum from interaction design and information science, with computing as a subject placed somewhere midway.

For pure mathematics, a significant amount of knowledge must first be discovered and then understood before being applied. Described as 'the cumulative nature of MSOR', this is summarised succinctly in the MSOR subject benchmark statement:

> 2.1 The subjects included in MSOR are largely cumulative: what can be taught and learned depends very heavily, and in considerable detail, on previously learned material. This applies to MSOR very much more than to many other disciplines. An MSOR programme must be designed to follow a logical progression, with prerequisite knowledge always taken into account. Advanced areas of pure mathematics cannot be treated until corresponding elementary and intermediate areas have been covered (QAA, 2007b).

Similar comments have been made about pure computer science:

> One of the most difficult challenges is to incorporate research at the undergraduate level. This is due to the nature of Computer Science being a hard discipline: there is more of a hierarchical and incremental building of knowledge, and hence students need to have the necessary background on concepts and principles before they can engage in research-based activities and are able to understand the results of research. This makes it difficult to incorporate research findings or one's own research in undergraduate courses, in particular in the first two years' (Fasli, 2007).

Robertson (2007) reported such disciplinary variations in her study in New Zealand, summarising the variation as shown in figure 3.

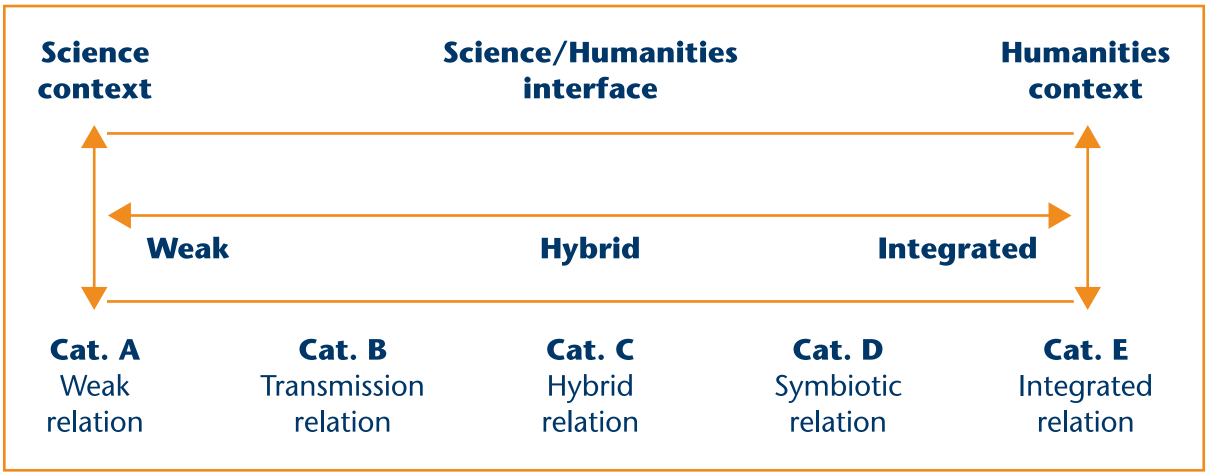

Figure 3: Variation in experience of the research/teaching relation at undergraduate level: a disciplinary perspective. Source: Robertson (2007)

Robertson judges that Category A disciplines have weak relations between teaching and research: 'Teaching is focused on the foundational disciplinary knowledge that students must acquire, while research occurs on a quite different and unrelated plane'. Category B disciplines are characterised by the transmission of research information to students, whereas Category C disciplines are those in which undergraduate students might participate in research or inquiry. In Category D disciplines, teaching and research are strongly related, whereas in Category E disciplines they are inseparable.

Responses received in this study suggest that pure mathematics programmes could be categorised at the Category A area (weak relation between research and teaching) whereas applied programmes such as media design could be categorised in the Category C or D areas. Certainly, programmes of study that focus on pure science feature less in the case studies than programmes that take an applied focus. It was typically more common to link research and teaching at undergraduate level if teaching is about ongoing (rather than historical) research, and where 'real world' applied research predominated.

Workshop

The Research-Teaching Linkages: Enhancing Graduate Attributes Theme Outcomes Event on 6 November 2008 was used to consider graduate attributes and the types of research-teaching linkages possible in particular subject areas. This event provided an early opportunity to present and test the model of figure 3 in the context of ICS and MSOR. Two workshops were held with academics and heads of teaching and learning from a wide variety of disciplines.

A 'snapshot' diagram of the differences between subjects in the discipline was used as an illustration of the model, and formed the basis of the discussions held. At the left-hand side of the scale, bringing research practice into teaching is challenging; at the right-hand side, research on the part of the students is actively encouraged. The left-hand side represents a very linear mode of teaching, whereby students begin with the basics before they are able to move on to learning what contemporary research within their field is and about the techniques within this field.

Feedback from delegates was helpful and ranged from surprise that the mathematical and information sciences were as different as depicted, to confirmation of our initial understanding: that it is difficult to introduce research into mathematics teaching at an early level, both from a practical point of view (in that many mathematics courses at first and second year are 'service' elementary maths courses provided to both non-maths and maths students) and as a result of the cumulative learning nature of the discipline. One delegated commented that:

> '[the workshop] set out very clearly the tensions between an orientation of enquiry as an approach to student learning and research-led teaching of mathematics'.

On the other hand, a delegate from the arts, whose culture is closer to the media design end of the spectrum, noted that the problem her discipline has to overcome is that 'it doesn't have a left side'; in other words, the graduate attributes that are attained from a research intensive-based course do not necessarily include those important attributes that can be gained from courses identified on the left-hand side.

3.4 Graduate attributes

QAA subject benchmark statements

Key influences upon the identification of important graduate attributes are QAA and relevant professional bodies and societies. QAA subject benchmarks statements 'define what can be expected of a graduate in terms of the abilities and skills needed to develop understanding or competence in the subject'.

Undergraduate computing
The QAA subject benchmark statement for Computing highlights the importance of research in the undergraduate computing curriculum:

> In a HEI offering honours degrees in computing, it would be expected that: ...learning is enriched by appropriate underpinning, current research, industrial applications and the development of transferable skills (QAA, 2007a, section 5.2).

Section 6.5 then identifies six statements describing the typical standard that an honours-level student studying computing should achieve (see Appendix 7.3 of this report).

Undergraduate mathematics
While the QAA subject benchmark statement *for Mathematics, statistics and operational research* emphasises the cumulative nature of the subjects, there is recognition that research interests of academic staff can influence the curriculum:

> 2.6 The diversity of provision is invaluable...
>
> 2.8 An important further source of diversity is, in many cases, the influence of the research and professional interests of the academic staff. While undergraduate programmes in MSOR are not expected to reach the frontiers of knowledge, it is a stimulating experience for a learner to be taught a subject by someone who is an active researcher or professional in the field. The choice of material presented in MSOR programmes, whilst mainly determined by its educational value, will nevertheless often be influenced in detail by the research and professional interests of the academic staff. (QAA, 2007b, section 2)

Thereafter a set of graduate attributes is presented to describe what is expected of a typical level graduate of mathematics, statistics and operational research (see Appendix 7.3 of this report).

Postgraduate

No master's level subject benchmark statement exists for computing. For mathematics, an annex to the 2007 subject benchmark statement provides further information concerning integrated master's programmes in mathematics and refers to awareness of current research, and knowledge and understanding of techniques for mathematical research:

> MSOR is a very advanced and highly developed subject and is being continually expanded by further advances in research. Many master's level programmes will nonetheless be informed by current research activity. Graduates from MMath programmes will have demonstrated knowledge (including some awareness of current research problems) and understanding that is founded upon, extends and enhances that typically associated with the bachelor's level. That knowledge and understanding, and the general techniques for mathematical research that will have been acquired, will provide a basis for originality in developing and applying ideas (QAA, 2009, section A15).

Statements of the expected abilities of a MMath graduate reinforce the research context (see Appendix 7.3 of this report).

Professional bodies and societies

The British Computer Society

Similar expectations of undergraduates are indicated by the professional body for Information Systems in the UK, the British Computer Society (BCS). Programme accreditation guidelines provide details of expectations for programmes leading to Certified IT Professional (CITP), Chartered Engineer (CEng) or Chartered Scientist (CSci) registration (BCS, 2007). Key criteria in the guidelines include the following for CITP:

- programmes are influenced by research, industry and market requirements (section 1.1)
- recognise the legal, social, ethical and professional issues involved in the exploitation of computer technology and be guided by the adoption of appropriate professional, ethical and legal practices (section 2.1.6).

Additional criteria for CEng or CSci at master's level include:

- systematic understanding of knowledge and a critical awareness of current problems and/or new insights, much of which is at, or informed by, the forefront of their field of study (CEng section 3.1.5; CSci section 4.1.5)
- comprehensive understanding of techniques applicable to their own research or advanced scholarship (CEng section 3.1.6; CSci section 4.1.6)
- develop and apply new technologies (CEng section 3.2.4)
- show critical awareness of current problems and/or insights (CSci section 4.2.4)
- show originality and innovation (CEng section 3.2.5; CSci section 4.2.5).

Master's level programmes must also satisfy the following criteria:

- consistently produce work which applies and is informed by research at the forefront of the developments in the domain of the programme of study; this should demonstrate critical evaluation of aspects of the domain (section 7.2.1)
- a project undertaken at master's level should reflect the ethos of advanced study and scholarship appropriate to a Master's degree (section 8.1.5).

The Institute of Mathematics and its Applications
The Institute of Mathematics and its Applications (IMA) is the professional and learned society for qualified and practising mathematicians. It does not prescribe specific criteria for approved BSc programmes for graduates seeking to reach Chartered Mathematician status.

Information and mathematical sciences graduate attributes

A close match is evident between the initial set of generic graduate attributes suggested by the Enhancement Theme and the subject benchmark statement and professional body expectations; differences are omissions rather than contradictions. At undergraduate level, computing statements do not map to (1) awareness of the provisional nature of knowledge or (2) the need for originality and creativity in formulating, evaluating and applying evidence-based solutions and arguments. Undergraduate MSOR statements do not refer to these, or to (3) current developments in the subject or (4) understanding of the need for a high level of professional conduct. All of these except (1), however, are included for MSOR at postgraduate level.

Section 4 of this report summarises the views of responding academics and students about subject-level graduate attributes and how research-teaching linkages can enhance these.

4 Findings

Course prospectuses and website descriptions across a range of universities were found to advertise research-teaching linkages, evidently to promote these as impressive features of the departments and/or programmes in question. Examples are provided in table 1, below.

Subject	Prospectus	Website
Computing	Level 4: research methods	We provide innovative and relevant courses that match the needs of business with the research excellence to innovate ourselves
Computing Science	Involvement in research by senior students is encouraged	...a highly successful research-led degree programme
Computing		Optional modules provide choice and variety and often reflect the research interests of staff
Information Systems	Modules offered at the honours level continue to develop theoretical knowledge and practical skills but also address current research themes in information systems	
Business Technology	Students have the opportunity to demonstrate their ability to integrate business and technology aspects of the programme into a major, individual research project	
Mathematics	Year 4: undertake project work, giving you a flavour of research in mathematics	
Mathematics	A group project giving training in research and presentation skills is a compulsory element. Our graduates are well equipped to carry out research in a number of multidisciplinary areas	A five-year undergraduate master's course has recently been added to our portfolio of courses and this provides an excellent foundation for students aspiring to a career in research
Mathematics; Statistics	All degrees offered can include topics from more than one research area. In the final year, students undertake a research-based dissertation	Aim - to provide the necessary skills and training for further study or research in.... Learning outcome - to possess the basis for research work in....

Table 1: examples of advertised research-teaching linkages

There was no indication of a progressive sequence for research-teaching linkages from first year to final year and postgraduate study, however: visible links were mostly for level 4 study only. Often an emphasis was placed upon student choice to select modules or courses that have a research focus, rather than research-teaching linkages being core material that would enhance employability or continuing professional development. One institution has developed a set of campus-wide graduate attributes that it seeks to develop in all of its students. As part of the university's strategic plan, teaching strategies have been reviewed to ensure that these graduate attributes are developed, although these are not advertised in the prospectus or website entries for the discipline.

Sections 4.1 and 4.2 of this report present the information gathered from discussions, questionnaires and interviews with academics and students respectively. From these it is clear that the advertised summaries of courses do not reveal the full extent and nature of research-teaching linkages in ICS and MSOR.

4.1 Academics' experience

In spite of the relatively limited instances of research-teaching linkages advertised, survey responses from academics indicated overwhelmingly that they believed that students do gain from being exposed to research. It should be noted that when the project team approached institutions and staff, it adopted the Enhancement Themes' wide view of what is meant by the term 'research', meaning that it could include:

> 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.[3]

In their responses, many academics clearly interpreted the term in a more narrow way, focusing upon that subset of the above which was most natural to them.

Level of study

Irrespective of their subject, academics clearly believed that exposure to research is beneficial at level 4 and master's level (more than 80 per cent). However, less than 50 per cent of all respondents believed that students at levels 1 or 2 benefit from research exposure, compared to approximately 70 per cent believing benefit accrued at level 3.

The level of undergraduate study is a major constraint upon linking research and teaching in the areas of mathematics in particular. For a small number of our respondents, the idea of bringing research into teaching is seen as being nearly impossible, particularly at first-year level:

> 'Research in mathematics cannot be given to undergraduates: it doesn't make sense because they are ill-equipped to do anything related to it. ...it is impossible to incorporate maths research into undergraduate teaching' (Professor, MSOR).

This matches a response made by an academic in the Robertson study of 2007:

> It's quite difficult to get students up to the level where they can do research without them having done a full four year degree first (Robertson, 2007).

[3] See www.enhancementthemes.ac.uk/themes/ResearchTeaching/overview.asp

A majority of our mathematics respondents commented that the cumulative nature of learning made it difficult to incorporate research into teaching, even at a most basic level:

> 'When a student learns a subject, or looks into a problem, they are performing a mini research project of a kind. However, it can be difficult in an easy undergraduate course to engage students in modern pure mathematics research in a deep way, because of the required technical prerequisites' (Lecturer, MSOR).

> 'The best sort of exposure is practice. But in my subject it is difficult to think of interesting research problems for first or second year students to look at which were not solved by someone else over 100 years ago' (Lecturer, MSOR).

> 'I don't remember ever looking at a research paper during my maths degree, and I'm fairly certain that it was never suggested that we do so' (Lecturer, mathematics).

Linking research and teaching was more positively supported and encouraged within information sciences, for example:

> 'What I don't understand is why anyone would even question whether we should discuss our research work with the students' (Lecturer, ICS).

No mention was made of the need to introduce topics in a hierarchical manner; rather, the consensus was that introducing students to research can enthuse and encourage them to better understand the topic. Furthermore, this was something that should be encouraged from first year. For example:

> 'If you don't expose computer science students to cutting-edge research early on, they may well switch off' (Lecturer, ICS).

> 'Students can gain from being exposed to research at all levels of the curriculum. It is tempting to consider that such exposure should be confined to students in year 4, or at master's level, to prepare them for possible further study leading to a higher degree. However I believe that exposure to research can be beneficial to students at lower levels of an undergraduate degree programme also, to help engage and enthuse students with the subject. This could in turn help with student retention. Having said this, the level and method of exposure needs to be carefully balanced in years 1-3 of an undergraduate degree programme' (Lecturer, ICS).

In summary, the final year was found to be the typical level for interactions between research and teaching:

> 'Those who are research active often include research driven material in their final-year modules as a matter of course. Indeed our final-year modules positively encourage this' (Professor, ICS).

Ways of aligning research and teaching

Teaching can incorporate research in a diverse set of ways, although clearly some techniques are more appropriate or easy to apply than others depending upon the subject specialism (see figure 4).

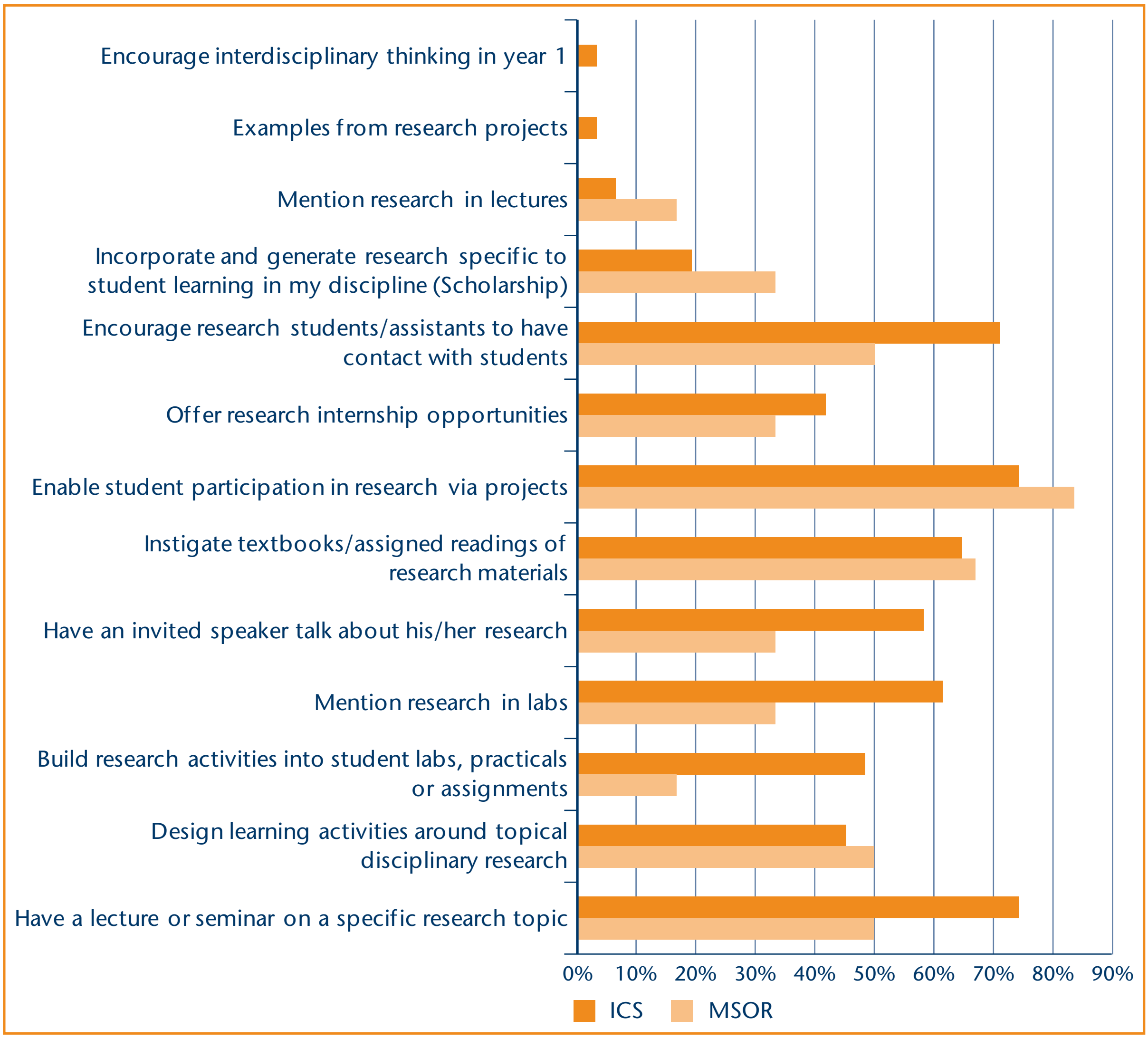

Figure 4: uptake of various incorporation techniques

Project work and specialist lectures are particularly common ways of introducing research content or process, whereas actual research projects or early-stage interdisciplinarity is uncommon.

Figure 5 summarises some of the activities undertaken within the information and mathematical sciences disciplines in higher educational institutions throughout the UK. This information is taken from the case studies presented in this report, as well as from the relevant discipline's homepages and prospectuses of universities across Scotland. We have summarised the activities into seven categories:

- problem-based learning (PBL) (group) projects
- encouraging personal study
- involvement in departmental research

- sponsored summer schools
- (research-linked) honours/master's level projects
- research-informed discussion sessions
- general research modules.

Figure 5 also illustrates how we found each of these activities located within the individual subject area of information and mathematical sciences:

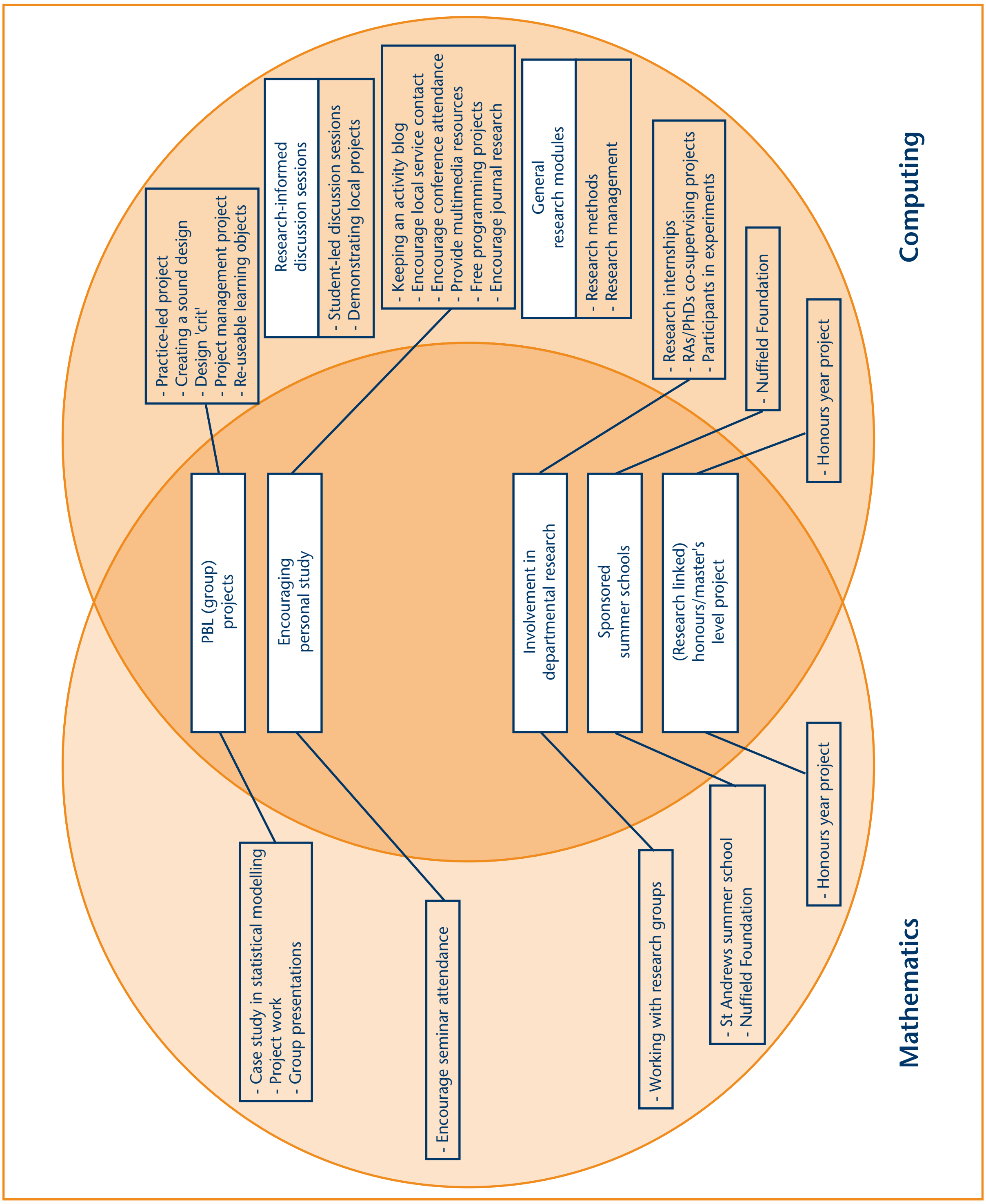

Figure 5: location of various incorporation techniques

Five out of the seven activity categories were found to be routinely carried out within mathematics and computing, confirming strong correlations between the research-teaching linkages within those subjects. It was noted that research-informed discussion sessions and general research modules (that is, modules which specifically concentrated on research methods within the discipline) were more likely to be found within ICS than MSOR. Again, this could be an indication of the cumulative nature of mathematical learning, in which discussion sessions may not be as accessible to students who may still be learning the basics of the discipline, as they may be within the information sciences.

Value of a research experience

Figure 6 presents responses to the question: 'Which graduate attributes are important in your discipline?'. Responses corresponded with the graduate attributes emphasised in the QAA subject benchmark statements and the professional bodies: little rated were the awareness of the provisional nature of knowledge and the need for originality and creativity in formulating, evaluating and applying evidence-based solutions and arguments. MSOR academics did not rate highly either current developments in the subject or understanding the need for a high level of professional conduct. Nonetheless, key comments made by academics of ICS and MSOR should be noted:

> 'All are relevant to some extent but the selected ones characterise the essence of what really matters' (Senior Lecturer, ICS).
>
> 'All of these attributes are important in just about any discipline' (Lecturer, ICS).
>
> 'A university course should transform a school-leaver with a basic knowledge of a discipline like mathematics into someone who is capable of understanding cutting-edge work in that discipline, so their course has to be delivered by staff whose abilities, interests and motivation makes this possible' (Vice-dean, MSOR).

Benefits expected for students (most commonly cited first) were:

- increased lecturer enthusiasm and motivation when teaching
- improved student learning experience
- increased knowledge of subject area
- increased knowledge of the research process
- improved staff/student relationship
- inclusion in a research community.

Increased student motivation was frequently mentioned:

> 'Shows them what kind of activities they would be involved in if they chose to stay on and do research. Gives the topic being taught a bit of realism - students can see how the topic they're learning about is relevant and important' (Lecturer, ICS).

Other value to students included:

- get something extra which they won't find in standard texts
- better contextual understanding of the subject area, and an idea of the broader scope of the subject
- awareness that not all questions have answers and the field is dynamic.

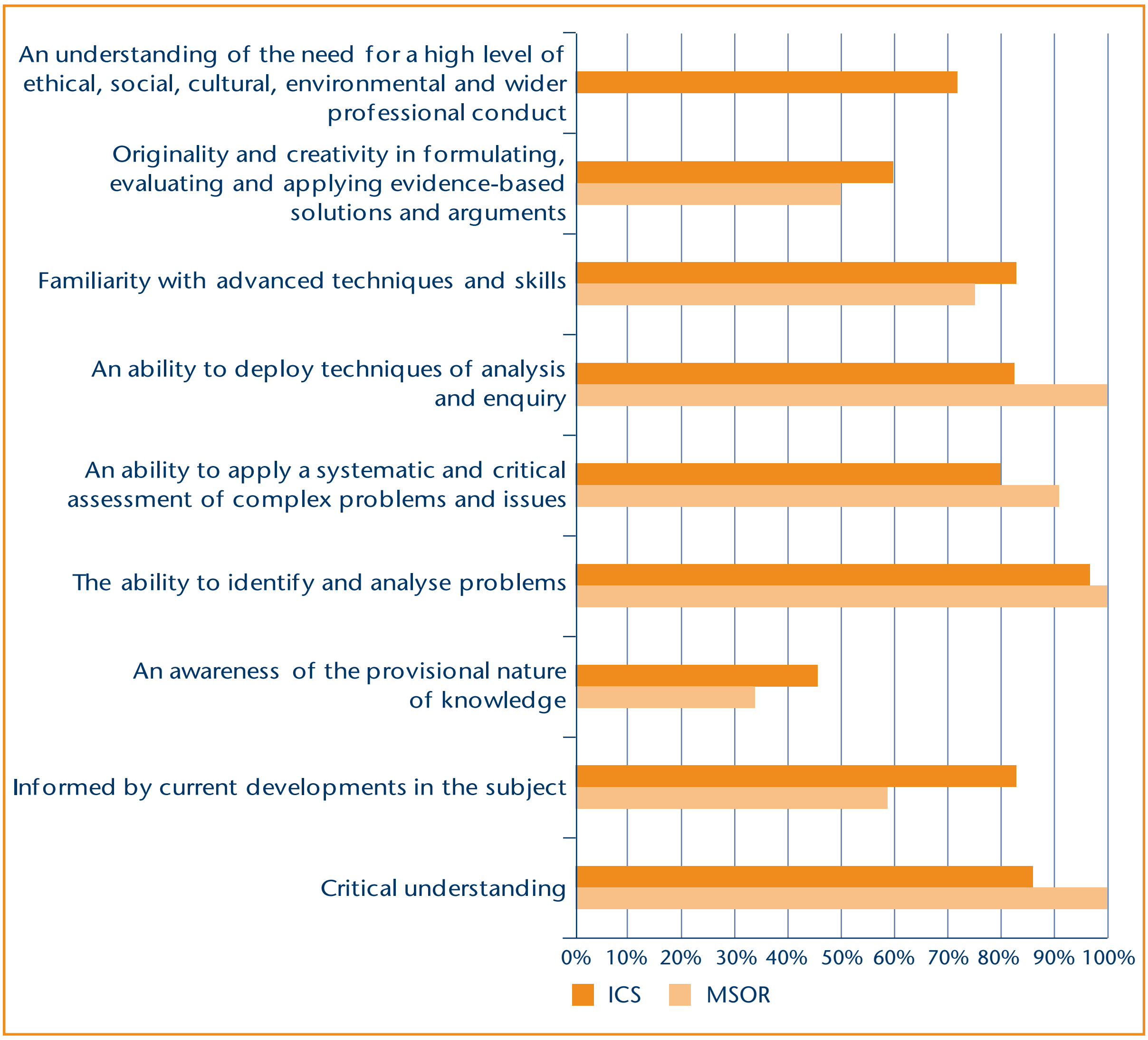

Figure 6: Which graduate attributes are important in your discipline?

The last point may be appropriate for both ICS and MSOR, but perhaps is more easily addressed in ICS programmes. Certainly there appear to be more opportunities to emphasise the provisional nature of knowledge in ICS programmes than in MSOR programmes. Examples feature here in the case studies that relate to computer security and computer forensics programmes. Similarly, Rigby, Dark, Ekstrom and Rogers (2007) have commented upon the complex and ill-defined nature of the types of problems that face graduates of information assurance and security programmes, and therefore of the need for educators to prepare professionals to recognise and manage complexity. These authors recommend consideration of a teaching approach known as 'Model Eliciting Activities' as one approach to help students recognise and manage complexity:

> ...simulations of real-life problems where the learners develop models and conceptual tools for making sense of complex systems.
>
> A multi-categorical problem also involves learners across a spectrum of thinking activities: problem finding, trouble shooting, detecting inequities and contradictions, making choices, and creating new ideas and objects. And finally, a multi-categorical problem is one that targets varying levels of complexity....
>
> (Rigby et al, 2007)

Concerns for students

It was recognised that linking research to teaching might hold disadvantages for students: distortion of the curriculum; students not perceiving they are stakeholders; alienating weaker students; lecturers being less available to students; and lecturers being preoccupied with their research:

> 'There are also negative aspects. For example, when I design coursework which requires a bit more independent thought, the weaker students may struggle a large amount with it. This can often discourage them' (Lecturer, ICS).

> 'I don't think that my own research interests distort the curriculum (though of course I may be wrong) but I have seen it happen with other lecturers' (Lecturer, ICS).

It was also noted that students did not necessarily understand or appreciate the benefit of research being linked to teaching. Attitudes ranged from welcoming through to mixed, indifferent, unaware and frustrated (time should be spent on 'stuff which will look good on my CV and get me a job').

4.2 Students' experience

In this section, we have categorised the experiences of students into key areas. These may provide discussion points for including the student perspective if planning to extend the incorporation of research into teaching practice. Opinions given were drawn from various sources, including:

- questionnaires sent out to students (see Appendix 7.1)
- follow-up online interviews with respondents
- face-to-face interviews with students, both on an individual and on a group basis
- statements given within the 'Student Feedback' sections of the Nuffield Foundation's student undergraduate research bursary reports and from covering emails.

Students' awareness of research

Students were asked to describe what the term 'research' meant to them. Definitions for research varied from the stereotypical ('when I think of research, I think of chemistry labs' (UGY1, ICS) through to generic terms such as 'innovations' (UGY1, ICS) and 'experimenting with things that haven't been done before' (UGY4, ICS), and specific references to the domain of computing:

> 'Someone who is trying to find out technologies in the computing area. I like to consider the computing area as being like medicine in the 18th century. There is still so much to discover. And there are loads of areas to research' (UGY2, ICS).

> 'I would think they are making a new type of technology. ...So if they are researching it now, we'll probably find it affecting us in a few years time' (UGY1, ICS).

Many students, however, were unaware of research, or felt that they were not given the chance to be exposed to research as part of their course. No more than two-thirds of students questioned were aware of research occurring in their university (seminars, conferences, reports, posters, exhibitions, displays, notice boards advertising research and postgraduate opportunities) or of the university's research structure and reputation. Ten per cent of the sample group reported no awareness of any of these at all.

Queried about staff research, many students had little awareness of:

- how many staff in their department were involved with research
- what staff research activities or interests were
- the research reputation of the staff in their subject area
- if the department's research profile was any different to that of the university as a whole
- any benefits that staff involvement in research had for them as students.

In summary, students' awareness and understanding of the research taking place in their department was extremely limited.

Level of study

The question of bringing research into teaching at first-year level resulted in a difference of opinion. Some students felt that first-year level was too early for them to be learning about the research process, as they perceived it:

> 'I think 1st year would be a bit too daunting' (UGY1, ICS).

> 'I don't think it should be introduced straight away in first year. Maybe we should get more introduced to it towards the end of the year, and then do stuff in second year' (UGY1, ICS).

Reasons given for this included the students' perceptions of the cumulative nature of learning. For example:

> 'You've got to strike the balance well, because a first year student doing Java doesn't even know what anything is. They would still understand research, but I think you've got to know the basics before you know what the front edge is' (UGY4, ICS).

> 'It would be more beneficial to give the students the fundamentals, as without them they won't understand what's going on at the top level. So the base level, the fundamentals, is important. Once this is done, the students will develop their own interests - "I want to know more about this, I want to do this". And then, when they go for the honours or master's, they will have developed this interest' (MSc, ICS).

On the other hand, there was general agreement that, if students were to become involved in research as part of their course, it should not just be the 'brightest' students who took part. Rather, taking part in research should be an option for all students:

> 'It would have to be voluntary. So, you would have normal courses, and then someone might say "we're doing research, does anyone want to join in?"' (UGY1, ICS).

'I think the best students would volunteer. You wouldn't get the slackers offering their free time for it. I think everyone should be given the chance between doing research and doing another course' (UGY4, ICS).

Ways of experiencing research

In the previous section it was observed that some of the diverse ways of incorporating research into teaching may be more appropriate than others depending upon the subject specialism. Students' experience appears to confirm that a lot of opportunities are apparently not used (see figure 7).

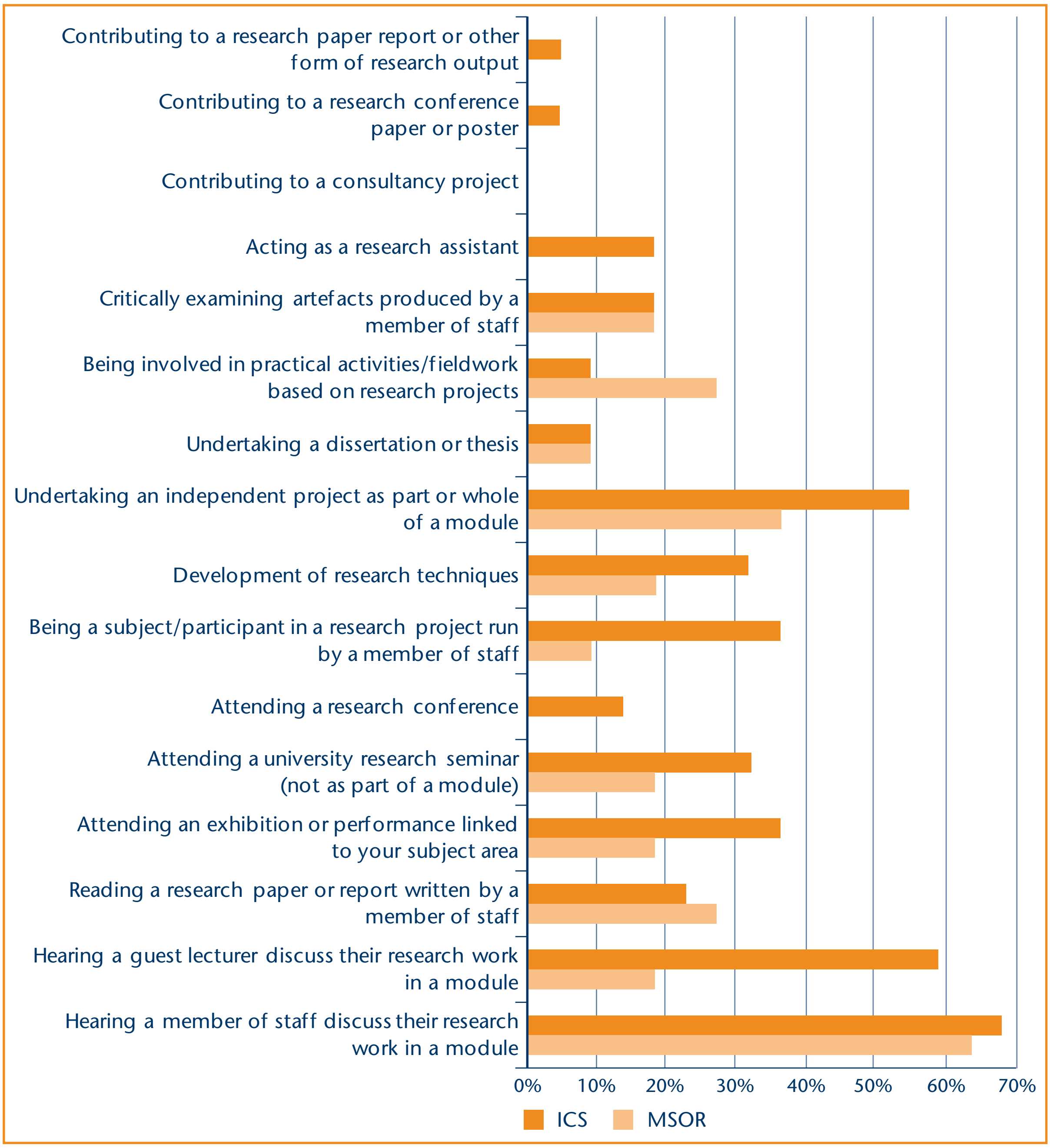

Figure 7: experience of various incorporation techniques

Those events that are most commonly experienced are of a passive type, rather than involving active participation:

> 'Usually [research] is briefly mentioned as part of a lecture, so if we find out about it, it's really just by chance' (UGY1, ICS).

> 'I know what my lecturers' research is because they tell us, either through lectures or me just asking them. With the researchers that I don't have as lecturers, I don't really know much about them, I don't tend to catch as much' (UGY3, ICS).

Value of a research experience

Where students **have** been aware that they were being exposed to their lecturers' research interests, responses were generally positive:

> 'Computing is a practical course, and most people on it will be doing it because of the direct learning approach rather than just reading stuff. I remember seeing the various bits of software used at [the local] hospital. I tell friends that I did this course over a games course because I could be programming software that ends up saving lives' (UGY1, ICS).

Research was considered to enhance the students' experience in a number of different ways, principally stimulating interest and enthusiasm, and increased understanding:

> 'Seeing the interest the staff have had in their research, and showing me the numerous possibilities for new discovery has made me even more enthusiastic about my degree, and has made me work harder to get good understanding in most of my modules' (UGY3, ICS).

Students also identified several other ways in which their experience was valuable to them:

A 'taster' for research

Some students also found they were motivated to consider pursuing postgraduate research. This corresponds well to the hopes of many of the Nuffield grant holders, who took on students to give them a 'taste' for research, thus to provide the student with the opportunity to choose whether or not they wish to follow an academic career:

> 'One colleague this past summer had a mature student working on a project in relativity. The option to "try out" research was welcomed by this mature student: given his age, he felt he could not afford a false start in his future career' (Nuffield, MSOR).

> '[The project] was good for [the student's] CV and self confidence, and will help him make up his mind if post grad research is for him' (Nuffield, ICS).

> 'In my view the main benefits of this project are that the student is now extremely keen on the idea of research and she has now some mature view of what that might entail' (Nuffield, MSOR).

Nuffield students often agreed with this viewpoint:

> '[The Nuffield project] has shown me research is very diverse and a lot gets learnt very quickly between groups, and the available information is phenomenal' (Nuffield, ICS).

> 'The bursary has broadened my perspective about what research is about' (Nuffield, MSOR).

Nuffield projects were often designed to emphasise the dynamic nature of research to the student:

> '[This was an] interesting project for the student to have been involved with, showing all the difficulties of the research process' (Nuffield, MSOR).

> 'I believe the project greatly enriched the student's experience, and I believe this in part having discussed the experience with the student. He saw first-hand what mathematical research entailed, even with the changed project, and he was forced as well to pull together his own knowledge from a variety of different and disparate sources to address some of the questions' (Nuffield, MSOR).

As a result, it was not uncommon for work carried out by the student to be published within conference proceedings, or even a journal:

> 'The student worked pretty much "by himself" i.e. there were no relevant post grads around. It built on earlier work (by a previous PhD student) and resulted in a paper which has just been accepted for publication in Physica A, so real questions were answered in terms of research.... It gave the student a good feel for what it was like to do research, and a sense of achievement when he was able to come up with results which were new' (Nuffield, ICS).

Working with 'real' rather than 'artificial' problems
Students who were exposed to 'real' problems in both computing and mathematics appeared to agree that this made the particular topic easier to understand:

> 'Increased understanding by example, to see something work and know why goes a long way to understanding something better' (UGY3, ICS).

Nuffield projects designed with real data in mind appeared to validate this:

> 'I think the student really liked the idea of dealing with real epidemiological time series and this has really fired her up with enthusiasm' (Nuffield, MSOR).

> 'I believe the student learnt what it was like to work on a non-trivial (open) problem using his own strengths' (Nuffield, MSOR).

> 'I found that producing a piece of software that solved a real scientific problem whose solution might be useful to someone else was especially rewarding' (Nuffield, ICS).

Incidental/expansion of knowledge

A significant outcome of the Nuffield experience is that both staff and students are able to improve or gain new skills of particular techniques or technologies that they may not experience as part of their degree. For example, computing students often found that their understanding of particular programming languages increased during the course of the project:

> 'I learnt a great deal from the bursary experience, expanding my knowledge of computer science both in the mainstream fields (Linux, databases, C programming and communication protocols) and the specialist field of synchronous reactive systems programming (Esterel)' (Nuffield, ICS).

> '[The student] learned a lot which was useful for her 4H project (Latex, for example)' (Nuffield, MSOR).

Similar findings were discovered within the mathematical sciences:

> 'My knowledge of time series analysis before this project was very limited, so this project allowed me to branch out into an area of statistics I had not encountered before...I developed my skills in the software package, R to a much greater degree. Having already come across the package in my studies, I found the knowledge learnt over the summer has assisted me in my undergraduate work this year' (Nuffield, MSOR).

> 'I learnt to absorb new knowledge in a short amount of time, and was able to improve my understanding in one of my weakest areas. [I have gained] the skill of using computational software to do calculations and plotting the appropriate graphs illustrating each different case in the project' (Nuffield, MSOR).

Freedom and independence

A further advantage that those involved in the Nuffield Foundation bursaries offered was the freedom and independence that students could experience when they undertook such projects. From the point of view of the grant holder, this provided an extra means by which they could inform the student about research:

> 'Experience was enhanced...to realize that there was more to doing research than just doing as one is told' (Nuffield, MSOR).

> 'I think it gave [the student] a first taste of research work (rather than mostly spoon fed lectures and the associated exercise sheets)' (Nuffield, MSOR).

> '[The project gave the student] the confidence that [his strengths] could work independently' (Nuffield, MSOR).

Those students who took part in extended projects also appreciated being given the space and the hands-on experience that they may not always have during traditional lecture and tutorial times, and which may help them in their future careers:

> 'I [enjoyed] having the freedom to approach [the project] in a way that suited me' (Nuffield, ICS).

'I learnt about working in an academic situation, where the day's work and finite targets are set by myself. This is much different from normal university life where deadlines are given for assignments and worked towards.... No matter what type of work I go into later in life, if the employer asks for something just to be done, I can assess what needs to be done specifically first before tackling the job' (Nuffield, ICS).

'I enjoyed the flexible working hours as it gave me the freedom to work when I wanted to and it allowed me to explore specific ideas in more depth to evaluate how well they worked' (Nuffield, ICS).

'I learnt about self-discipline in a research-led environment, which is different from the experience on a taught undergraduate degree programme...lots of freedom was given to me' (Nuffield, MSOR).

'The experience of working independently on a project has greatly improved my motivation and independence towards my work' (Nuffield, MSOR).

Indeed, supervisors felt that a tangible change occurred when students were provided with the freedom and independence to use their own initiative:

'When freed from the constraints of a UK undergraduate degree syllabus, he was almost unstoppable in his enthusiasm for learning the new mathematical techniques that were required in the project' (Nuffield, MSOR).

Time management skills

Responses from students indicate that they learned about the partnership between independence and time management skills:

'After being given instructions, it was largely up to me when to do the work and I enjoyed this freedom whilst recognizing the responsibilities to finish the work in the tight timescales of 10 weeks' (Nuffield, MSOR).

'I feel more competent in personal time management more than ever now' (Nuffield, ICS).

Motivation and enjoyment

Staff involved in research were judged to be more enthusiastic about their subject than other staff. A link was clear between how much enthusiasm lecturers showed for a particular research area and how much more a student wanted to become involved within that area. This was highlighted in some of the questionnaire responses we received:

'They have a passion for their subject and this in turn has stimulated my thirst for knowledge within the subject area too' (UGY2, ICS).

'Seeing the interest the staff have had in their research, and showing me the numerous possibilities for new discovery has made me even more enthusiastic about my degree, and has made me work harder to get good understanding in most of my modules' (UGY3, ICS).

Nuffield undergraduate research projects certainly provide one way of encouraging students:

> '[The project] gave him the opportunity to participate in our research and not just the lectures, which, as far as I can tell of course, he enjoyed a lot; in particular the advanced programming and related maths' (Nuffield, ICS).

Further academic study

From the questionnaire responses we received, some students indicated that being exposed to research that was being applied to 'real life' problems had encouraged them to consider following a research career path. For example:

> 'The department in which I study offers summer projects. I was involved in a visualisation project this summer and from working part-time with the lecturers I was motivated to possibly pursue postgraduate research' (UGY3, ICS).

> 'Seeing how staff not only do research in one field but also try to link mathematics to other subjects, I decided to apply for postgraduate studies in applied maths' (UGY4, MSOR).

Additionally, as previously stated, students who had been identified as having the potential to undertake a PhD after their undergraduate studies were encouraged to take part in Nuffield-funded projects, with positive results:

> 'After finishing his undergraduate studies, [the student] enrolled in the PhD programme at the University of York' (Nuffield, ICS).

> '[The bursary] has increased my interest in doing a postgraduate degree after I finish my honours degree' (Nuffield, MSOR).

One undergraduate student and one postgraduate student interviewed further commented about the graduate attributes they felt to be particularly important. The undergraduate student provided the following choices and reasons behind choosing them:

> Systematic and critical assessment:
> 'For a variety of reasons, I work best with process and systems; they make it easy to follow a process through and avoid distractions and mistakes. I use an iterative technique during some tasks, making sure something is right, can I do it better next time, re-evaluating my output, and so on. Examining others' work and having others evaluate mine shows up areas that I may have skipped over or not thought through properly'

> Professional conduct:
> 'Having worked in a variety of fields before re-entering education, I'm familiar with the responsibility of handling information and carrying out studies in an appropriate manner, bearing in mind the subjects with whom I would be dealing, the issues that may arise and need to be worked around'

> Familiarity with advanced techniques and skills:
> 'Though at this time I have little knowledge of the skills used in gathering information and performing adequate research, it is a field in which I intend to work upon completion of my degree at [named] University. This course and its

> content hopefully will give me guidance on the current and emerging techniques, the individuals to try to emulate and follow' (UGY3, ICS).

The postgraduate student identified 'critical understanding' as most important to him for the following reason:

> 'I think "critical understanding" is really important and it helps us to gain genuine knowledge. It is knowledge which will help us for future career or postgrad research' (PGY1, ICS).

Concerns of students

Although awareness of research was not high, students did not share the concerns of staff that lecturers would be less available to students if they were preoccupied with their research. There was no comment about weaker students being disadvantaged, and only one comment was made about a possible distortion of the curriculum:

> 'The work we have done sometimes feels as if we're being moulded into puppets for areas of their research' (UGY3, ICS).

Examples of research-teaching linkages

The remainder of this section of the report provides case studies of the experiences summarised above.[4] Section 5 then considers the main issues that have been identified across institutions and the disciplines.

4.3 Case studies - learning through research content

In this section we present case studies in which the student learns through research content. The case studies illustrate the ways in which lecturers bring their own research interests into the teaching curriculum. As a result, students are learning about research being conducted within a particular discipline, but are not necessarily actively researching themselves. Nine case studies are presented in order of level, beginning with undergraduate level 1 and concluding with postgraduate.

Computer Security and Computer Forensics (levels 1-3)

Contact	Dr John Haggerty
Institution	Liverpool John Moores University
Email	J.Haggerty@ljmu.ac.uk
Discipline	Computing
Course title	BSc Computer Forensics
Level	Undergraduate

Course details

Computer forensics is emerging as an important tool in the fight against crime and malicious activity. This new discipline is based on forensic science and computer security technologies, and involves the application of scientific methods for the collection, analysis, interpretation, and presentation of potential evidence. This degree aims to provide students with the technical, analytical and evaluative skills required for the development of computer forensics solutions, so that they can implement computer forensics-based

[4] Case studies are available at www.computing.dundee.ac.uk/rtl/casestudies.asp

investigations within organisations, law enforcement and national security. Upon completion of this, degree students will be competent in all areas of computer forensics: ethical and privacy considerations, technical considerations, legal requirements and investigative processes. We suggest that an ideal course on computer forensics should span the computing spectrum, from information systems through to software engineering. As a result, the programme should be rooted in computer science with specialist modules within forensics. Some suggested lecture topics are: what is computer forensics?; basics of HD/storage media; legal aspects; uses of computer forensics; procedures; Windows, Linux; network forensics; ethics; data hiding and investigating fraud; and future issues. Carrying this forward, the issues we need to consider are:

- moving to mobile/pervasive network devices
- expanding memory availability
- user security
- secure networked applications (for example, Skype)
- investigatory procedures/frameworks in corporate environments
- the law and technology (geo-political borders)
- the multidisciplinary nature of the field.

How research and teaching is linked

The following research areas could be brought into teaching practice:

- process automation
- development of scalable tools and techniques
- development of standards outside law enforcement
- understandable and applicable investigation frameworks
- security with accountability
- the multidisciplinary approaches encompassing law, technology and trust.

To make this possible, it is necessary for staff and students to form links with local practitioners, police and other services. Students should also be given access to multimedia resources, such as videos and MP3 files. We encourage students to attend conferences such as 'Advances in Computer Security and Forensics', in which they are able to meet with practitioners and researchers. Students can attend this conference for free and they also have the opportunity to present their projects in poster format.

Further information:

www.ljmu.ac.uk/courses/undergraduate/87382.htm

Project Management Patterns (level 3)

Contact	Dr Andrew Hatch
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Discipline	Computer science
Course title	BSc Computer Science
Level	Level 3 undergraduate (England)
Unit/module	Project Management

The content of this case study is drawn exclusively from the publication by Hatch, Burd, Ashurst and Jessop (2007) and used with the permission of Dr Hatch.

Course details

Level 3 students have an opportunity to learn and practice project management: along with lectures, the practical element of the course requires students to project manage a team of level 2 undergraduates who are embarking on a software development project that spans an academic year. The course design is such that lectures introduce theory that the project managers can use at the time at which they will have an opportunity to use it.

Project management patterns were seen as a suitable way to allow students to reason about their activities as a project manager. As a cohort, they were asked to develop a pattern language that captures advice about how to project manage level 2 software development teams. Project management patterns therefore formed an integral part of assessment, and to support this, two workshops delivered jointly by both the Business School and the Department of Computer Science. These workshops were designed to introduce the students to project management patterns and to allow them to engage with staff and each other in debate.

Three elements of assessment were used. Students were asked to deliver a mid-course presentation that evaluates their own performance as project managers, and describes how they intend to improve. An end of course summative essay was also used to assess critical thinking on project management patterns. A significant part of the assessment (30 per cent) required each student to keep a 'blog' (weblog, or online diary) throughout the year. Students were asked to add entries to their blogs that capture both their project management activities and the development of project management patterns. The assessment was looking not only for the development of new patterns, but also rewarded the application and development of existing patterns. In line with the social elements of pattern languages, students were encouraged to utilize patterns developed by other students and encouraged to critically evaluate their own work and the work of others.

How research and teaching are linked

By nature, project management is both theoretical and practical. Reflecting this, the course design adopts a problem-based learning (PBL) approach. Whilst there are different views on what PBL is, central to the strategy is the **problem** - in this case, using the management of a software development team as the real problem. For PBL, constraints are required to avoid the potential for missing necessary learning objectives. In this, design, patterns, pattern languages and the reflective nature of the assessment are ideal in constraining student learning to the course's learning objectives.

At the outset of the module, it was made clear that the resulting pattern language would then be used as a knowledge base that could be transferred to the following year's cohort of project managers. To allow for this, release forms were required to be signed by all students. It is intended that the patterns created by one year's cohort will be reviewed by the new incoming project managers throughout their project management activity. Patterns may be adopted, adapted or rejected in their new pattern language.

Lecturers were able to take suitable patterns that had been developed by students, and integrate them into the course of the lecture. Student feedback indicates that this was particularly useful in helping them appreciate the value of their work, and to see it in the wider context of the theory.

Graduate attributes developed

Students gain experience of working in research that has never been attempted previously.

Feedback - the result of one academic year of the project management module

Benefits for research

Blogs had proven useful in allowing lecturers to see the progression of students throughout the year, and to be able to identify those students who were not consistently adding entries to the blogs. RSS (Really Simple Syndication) technology supported by the blogging software (WordPress) and modern browsers made this task simple. It was found that the workshops facilitated useful debate between undergraduate students and also between students and staff. This is particularly true after the second workshop when students had real experiences to draw on. The contribution of all members of the workshop identified potential areas for future research. More obviously, the product of the student's work is a pattern language that has been produced in a controlled and monitored environment. This pattern language is a set of data that can be studied not only as a set of data; a product, but also in the context of the process that produced the product, captured through the blogs. Often, as researchers become absorbed into their subject, they lose the benefit of being a newcomer. Areas of the subject become so familiar that they are unquestioned. By reading the accounts and critiques of those who are new to the subject, researchers can gain a new appreciation of the familiar that may sometimes inspire lateral thinking on such topics.

Benefits for students

Student perceptions of the benefits of participating in such a scheme are yet to be fully evaluated. The following findings are based on informal and anecdotal evidence. Students have stated that they appreciate the opportunity to be involved in the Business School's research - to be involved in work that has never been attempted previously. They have also indicated their appreciation of the effort the Business School has invested in their module. This was particularly evident in both module feedback data, and the Staff Student Committee, that identified the workshops as stimulating, enjoyable and useful. At present it is unknown whether students will appreciate being given a body of knowledge of the experiences of other students in the context of project management. However, evidence from other modules shows that students value opportunities to discuss issues with other students who have already experienced those issues.

Further information:

www.ics.heacademy.ac.uk/events/8th-annual-conf/Papers/Andrew%20Hatch%20final.pdf

Mathematical Biology (level 4)

Contact	Dr Fordyce Davidson
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Email	davidson@maths.dundee.ac.uk
Discipline	Mathematics
Course title	BSc Mathematics; BSc Mathematical Biology
Level	Level 4 undergraduate
Unit/module	Mathematical Biology I and II
Mandatory/optional	Mandatory (optional for joint honours students)
Number of students	~20

Course details

Mathematical biology involves using mathematical techniques and computational tools to answer problems that arise in biology. New, exciting challenges in the life sciences are now being met using mathematical modelling. This is having a direct impact on health, social and ecological aspects of modern life. The mathematical biology modules provide an introduction to the use of discrete and continuous modelling techniques applied to problems drawn from population dynamics, disease spread, cancer, biochemical reactions and pattern formation. Emphasis is on model construction and methods of analysis. The courses are delivered in a standard manner using a combination of lectures and problem-solving classes. Assessment is by examination (80 per cent) and coursework (20 per cent).

How research and teaching are linked

Mathematical biology is a major and highly active research area in the division. A substantial research group is in place, which attracts regular visitors and seminar speakers, and plays host to major national and international conferences. The group also has significant links with local biotech companies. The undergraduates are very aware of this and it provides a context and stimulus for the ideas developed in the modules. Research done by the group is used to inform and update lecture notes and illuminate the topic by providing examples of applications and the history and development of the subject and key personalities involved. All students must also do a significant project in level 4, which can be an extension of ideas developed in these modules. This provides further exposure to research in this area. (All BSc Mathematical Biology students must take such a project.) Students are encouraged to attend seminars where appropriate and are kept informed of opportunities to move into research within the group.

Graduate attributes developed

- General problem solving.
- Modelling of complex processes in biology.
- Technical skills regarding analytical and numerical solution of difference and differential equations.
- Foundation skills for employment in biotech, environmental and health industries.

Feedback

Feedback forms and general discussions reveal that the students find these modules enjoyable but challenging. The connection with research activity and beyond (for example, to the biotech industry) appears to provide a 'real world' image of mathematics that the students relish.

Advanced Distributed Information Systems (level 4)

Contact	Dr Wamberto Vasconcelos
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Discipline	Computer science
Course title	BSc Computing Science
Level	Level 4 undergraduate
Unit/module	Advanced Distributed Information Systems (CS4022)
Mandatory/optional	Optional

Research interests of lecturer

The research interests of this lecturer lie in employing computational logic to explore new ideas in software engineering and, in particular, the synthesis and simulation of large multi-agent systems. Dr Vasconcelos is currently involved in the following research projects:

- International Technology Alliance (ITA): a multi-partner consortium performing research in network centric systems within the UK and US armed forces
- Coordination, Organisation and Model Driven Approaches for Dynamic, Flexible, Robust Software and Services Engineering (ALIVE): a European Commission-funded research project looking to develop new approaches to the engineering of distributed software systems based on adapting coordination and organisation mechanisms associated with human and other societies to service-oriented architectures.

Course details

This course covers the following concepts:

- distributed and concurrent programming
- tuple spaces (with JavaSpaces and Jini)
- multi-agent systems
- peer-to-peer systems
- web services
- ubiquitous and pervasive computing
- digital libraries.

How research and teaching are linked

Most of the course concepts covered are within the scope of both the ITA and the ALIVE projects, thus I will often introduce the research I am doing as part of these projects within the lectures. Lectures and practical sessions are very closely linked. Indeed, after the student has completed all the 'standard' questions related to the lecture within a particular practical session, they are encouraged to look at the links to my own research.

Enabling the student to participate in research via projects: I am currently supervising four honours students on their final-year undergraduate project. Two of these students are working on projects specifically related to my research; one on a project related to ALIVE, and one related to some general research interests I have. These students also benefit from the knowledge within the department, so are encouraged to speak to research fellows and assistants working on similar projects.

Graduate attributes developed

Students are often confused by what is meant by 'research' - that is, if they ask a question related to the research project, they expect to receive a straightforward answer, as one would with an examination question. In other words, they find it unusual that the researcher does not know the answer - however, once they know that no one knows the answer, they are more excited by the concept of research.

Feedback

Students appreciate the 'applied science' nature of these projects in which there are 'real life' problems to be solved: within the ALIVE project, this involves the creation of complex systems to use web services, while in the ITA project, this involves helping the military to create teams and to collaborate. Students are often excited and shocked by the problems that the tools are being used to tackle. For example, in the ALIVE project, one of the aims is to help the Dutch Government prepare emergency responses for the expected humanitarian problems that will be encountered should the country's flood defences break down.

Sound Design (level 4)

Contact	Iain McGregor
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Discipline	Computing
Course title	Interactive Media Design
Level	Level 4 undergraduate
Unit/module	Sound Design (IMD10102)
Mandatory/optional	Optional
Number of students	17

Course details

The Sound Design module within the Interactive Media Design course at Napier University is run over a period of 12 weeks, involving 24 hours of lectures and 24 hours of tutorial sessions. The course covers the following broad teaching areas:

- making effective use of the underlying principles of sound design
- constructing effective methods of planning sound design
- analysing appropriate methods of implementing sound design
- appraising appropriate methods of evaluating sound designs.

As part of their coursework, students are asked to create a sound design for a five-minute section of an existing movie. Students are asked to critique the original soundtrack against their own. The sole lecturer assesses the module.

How research and teaching is linked

The lecturer is currently pursuing a PhD within the domain of soundscapes, that is, the study of the auditory environments within which people inhabit, and general sound design. Teaching is therefore drawn from his literature review conducted within those areas.

Graduate attributes developed

- A critical understanding of the way in which sound is designed for a variety of industries.
- The ability to analyse existing sound designs as well as to create alternatives.

Feedback

The module was introduced into the Interactive Media Design course in October 2008, thus, while there is some evidence that students appear to be enjoying it, complete feedback is not available at the time of writing. Feedback will be taken in the form of a questionnaire on the WebCT portal. Future plans include placing a greater emphasis on the critical theory of sound design, encouraging students to read more and to expose themselves from more examples from art as well as from industry. Thus far, the module has been a success, and will be run again next year, but more work needs to be done to motivate the lower ability students.

Distributed & Parallel Technologies (level 4/5)

Contact	Dr Greg Michaelson
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Discipline	Computer science
Course title	BSc Computer Science; MEng Software Engineering
Level	Level 4/level 5 undergraduate
Unit/module	Distributed & Parallel Technologies
Mandatory/optional	Optional
Number of students	~10-20

Course details

Traditionally, computers ran processes in a sequential manner; that is, processes were broken up into a list of instructions run on a single computer with a single central processing unit (CPU). Each of these instructions would run one after the other, and no more than one process could be executed at any one time. However, as technology has become more complex, and therefore demand for processing grows, the concept of 'parallelism' has been introduced to allow processes to run simultaneously through multiple processing units. This course provides students with an overview of the distributed/parallel hardware and software available. Students learn how to programme for parallel computers using the C and Haskell programming languages. The course runs for 12 weeks, with two lectures and one tutorial per week, and is delivered jointly with Dr Phil Trinder. Assessment is 20 per cent practical and 80 per cent examination.

How research and teaching is linked

Both academics are active researchers in parallel/distributed/mobile programming language design and implementation, and thus they often bring this research into lectures and tutorials.

Graduate attributes developed

- Critical understanding.
- Informed by current developments in the subject.

- The ability to identify and analyse problems and issues to formulate, evaluate and apply evidence-based solutions and arguments.
- An ability to apply a systematic and critical assessment of complex problems and issues.
- An ability to deploy techniques of analysis and enquiry.
- Familiarity with advanced techniques and skills.
- Originality and creativity in formulating, evaluating and applying evidence-based solutions and arguments.

Additionally, students gain a methodical/systematic approach to problem solving.

Feedback

Feedback from students, drawn via feedback forms and general discussions, has been extremely positive; they perceive it as 'techy' and challenging. Colleagues within the department now wish to include the course within the MSc programme. In the early days, the course suffered from a lack of support technology, but this has now been rectified, and the course is currently ongoing. More recent developments within the field, such as multi-core and vectorisation, are being brought into the curriculum.

Further information:

Lectures and tutorials for 2008/09 can be found at:
www.macs.hw.ac.uk/~greg/courses/F21DP2/index

Technologies for eCommerce (level 4)

Contact	Dr Abel Usoro
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Discipline	Computing
Course title	BSc Business Information Technology; BSc (Hons) eBusiness
Level	Level 4 undergraduate
Unit/module title	Technologies for eCommerce (COMP09055)
Mandatory/optional	Optional
Number of students	5-10

Course details

Technologies for eCommerce are used both in business and non-business organisations to make money, provide products and/or services, and make internal and external processes function more efficiently and effectively. This module begins by introducing students to different types of electronic organisations, showing how eCommerce technologies are used generally both for business and non-business purposes. The module then specifically examines critically how technologies of eCommerce can be used to manage processes and transactions, supply chain, and intellectual capital. The three areas are broad and therefore have sub sections. Several case studies are used to illustrate the concepts and themes of this module.

At the end of this module, the student will be able to:

- discuss the issues, problems and advantages of setting up and managing an e-organisation
- identify and recommend ways to manage, control and organise the systems, processes and transactions within an e-organisation and its supply chain
- distinguish between different types of e-organisations and evaluate their application to different scenarios
- critically evaluate, select and combine appropriate management strategies, methods and tactics in order to maximise the leverage of the intellectual capital in electronic organisations.

Two hours a week are spent on lectures, while one hour is spent on tutorials. Examination is 60 per cent and coursework 40 per cent. A minimum of 30 per cent must be achieved for each component of assessment.

Typical areas that students choose for the research-based coursework are e-learning, supply chain management, intellectual capital, e-payments, knowledge management, business process engineering (BPR), e-procurement and customer relationship management (CRM). I encourage students to regularly visit library shelf mark 658.054678 where there is a concentration of e-business books to do personal research topics as we discuss in the class. The outcome of their research would be evident in the tutorials which, more than lectures, require input from the students. The lecture itself is also very interactive; fortunately the class size is small.

How research and teaching are linked

About five years ago, I started a postgraduate module Global Information Systems (GIS) with the specific objective of making strong links with my research. The module requires students to conduct a rigorous, in-depth and critical secondary study in a small area of the module. The secondary study brings students to the frontiers of knowledge such that they can identify gap or conflict in knowledge to which they formulate research question(s) and then argue out a research model. This module has produced good work that covers eCommerce and its technologies and therefore fits into the module that I'm reporting about in this report. The GIS module has also produced not only PhD students, conference and journal papers with students as first authors, but also (GIS student) guest speakers to the Technologies for eCommerce (TeC) module. Some of the lecture materials of the TeC module are drawn from research done on the GIS module. Besides all of this, the module coursework itself requires students to apply the module on a live case study or to perform a mini secondary study in any small area of TeC similar to the requirements of GIS. This exercise has also produced good material that feeds into teaching. Students are taught how to search from e-journal databases and how to critique and use the materials for academic writing including proper citation and referencing.

Graduate attributes developed

- Critical understanding.
- Informed by current developments in the subject.
- An awareness of the provisional nature of knowledge, how knowledge is created, advanced and renewed, and the excitement of changing knowledge.
- The ability to identify and analyse problems and issues to formulate, evaluate and apply evidence-based solutions and arguments.
- An ability to apply a systematic and critical assessment of complex problems and issues.
- An ability to deploy techniques of analysis and enquiry.

Additionally, the following employability and personal development planning (PDP) skills are given in the course guide:

Knowledge and understanding

Knowledge of different types of e-organisations, a general knowledge of their technologies and how they are used to provide effectiveness and efficiency.

Practice - applied knowledge and understanding

Critically apply relevant approaches, technologies and techniques to appropriate organisational settings through the ability to critically synthesize and evaluate information from a variety of sources, such as the internet and research journals.

Generic cognitive skills

Critically analyse and evaluate existing knowledge and practices within the area of managing technologies for eCommerce, with a view to identifying and exploring ways in which key issues might be addressed further.

Communication, ICT and numeracy skills

Develop a critical understanding and an ability to communicate using a range of print and electronic communication methods for academic and professional audiences.

Autonomy, accountability and working with others

Exercise a substantial ability to work autonomously, demonstrating critical inquiry in producing quality work underpinned by rigorous investigation. Demonstrate an ability to manage and work autonomously with a range of self-directed learning resources.

Feedback

Students are delighted with the module. I was asked to do a reference for one of the students who applied to become a research student straight after his honours year. The coursework he produced on e-learning is now in line to be turned into a journal or at least a conference paper.

The external examiners have consistently given positive comments on the whole module and the performance of students. The whole module, including all the assessments, is also internally peer reviewed with consistent success.

Natural Language Generation (level 4 and postgraduate)

Contact	Dr Ehud Reiter
Institution	University of Aberdeen
Email	e.reiter@abdn.ac.uk
Discipline	Computer science
Level	Taught postgraduate and level 4 undergraduate
Unit/module	Natural Language Generation
Number of students	10 and 15-20

Research interests of lecturer

Over the past decade Dr Reiter has taught both at undergraduate and taught master's level at the Department of Computer Science. His research interests lie within the domain of Natural Language Generation (NLG), a branch of computational linguistics and artificial intelligence. He is interested in presenting information to human users in an appropriate and intuitive form, through the automatic generation of text or speech from large amounts of data.

Course details

i) This was a second semester course, made up of lectures and practical sessions. Dr Reiter and his colleagues used a software tool called 'Simple NLG' to demonstrate how NLG techniques could be used in practice. This tool was developed as part of ongoing research at Aberdeen. By basing teaching around the use of this tool, and of other research going on within the department, the course was made more exciting for the students, as they were able to see how the theories they were learning about were used in practice. Dr Reiter also used the opportunity to gain feedback on the tool from the students in order to make it more intuitive, so it also helped him to further his own research. (Note: this course is no longer taught at the University of Aberdeen.)

ii) An eight-week level 4 course in Natural Language Processing (NLP) coincided with a research project managed by Dr Reiter: a software tool was developed based upon NLP techniques to generate tailored letters to smokers to help them to stop smoking. The tool was demonstrated to students in one or two lectures. Students were given the opportunity to use the software and to see how it worked.

How research and teaching are linked

Introducing master's students to some of the ongoing research work at the University helps them to contextualise their learning within 'real life' projects. Grounding the research within lectures and practical sessions has made the courses feel more realistic to students. Dr Reiter felt that some students were more enthusiastic about the degree as a whole by being given the opportunity to see what work was actually going on locally at the University. This works more at level 4 and level 5 than at level 2 where the emphasis is more on the pragmatics of programming and database design.

Computer Security (level 5)

Contact	Dr George Weir
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Discipline	Computer and information sciences
Course title	MEng Computer Science
Level	Level 5 undergraduate
Unit/module	Computer Security (52.507)
Mandatory/optional	Optional
Number of students	~20

Course details

This course, which began in 2005, seeks to address key concepts in system and information security in relation to end-users and networked systems. Major threats, security risks, vulnerabilities and preventative measures are described in relation to desktop machines, intranets and internet-linked networks. The course runs as a mix of traditional lectures and student-led presentations. There are no separate tutorials. Over the past three years, the course has evolved slightly to take account of changes within the security arena, and is now taught jointly with two academics. Assessment is 80 per cent examination and 20 per cent coursework, with the lecturers marking all assessments.

How research and teaching are linked

Research topics are introduced in some lectures, and are also set as discussion topics for student-led sessions. Discussion materials are drawn from current computing publications such as *Communications of the ACM and IEEE Transactions*. The assessed coursework includes group activities such as critical reviews and presentations on sample topics.

Graduate attributes developed

- Critical understanding.
- Informed by current developments in the subject.
- An awareness of the provisional nature of knowledge, how knowledge is created, advanced and renewed, and the excitement of changing knowledge.
- The ability to identify and analyse problems and issues to formulate, evaluate and apply evidence-based solutions and arguments.
- An ability to apply a systematic and critical assessment of complex problems and issues.
- An ability to deploy techniques of analysis and enquiry.
- Familiarity with advanced techniques and skills.

Additionally, students also benefit from engaging in group work, which helps to develop skills in negotiation and collaboration.

Feedback

The course is successful in engaging students and helping them to appreciate current problems and techniques in the area of computer security. This view is based upon informal student feedback, and the level of student performance. Students appreciate the importance and relevance of the subject matter.

Computer Forensics (postgraduate)

Contact Dr Theodore Tryfonas
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Discipline Computer science
Course title MSc Computer Forensics (University of Glamorgan)
Level Postgraduate
Unit/Module Computer Forensics (IS4S05)

The content of this case study is drawn exclusively from the publication by Tryfonas (2008) and used with the permission of Dr Tryfonas.

Course details

Some of the challenges faced in the tuition of computer forensics have to do with student exposure to real life data in the course of practical sessions, as well as with delivering a relevant set of skills that reflects the requirements of the professional field. The development of a case-based environment can provide an appealing mechanism to students that may enhance engagement and deliver learning objectives in a practically orientated manner. The tuition of practicalities via an interactive, cohesive and meaningful environment as opposed to a number of unrelated topical tutorial sessions delivers the potential for a higher degree of student engagement in an environment that the instructor can set learning objectives against requirements that stem from the professional field itself.

How research and teaching are linked

We provide a learning environment including electronic resources for students: fictitious digital evidence, realistic case descriptions and paperwork, analytical toolset (forensic analysis workstation). (Further resources are included for instructors and the computer forensics teaching and learning community.)

The students are asked to contribute hypothetically into the disk analysis research by performing a forensic examination of the artefact handed out. In the example of this coursework (see below) the students were called to put together the individual skills they practise throughout all sessions. Most students were expected to conduct the investigative work required at our Computer Forensics Teaching Laboratory, fully equipped with academic versions of forensic software and appropriate hardware.

Graduate attributes developed

Students need to consider all aspects of analysis as required by the guiding research record sheet and write a short technical report documenting their findings.

Real life examples of similar work are provided, and students are guided to published work for research methods and outcomes that may help in their investigation.

Feedback

- Enthused students, as assignment had some real grounds.
- Better overall performance than last year's.
- Evaluative student focus group confirmed results.

Further information

www.ics.heacademy.ac.uk/projects/development-fund/final_reports/101ov_tryfonas-overview.pdf

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Example coursework requirements (as given to students): disk analysis research

You are part of Glamorgan's Information Security Research Group assisting with the on-going research on residual disc analysis, a longitudinal inspection on what is left on second-hand hard drives sold through on-line auction sites. Example results of this work in the past can be found at the following links:

www.news.com/Study-Businesses-falling-short-on-data-disposal/2100-7355_3-6209732.html

www.theregister.co.uk/2006/08/15/data_scavenging/

http://news.bbc.co.uk/1/hi/wales/4272395.stm

You have been assigned a forensically sound acquired image of a hard drive (raw image file HDD.img) and you're called to analyse it. You must:

- Fill in the analysis record sheet provided with the disc image (you do not obviously need to fill in the acquisition details on the form);
- Write a short **technical report**, of no more than 2,000 words, detailing your findings and observations with regards to the item inspected.

Related ISRG references to the research's methods and outcomes that could help you:

Thomas, P and Tryfonas, T (2007) Hard-drive Disposal and Identity Fraud, in *Security and Control of Identity in Society Workshop (SCITS 4), International Federation for Information Processing*, vol 232, pp 461-466, Johannesburg, South Africa, 14-16 May 2007

Jones, A, Valli, C, Sutherland, I and Thomas, P (2006) The 2006 Analysis of Information Remaining on Disks Offered for Sale on the Second Hand Market, *Journal of Digital Forensics, Security and Law*, vol 1, no 3, pp 23-36

Fragkos, G, Xynos, K, Angelopoulou, O and Me, V (2006) An empirical methodology derived from the analysis of information remaining on second hand hard disks, in *Proceedings of the First Workshop in Digital Forensics and Incident Analysis*, Glamorgan, UK, 1 December 2006

Jones, A, Mee, V, Meyler, C and Gooch, J (2005) Analysis of Data Recovered from Computer Disks released for Resale by Organisations, *Journal of Information Warfare*, vol 4, no 2, pp 45-53

4.4 Case studies - learning about research processes

This section presents case studies in which students are actively learning basic research methods and techniques through individual or group project work. Students must use their own initiative and creativity to develop responses to the problems set. Nine case studies are presented in order of delivery, beginning with undergraduate level 1 and concluding with postgraduate.[5]

Free Programming Projects (level 1)

Contact	Dr Quintin Cutts
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Discipline	Computing science
Course title	BSc Computing Science; BSc Software Engineering
Level	Level 1 undergraduate
Unit/module title	Computing Science 1P (7FWU)
Number of students	~180

Course details

This course introduces students to the skill of computer programming, and is one of two courses that students take on entry to a computing science degree programme - either Computing Science or Software Engineering Honours, or a range of joint degrees. The course may also be taken as a 'third subject' for those interested in finding out more about programming. The course is therefore mandatory for those intending Computing Science and related honours degrees, and optional for other students.

The course consists of two one-hour lectures and a two-hour lab every week, for 22 weeks. The lab session starts off in a tutorial room in case the tutor wants to undertake any small group teaching (group sizes ranging from 8-16), before progressing to the lab for practical programming activities. The teaching sessions are organised so that there is a weekly cycle where the two lectures straddle the lab session. The first lecture introduces a topic, the lab session comes next for all students, and in it they work with the topic practically, and the second lecture is developed 'just-in-time' on the basis of the feedback from tutors on their students' progress.

How research and teaching is linked

Introductory programming courses typically have a sequence of exercises developed by the teaching staff. The ownership of the exercises essentially lies with the staff. This course is unusual in that it has two opportunities where students are allowed to devise their own exercises - each is known as a 'free programming project' (FPP). While the FPPs do not necessary uphold a direct link to any particular research area, they support the development of a number of skills that might be thought of as research-oriented, such as:

- creativity and free-thinking
- ownership of work
- independent learning
- enhancement of problem-solving skills.

[5] Case studies are available at www.computing.dundee.ac.uk/rtl/casestudies.asp

Graduate attributes developed

- Critical understanding - the students need to analyse their problems, search for the relevant skills and techniques that they need to implement their problem, and develop their deeper understanding of the subject, through applying it to harder problems.
- An ability to deploy techniques of analysis and enquiry - as above.
- Informed by current developments in the subject - students become more aware of the subject around them.
- Familiarity with advanced skills and techniques - the students often pick up concepts and skills way ahead of their level, and sometimes approaching graduate level.

In addition, I would also suggest that the attributes mentioned in the previous section - creativity, free thinking, ownership of tasks, independent learning skills, and enhanced problem solving skills - are all fundamental graduate attributes that we would want all our students to have. The earlier they can be fostered, the better.

Feedback

The students approve of this aspect of the course in general. The information was gathered via questionnaire and focus group. Particular items that have surfaced in the evaluations are as follows (note that many of these could be comments coming from a first-year postgraduate student):

Expectations - students were uncertain of what was expected of them, and definitely appreciated the very open remit. One student said '[it would] put a lot of pressure on people if you started knowing exactly what standard was expected before you start'. Nurturing creativity and retaining it as an enjoyable activity may require this open remit.

Choosing - students on both courses found deciding on a project of appropriate complexity and interest to be very challenging. For example, one said 'Once you know what you're going to do, you can just get on and do it. But it's quite easy to get stuck with lots of bits of paper, wondering what to do'.

Design - students found it easy to pick something too large, only to get hopelessly stuck as soon as they got going with it. After radical re-thinking of their problem, this process helped students to appreciate the scale of problems.

Closure - students in particular wanted a greater sense of closure at the end of the FPP. Although tutors looked at all submissions, this happened right at the changeover between semesters and lecturers, and it appears that the impetus was lost. '...only thing that was missing was that final run down - well done guys, we like what we've seen, this is a good example of X, this is a good example of Y, clap, clap, clap'. Although the FPP is designed to encourage ownership, nonetheless, it is natural for humans to want their endeavours to be acknowledged. This closure aspect has been addressed in later versions of the FPP process.

Value of FPP within course - it is challenging to find the balance between permitting a student to do any project they like, no matter the size, and assigning a fixed proportion of the course credit to that project. A Glasgow student said 'Leaving it free is one of the most important things...ultimately it's your thing, and if you think it's good and it works then that should be accepted by your tutor'. Hence a small but perfectly-formed project is as good as one requiring many thousands of lines of code. But then another student pointed out that it was 'crazy that we only get one tick [assessment unit] for the program' - this clearly wasn't seen as enough for a student who had written a large program.

Generally-held benefits - these are summarised in this one quote: 'The whole concept of it, write your own program, write something that you want to write, work on your own through it, learn from your own mistakes'. There's a lot of ownership in that sentence. The sense of learning is evident in other comments, where students acknowledge that they are much more able to solve their own problems using web-based resources: 'half the time writing code, the other half browsing docs - the internet is my friend'. Students variously recognised the value of doing their own work, thought it more interesting, or appreciated the value of integrating skills and knowledge.

Inverting expectations of learning - students were genuinely surprised to find the FPP went firmly against their expectations of learning, exemplified by these quotes: 'if we write our own program then we may end up with something we'd actually use' implying that artefacts of a learning process are usually entirely academic; '...getting credits for something you thought of on your own' implying perhaps that knowledge and skills leading to credit traditionally only come from others; and 'it's funny that computing, considered as one of the least creative subjects [at school?], gives you the most creativity in first year, which is quite cool'.

Taking it forward

The FPP will remain a component of this foundational course. We are developing a number of simplified library units that will enable the students to complete more impressive projects than many of them are currently able to do. We expect this will enhance their sense of ownership and ultimate satisfaction.

Inquiry-based learning in the first-year (level 1)

Contact	Dr Andrew Cox
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Discipline	Information studies
Course title	BSc Information Management
Level	Level 1 undergraduate
Unit/module title	Inquiry in Information Management (INF106)
Number of students	~30

The content of this case study is drawn exclusively from the publication by Cox, Levy, Stordy and Webber (2008) and used with the permission of Dr Cox.

Course details

The Inquiry in Information Management module is a module drawing upon an inquiry-based learning (IBL) approach. Students undertake a small scale, group research project, choosing a research question, conducting the research and reporting their results in poster form to invited staff and their peers, while also maintaining a group blog. The module builds on first-semester modules that introduce students to foundation principles and concepts in information management. It is structured around one two-hour workshop each week for 12 weeks, plus group tutorials and independent activity.

Two main aims are:

- to enhance students' engagement with, and understanding of, information management as an academic discipline and professional practice
- to provide students with an opportunity to develop their research understanding and skills.

We felt that an inquiry-based approach would help students to develop as creative, critical and inspired learners, as well as to develop their inquiry-related understanding and skills, including in the area of information literacy. Setting out explicitly to engage first-year undergraduates in a collaborative 'research community' activity was also a way to involve them at an earlier stage in the research-led culture of the Department and the University. We hoped that including our undergraduates at the earliest stage of their career in one of our most valued practices - that of research - would begin to induct them into the community of inquiry represented by the Department of Information Studies, and to introduce them to the connections between research and practice in information management. Beyond this, we wanted to contribute to fostering a critical, 'inquiry orientation' amongst our students that we see as central not only to academic endeavour but to life and work outside the academy in a profoundly complex and challenging world.

The **central inquiry task** invited students to work in groups of three to carry out a small-scale research project, from generating a valid, practical and worthwhile research question through to presenting findings at a research 'mini-conference'. Conducting such research implied some depth of engagement with the thinking and concerns of the discipline, and an introduction to assumptions underpinning typical approaches to research methods. Students started work on these projects in the fourth week of 12, following a series of preparatory workshops. Each research group had a member of staff acting in an advisory capacity. Tutorials were held as part of some of the workshops and at other times. Groups also discussed how to locate relevant literature for their project with a subject librarian, and gained feedback on their developing projects from two visiting expert practitioners. Projects chosen included:

- a usability study of the university portal, drawing on student input through questionnaires
- a study of the use of Facebook for personal information management, based on an online focus group
- an investigation of intellectual property rights issues in the University, based on expert interviews.

In the final week, groups presented research posters to each other and guests, including the Head of Department and other staff and student researchers from the Department.

How research and teaching are linked

In designing Inquiry in Information Management, we wanted to embed an authentic, if small-scale, research experience into the first-year BSc curriculum, thereby inviting students, with our support, to engage with the challenge of taking a significant level of responsibility for both the direction and process of their learning within the module. While we did not design the module as a detailed 'introduction to research methods', we did want to introduce a relatively strong focus on exploring the nature of the research process and on fostering students' self-reflexive awareness of themselves as developing researchers. We did not attempt to consider different research paradigms, or explain data collection methods, in any depth. Instead, we aimed for students to gain a sense of the overall shape of a research project at an early stage in their undergraduate careers.

We were fortunate to have the opportunity to hold all the module workshops in a CILASS 'inquiry collaboratory' - a newly-refurbished learning/teaching space designed specifically to facilitate information - and technology-rich collaborative inquiry activity (see www.jisc.ac.uk/eli_learningspaces.html). Its facilities enabled students to access a wide range of digital resources during workshop activities, and also to generate digital material that included presentation slides, blog entries and material captured from (off-line) whiteboards. The room was arranged to enable students to cluster in small groups with access to laptops and plasma screens, which were used for group presentations. Whiteboards were available to write on, and 'copycam' technology and digital cameras were used to capture material generated on these for uploading to the module's virtual learning environment (VLE) site.

As well as making a range of resources available via the VLE, we made extensive use of it to capture and share student work and workshop activity. It was also used to support individual student reflection, with each student having a 'personal journal' space using the bulletin board tool. A blog was created for each student research group and we encouraged groups to use their blog to discuss, record and reflect on their research activity. The teaching team kept a blog that was accessible to students via the VLE. We used this blog to discuss aspects of 'doing research' from our personal perspectives and to reflect on the use of blogging to support research activity.

Feedback

Overall evaluation pointed to positive impact in engaging students with both information management and the process of inquiry. The particular highlight, for us, was the quality of many students' engagement with the inquiry task and the student work that was presented at the mini-conference. Students had successfully defined a research question, gathered primary or secondary data, analysed them and produced effective presentations of the results in poster form. This represented a rounded accomplishment and a level of engagement in research that we rarely demand before the third undergraduate year. All the work was good, and several pieces were excellent. Students' depth of understanding, while not always fully reflected in the posters, was evident in their discussions around them at the closing mini-conference. This was remarked on by guests, and it was clear that students (rightly) felt pride in what they had produced and that presenting work to external visitors was motivational and satisfying. Following on from the conference, we have displayed students' posters alongside other research posters in the Department.

Student attendance on the module was high overall, and some workshops in particular generated a high level of interaction amongst peers. Student feedback via a number of channels (focus group, feedback questionnaire, reflective portfolios) was positive, with the new module gaining high scores on questionnaires on every criterion.

Further information

www.ics.heacademy.ac.uk/italics/vol7iss1/pdf/Paper1.pdf
www.shef.ac.uk/cilass/cases/informationmanagement.html

Professional Development Theme (levels 1 and 2)

Contact	Dr Jim Bown
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Discipline	Computing
Course title	BSc Computing; BSc Web Design and Development; DipHE Computing and IT
Level	Levels 1-2 undergraduate
Unit/module	Professional Development
Mandatory/optional	Mandatory

Course details

The Professional Development Theme is 25 per cent of the first three years of study and 50 per cent of the final year. The Theme encapsulates underpinning academic skills, an awareness of professionalism within the field of computing, and projects, both as an individual and in groups. In year 1, students will be exposed to problem solving and presenting ideas in an interdisciplinary context. Year 2 considers the development of academic reading and writing skills in a programme-related area. In year 3, students will explore issues facing the computing professional, planning large projects and intra-disciplinary group working. Year 4 will focus on a single and substantial honours project in a programme-related area. This case study focuses on years 1 and 2 of this theme. The four modules that comprise this case study are mandatory and there is one per semester per year.

In the first year, the modules are part of the Computing, Web Design and Development, and Computing and IT programmes with approximately 60 students undertaking the modules. The modules are co-taught to approximately 60 Nursing and Mental Health, and Counselling students. Students work in multidisciplinary groups to develop solutions to problems at the interface between computing and healthcare. Students develop a solution concept, create a range of presentational materials describing their concept, and present this solution. Students will be introduced to the concepts of group dynamics and team working, and will carry out research in a case study area to distil, highlight and evaluate relevant aspects of that case study.

In second year, the modules are part of the Computing and DipHe Computing and IT programmes of study with approximately 35 students undertaking the modules. In first semester, students identify a software tool and/or technology and explore its operation and function. Students create short user notes on their selected tool and/or technology that describe its purpose, how to use it and a short critique on its operation and performance. User notes are then peer reviewed in accordance with a structured framework and feedback given to authors. User note authors then update the user note in response to peer review. In semester 2, students select a topic area related to their programme of study. Students research into that selected area using suitable resource bases. This material will be structured, summarised, extended with additional material where appropriate, and integrated to form the basis of a report. Students create a written report based on the integration of that material in a prescribed format and properly reference source material. Students create a poster that communicates the key aspects of their research.

The modules are 100 per cent coursework, in line with all of our first and second year modules, assessed by the module tutor. The first year modules are a substantial redesign of modules that are three years old. The second year modules are new to session 2008/09. The modules have been redesigned to meet the University's new graduate attributes (see below).

How research and teaching are linked

In both years I seek to foster research-mindedness in the students. The attitudes and skills that these modules promote are, I believe, fundamental to the research process generally and of particular value in interdisciplinary research.

In first year, students are encouraged to think as creatively as possible and not be constrained in their solutions to problems posed by a lack of technical knowledge. This provides them with the opportunity to create ideas beyond their discipline underpinning, drawing on a range of previous and current knowledge. Students develop solutions to problems that span disciplines by working in multidisciplinary teams. This will require the development and exploitation of a range of new skills including team-working and presenting.

In second year, students must, with guidance, select an appropriate tool or technology to investigate and document how to undertake that process. In semester 2, students must investigate a selected area of development in their subject domain and report on that area in accordance with a defined framework. In both cases, students must develop the knowledge needed to undertake the investigations. In the case of semester 1, students must peer review documentation and feed back to those peers on the clarity and overall quality of that documentation to inform writing in subsequent years.

Graduate attributes developed

- Informed by current developments in the area.
- An awareness of the provisional nature of knowledge, how knowledge is created, advanced and renewed, and the excitement of changing knowledge.
- The ability to identify and analyse problems and issues to formulate, evaluate and apply evidence-based solutions and arguments.
- An ability to deploy techniques of analysis and enquiry.

Feedback

First-year students have reacted very well in comparison with previous years for the first semester. Engagement, and consequently submission rates, have been excellent. Feedback has been gathered informally through the distribution of post-it notes to gather comments from students and dialogue with students in laboratory sessions.

Second-year students have enjoyed the user note preparation of first term. They perceived the writing of such user notes as an industry-relevant activity and it was their first experience of self-selecting what topic/technology they were to study.

Positives and negatives

Overall, the modules ran well. There were minor issues in each year but nothing that cannot be addressed. For example, in first year, participation in groups caused some issues. These problems were managed by having sessions that focused on group progress and interactions that were distinct from the lab sessions that related to content generation.

In second year, the prospect of self-directed study was challenging for some students, but this was addressed through support in lab sessions in helping students identify appropriate tools to base user notes on.

Taking it forward

We plan to run the course again. For the first year, first term we will introduce an interim presentation on progress to expose any problems with group working at an early stage. This should limit the impact of differential participation in year 1 groups.

For the second year, we used staff-generated case studies of user notes. Next year we will provide a number of real, anonymised case studies that comprise the original user note, peer review and revised user note. This should reduce the sense of uncertainty that students reported.

Practical Interaction Design (level 2)

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Discipline	Computing
Course title	Interactive Media Design
Level	Undergraduate level 2
Unit/module	Practical Interaction Design, IMD08101
Mandatory/optional	Mandatory part of the Interactive Media Design programme, optional to other students within the school

Course details

Students in this module learn practical and professional skills in interaction design with an emphasis on hands-on experience of the interaction issues arising from new digital media. Students learn about how the principles of Human-Computer Interaction (HCI), interaction design, affordance and familiarity can contribute to influence the design of interactive media. Additionally, students are introduced to various HCI and interaction design methods to design and evaluate interactive systems to ensure that they are both usable and accessible. Such interactive systems can include hand-held devices, mobile communication systems, games, entertainment and social media.

Students attend a two-hour lecture, a one-hour lab and a one-hour classroom each week for a period of 12 weeks. There are no lectures or labs in week 11, as this is when the 'design crit' takes place, whereby students demonstrate their coursework. Tutorials are designed to provide students with hands-on experience of a range of practical interaction design techniques through applying them to their coursework. Students undertake three courseworks, attracting 50, 25 and 25 per cent of the module assessment respectively. Normally, the tutorial relates to the lecture material for that week. Because of the link to coursework, it is essential that students bring their work-in-progress each week. They are also expected to work on the coursework in their own time. Experience suggests that not all will do this, so in these cases some of the tutorial time - depending on the task - may need to be used for catching up on an individual basis.

How research and teaching are linked

The entire module is based upon the research of the module leader, who has investigated and published extensively upon the concepts introduced. The module uses material from the following publications:

Turner, P (2009) Practical Interaction Design, in *Proceedings of HCI Educators*, Dundee, UK, 22-24 April 2009

Turner, P (in submission) Distinguishing between Interaction design and HCI, *Interacting with Computers*

Turner, P (in submission) Are Stereotypes Inevitable When Designing With Personae? *Interacting with Computers*

Turner, P (2008) Towards an Account of Intuitiveness, *Behaviour and Information Technology*, vol 27, no 6, pp 1-8

Turner, P (2008) Being-with: A study of familiarity, *Interacting with Computers*, vol 20, no 4-5, pp 447-454

Turner, P, Turner, S and Van De Walle, G (2007) How Older People Account for their Experiences with Interactive Technology, *Behaviour and Information Technology*, vol 26, no 4, pp 287-296

Turner, P and Van De Walle, G (2006) Familiarity as a Basis of Universal Design, *Journal of Gerontechnology*, vol 5, no 3, pp 150-159

Turner, P (2005) Affordance As Context, *Interacting With Computers*, vol 17, no 6, pp 787-800

Graduate attributes developed

- Informed by current developments in the subject.
- An awareness of the provisional nature of knowledge, how knowledge is created, advanced and renewed, and the excitement of changing knowledge.
- The ability to identify and analyse problems and issues to formulate, evaluate and apply evidence-based solutions and arguments.
- Originality and creativity in formulating, evaluating and applying evidence-based solutions and arguments.
- An understanding of the need for a high level of ethical, social, cultural, environmental and wider professional conduct.

In terms of this specific module, students will be able to:

- select and use appropriate methods to design and evaluate interactive systems
- describe the key issues in designing usable interactive systems
- comprehend the importance of universal design
- design, develop and evaluate interactive applications adopting a problem solving approach
- demonstrate an insight into the role of familiarity in the design of interactive systems.

Feedback

At the time of writing, this is the first time this module has been run, and has proved to be surprisingly popular. Feedback has been gathered from feedback forms, but more usefully by means of a focus group. The accessibility lecture did not work out too well, but this may be because too much theory was involved. On the other hand, the dialogic nature of design seemed to work, as did the recognition that evaluation is central. A significant problem to arise was the inability of students to ignore simple instructions. There are plans to run the course again next year taking into account these issues.

Further information, including coursework assessments

Further details of the module, including the coursework timetable, and further details of each of the coursework assessment are given at:
www.computing.dundee.ac.uk/qaa_report/casestudy5.asp

Nuffield Undergraduate Student Research Bursary (level 2)

Contact	Dr Johannes Zimmer
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Course title	Nuffield Undergraduate Student Research Bursary
Level	Level 2 undergraduate
Mandatory/optional	Optional

Course details: analysis in asymmetric metric spaces

In mathematics, a 'metric' is essentially a distance function. In this project we investigated what happens if the assumption that distances are symmetric is removed, that is, what would happen if the distance of x to y were different from the distance of y to x? Counterintuitive as this may seem, there are surprisingly many applications in the worlds of fracture mechanics and materials science, some of which have only recently become apparent. Although work has been done on asymmetric metrics since the invention of metric spaces in the 1930s, it is still an area which is poorly understood and there are many questions still to be asked and answered. The main question we looked at in this project was whether one of the major theorems in analysis, the Arzelà-Ascoli Theorem, can be generalised to the asymmetric case, and we found that the answer was by no means as simple as people expected.

How research and teaching are linked

The research bursary has been successful in several respects. Firstly, an open problem has been solved by Julia which we need for an analysis of gradient flows in asymmetric metrics and their applications in materials science. This is linked to the second successful aspect: I feel that the project has been valuable in an educational way, since Julia had to work persistently, creatively, and had to familiarise herself with the literature.

Graduate attributes developed

The Nuffield project was useful in giving me both some technical expertise in my subject area and also good research habits. Very often I see people coming into research and not knowing what it involves or how to manage their time, so an undergraduate project is a great way to get preparation for that kind of thing.... The bursary also gave me the chance to learn new skills, such as typing in LaTeX, which will be invaluable for my future career (Julia Collins, Nuffield Student 2005, currently in third year as PhD student).

Feedback

Supervisor: it was crucial both to identify a relatively basic question that nevertheless relates to current research and have an extremely strong and motivated student work on it. I am delighted that the project encouraged her (Julia) to pursue a PhD. The scientific outcome of the project was of interest to several colleagues in quite different branches of mathematics, and a paper describing the outcome has been submitted to a well-established journal.

Student: doing this bursary was one of the best decisions I ever made. In just one summer I have met so many new and interesting people, been exposed to new and exciting areas of mathematics, learnt many new skills, and in conclusion have been completely inspired to do a PhD.... The experience was unlike anything I had encountered before, and I was surprised at how differently I had to work compared with my undergraduate studies. There were no clear aims at the start of the project, yet so many new questions kept arising that I never struggled to decide where to go next. The work was difficult and frustrating at times.... But this was a good thing for me to have encountered and I feel prepared for the hardships of embarking on a PhD. Before this summer I was slightly put off the idea of a PhD because I thought that studying the same thing for 3 years would become boring, but now I realise that research will always create more questions than answers, and even in 8 weeks I was surprised at the range of topics I covered.

Museum of Lost Interactions (level 3)

Contact	Graham Pullin
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Discipline	Computing
Course title	Interactive Media Design
Level	Level 3 undergraduate
Unit/module	Interactive Product Design (IM31001)
Mandatory/optional	Mandatory
Number of students	20

Course details

Twenty level 3 students were asked to explore the history of interactive design and reflect on the social impact that the technological changes have brought. They were asked to research Lost and Dead Media and build working models (using found objects and MaxMSP on iMacs) of fictitious historical products that might have been lost precursors to modern products and media. To underpin their authenticity, they filmed documentaries with archive film footage, and uncovered contemporary photography and packaging.

How research and teaching are linked

My research is about taking complex issues but using designed artefacts to make those issues more tangible and to help people discuss them. That's a good skill for any interaction designer to have in their armoury. So I'm hoping that I instil skills that they can use in the future. My research also covers new interactions with speech technology, and I find that I get much inspiration from historical examples of technologies than contemporary examples. If you look back to the historical examples, you will find that they are arguably more radical yet still as relevant today, and applying these historical ideas to modern computer-generated speech is very exciting for me.

Graduate attributes developed

One of the module's learning outcomes is: 'Demonstrate an appreciation of the state-of-the-art and research frontiers in interactive space design'.

Students' design skills would be markedly improved by the attention to detail that creating credible fakes would demand. By researching a historical context, deeper reflection on the relationships between societies and technologies would be encouraged.

The crafting of the exhibits is an example of 'learning through doing' described by Race and others. Researching the historical period and its contemporary technologies, and holding class discussions, ensures that reflective practice begins even at undergraduate level.

Feedback

The students created the exhibits, staged an exhibition in December 2006 and built a website. By April 2007, the website has received 30,000 hits and has been referenced on over 250 other websites worldwide. The quality of the students' design skills is indicated by the number of visitors to the exhibition and website who were taken in by the artefacts. The opportunities for critical reflection are indicated by the interest the project has attracted worldwide, with respectful articles appearing on respected websites, and interviews on BBC radio. The MoLI website includes a student testimonial (www.idl.dundee.ac.uk/moli).

The entire class contributed beyond the demands of the module. Eight out of the nine exhibits were realised to such a high standard that all eight have received separate, individual recognition on the internet. This overwhelming outcome speaks of the dedication and mutual support of the entire class, itself an indication of how engaging the design brief and teaching have been.

Further information

http://imd.dundee.ac.uk/moli

Research Experience in Mathematics (level 3)

Contact	Dr David Brown
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Discipline	Mathematics
Course title	Mathematics
Level	Level 3 undergraduate
Unit/module	Research Experience in Mathematics
Mandatory/optional	Optional

The content of this case study is drawn exclusively from the publication by Brown and Yurekli (2007) and used with the permission of Dr Brown.

Course details

Serving as a sort of capstone for the inquiry-based approach to mathematics is the research sequence of courses in the junior year. The sequence emphasizes that students truly 'own' the mathematics that they create and requires that they be able to clearly articulate their ideas. The problems in this course are at the level expected of juniors with significant mathematical background and maturity. The first course in the sequence, Junior Seminar, is required of majors, while the follow-up course, Research Experience in Mathematics, is an elective course. Instructors in the research sequence provide project topics, background information, and when necessary, guidance. Instructors take a hands-off approach, turning over the control to the students. Careful not to overly influence the direction of the research, instructors listen to the students' progress, provide comments, and query the students on the next steps.

For several reasons, this research sequence appears as an opportunity during the junior year. Since we hope to excite some students into deciding to pursue graduate studies in mathematics, having this opportunity as early as possible allows the students to apply for REUs, focus on a more concentrated self-guided study of mathematics, and the possibility to complete an Honors in Mathematics during their senior year. In addition, for students with very strong results, it provides time to complete a paper for publication before graduation, and hopefully, coinciding with their application to graduate schools. Another reason for the junior year timing is that we have a substantial number of teacher education students in our program. They do their student teaching during their senior year, so this schedule allows them to participate in the research sequence.

How research and teaching are linked

While the Junior Seminar is required for all math majors, the follow-up course is not required, thereby giving students who do not like this approach (there are students who do not like the open-ended approach of research) the opportunity to opt out of the research track. Most students do remain in the research sequence; in fact, the follow-up course has run at capacity in all years that it has been offered. There is a 'buzz' about research among the students.

Research Experience in Mathematics, the main course in the research sequence, focuses on the students' sustained and in-depth investigation of a research question initiated in the Junior Seminar. Completion of the research project involves, in addition to the mathematical arguments, a written report consistent with the standards of publication in mathematics and a public presentation at an academic symposium or conference.

Graduate attributes developed

A certain level of carefully monitored frustration leads the students to gain confidence, insights, and ultimately success. Implicit in all of this is the prudent choice of research projects and finding a reasonable match between projects and students. Another important component of the research sequence is the dissemination of completed student work. As important as it is for each student to develop strong research and proof skills, it is equally important that they be able to express their ideas in written and oral presentation. Students in the sequence are required to write research reports and each student is required to present their work at a mathematics conference or academic symposium. In addition, students must present their progress to the instructors during each class meeting. This continued emphasis on presenting mathematics fosters deeper understanding and stronger skills.

Required of all mathematics majors, the one credit Junior Seminar provides students with an introduction to mathematical research, including literature searches, proper mathematical writing and citation, and the idea of documenting investigations. The two instructors for this course will also conduct the Research Experience in Mathematics course in the Spring semester. Students investigate problems that are generated from previous research projects with undergraduates and from new projects designed by faculty. Students work in groups and present their findings each week to the instructors and the other class members. The problems chosen by the faculty are done so with the follow-up course in mind. While students work on problems, they are gaining the necessary background for the big projects that will occur later. Working on the multiple topics provided by the faculty, students get a sense of which topic might appeal to them as a research project for the entire year.

Feedback

The most striking outcome of the research course sequence is the student excitement generated within the experience. Students display incredible growth of self-confidence and the ability to independently learn mathematics. Emphasis on writing has strengthened their ability to communicate mathematics and improved their proof writing skills. Presentations at academic symposia and at conferences reinforce self-confidence and independence in developing mathematical ideas for themselves.

Students are able to defend their work, see the next logical steps in extending what they have done, and have a good sense of where their work sits in relation to other mathematics. More tangible outcomes include success as measured by conference participation and publications. Since the research curricular option began, student participation in conferences has grown dramatically. Students have presented in the J.J. Whalen Academic Symposium (Ithaca College's research conference), the National Conference on Undergraduate Research, the Nebraska Conference for Undergraduate Women in Mathematics and the Hudson River Undergraduate Mathematics Conference (HRUMC). HRUMC is the most anticipated event for our students each year and student speaker participation has grown to 12-15 speakers per year. Students now seek out faculty in the sophomore year, wanting to be involved in the research.

Publications provide another hallmark of the success of the program for students. Since the start of the research program, students have published seven peer-reviewed articles and more are in the review and submission process.

Research Summer Schools (level 3)

Contact	Dr Martyn Quick
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Discipline	Mathematics and statistics
Course title	Research Summer School
Level	Level 3 undergraduate

Course details

Students are recruited to separate schools in pure mathematics (concerned with algebra and analysis), solar theory, vortex dynamics, statistics, and so on. Each summer school runs for a period of (typically) six to eight weeks. During this time, students are introduced to topics on the interface between their undergraduate degrees and research interests of the staff involved.

In pure mathematics, typically lectures occur during the first half of the school, and in the second half of the school the students are set projects relating to research topics. Their conclusions are usually written up as project reports in the final week of the summer school. In applied mathematics, the schools are conducted more similarly to PhD supervision. The lecturers describe particular research problems to the student, who then spend all their time on research.

Undergraduates are usually recruited during their third year to attend the school between their penultimate and final years of study. Only those students who have performed well (typically, first class honours standard) on their modules in the January exam diet attend. Around 6-12 students attend each of the pure mathematics and applied mathematics schools, while a smaller number (two or three) attend statistics research schools. Furthermore, in the past five years, all divisions have attracted a fair number of students from other universities (including Oxford, Liverpool, Edinburgh and I'm told Cambridge and Imperial) to the summer school. The University has agreed a summer internship exchange programme with IAESTE. Last summer, we funded an outstanding Austrian student to attend the Pure Maths summer school. Further well-qualified undergraduate students from the EU will attend the summer schools held in 2009.

The precise details of each school vary. For the algebra half of last summer's pure maths summer school, we ran one lecture every morning for three weeks and one 'tutorial' almost every day for the whole six weeks. The term 'tutorial' is inappropriate, however, since in reality these were more discussion sessions where we experimented with mathematics, the students presented attempts to the projects set, and alternative and further project questions were raised. The analysis part of the school was run similarly. As mentioned above, the applied maths summer schools tend to follow more the PhD supervision model.

There is no assessment. The purpose of the course is to expose students to research methods and topics. It serves as motivation and advertising for PhD courses.

History of summer schools at St Andrews

Research summer schools of some form have been running in St Andrews over 30 years. Professor Hood tells me he attended one in the 70s when he was an undergraduate. Three of the current pure maths staff (two lecturers, one postdoc) attended summer schools when they were undergraduates.

In the last 10 years, there has been focus on the schools and we have increased the intake. Both pure maths and applied maths have greatly increased their intake from a few students to now taking a significant group of students. It is now viewed as an important recruitment opportunity for our PhD programmes.

Originally, the pure maths summer schools were run along similar lines to the applied maths ones. They followed the PhD supervision model. The major development here has been an intertwining of the algebra and analysis groups were they run systems of lectures in parallel and students attend to learn mathematics as well as see how research projects arise out of what they learn.

Links between research and teaching

There is direct link between the research and teaching. The topics chosen are those directly related and informed by our research interests. Students start the course with usually solid understanding of undergraduate mathematics, but are then required to perform investigations in a manner far more in tune with research activities.

Graduate attributes developed

- Critical understanding.
- Informed by current developments in the subject.
- An awareness of the provisional nature of knowledge, how knowledge is created, advanced and renewed, and the excitement of changing knowledge.
- The ability to identify and analyse problems and issues to formulate, evaluate and apply evidence-based solutions and arguments.
- An ability to apply a systematic and critical assessment of complex problems and issues.
- An ability to deploy techniques of analysis and enquiry.
- Familiarity with advanced techniques and skills.
- Originality and creativity in formulating, evaluating and applying evidence-based solutions and arguments.
- An understanding of the need for a high level of ethical, social, cultural, environmental and wider professional conduct.

Another attribute the students develop is the realisation that not all problems have simple solutions. Rather, real problems can sometimes be solved by calling on a wide range of methods taught across an undergraduate degree.

Evaluation

Quality mathematics is done during the summer schools: there are even cases of research publications written as a consequence. The students are motivated and choose to take their studies into a research situation. In addition, students tend to tell other undergraduates about their time, making recruitment relatively straightforward. Hence, students react very well and typically return to their curricular studies with renewed enthusiasm and motivation. We frequently see a marked increase in performance and many go on to study for PhDs afterwards.

Very few problems have arisen over the years. The occasional student fails to turn up to as many contact times as would be expected, but this is rare amongst a typically very motivated selection of students. Sometimes students choose to head off into investigations that are dead ends, but even this can be a learning process where the student can learn to discuss more carefully his ideas with the supervisor.

Future development

We expect to run these summer schools for the foreseeable future. We are investigating the amount of staff time involved in running the schools. They tend to be rather intensive of staff resources, so we seek how to continue to run them with reduced contact time yet still at the current high impact level on the students.

Further comment: Dr Lars Olsen

The students react very well and typically return to their curricular studies with renewed enthusiasm and motivation. We frequently see a marked increase in performance and many go on to study for PhDs afterwards. There are even cases of research publications written as a consequence. The students are motivated and choose to take their studies into a research situation.

Further comment: Professor Nik Ruscuk

I would say that more than 50 per cent of students taking part in our summer programmes continue to PhD studies. Roughly speaking, about 50 per cent of them stay in St Andrews, and 50 per cent go to other institutions. Excellent experience for all involved. It is, however, quite time consuming for staff.

Further information

Information about one past summer school in algebra can be found at:
www-circa.mcs.st-andrews.ac.uk/CIRCA/summerproj.html

Information about some past summer schools in analysis can be found at:
www.mcs.st-and.ac.uk/pg/pure/Analysis/Summer.html

Electronic Virtually Enhanced Research-Engaged Student Teams (EVEREST) (level 4)

Contact	Professor Julian Newman
Institution	Glasgow Caledonian University
Email	J.Newman@gcal.ac.uk
Discipline	Computing (School of Engineering & Computing)
Level	Level 4 undergraduate and postgraduate
Mandatory/optional	Optional

Course details

Electronic Virtually Enhanced Research-Engaged Student Teams (EVEREST) has been conceived as a rolling programme offering research opportunities to successive cohorts of advanced students (typically honours and master's level).

The aim of the EVEREST project is to lay the foundation for building such communities of student investigators across university boundaries. The infrastructure for collaboration will be built on an interworking services grid architecture in which each service will be capable of enforcing its own security policy according to user requirements. The work is being undertaken as a rolling programme by a number of students handling successive phases.

An initial study was conducted by two TEMPUS students on exchange from Astrakhan in May to June 2008. We were not successful in recruiting honours students to participate in the project in September 2008 as originally intended, but another TEMPUS student, from Kherson, is undertaking a full master's dissertation within the project from January to May 2009 and we expect to involve further students, both honours and MSc, from May and September 2009.

A service-oriented architecture appears particularly amenable to this style of development, which reflects the success of the FLOSS/GNU open source approach (Claburn, 2007) and the Mangrove semantic web project at the University of Washington (McDowell et al, 2004). As the initial results come on-stream, students at other institutions will be invited to participate and the developers themselves will form one of the first Student Virtual Scientific Communities.

4.5 Case studies - sponsored research studentships

BBSRC and the Nuffield Foundation both provide funded studentships for undergraduate research. BBSRC offer undergraduate mathematical biology vacation bursaries to maths departments holding BBSRC research funding, 'so they can experience work in a research laboratory'.[6] Feedback from 2007 participants indicates the success of these vacation scholarships in meeting this aim:

> 'Overall, I feel the summer studentship was extremely worthwhile. The placement has led to the student being more interested in mathematical modelling and simulation and she has transferred from our 3 year BSc to our 4 year MMathStat degree' (Nuffield, MSOR).
>
> 'When applying for this studentship, I was looking for some idea of the kind of work a job in research might entail and some guidance on whether to undertake a master's year. I feel more persuaded to pursue the master's route and thoroughly enjoyed the studentship' (Nuffield, MSOR).
>
> 'It is evident that the student got a lot out of the project in terms of research experience' (Nuffield, MSOR).
>
> 'After taking on this project, I feel that I may well go on to research and I know I will find it enjoyable and stimulating' (Nuffield, MSOR).
>
> 'I applied for the bursary with a view to finding out something about research in general but was completely surprised by how fascinating I found my time working in the SBC' (Nuffield, MSOR).

Nineteen such vacation bursaries in undergraduate mathematical biology have been awarded in 2008, four of which have been to Scottish universities.

Nuffield Foundation offers up to 400 undergraduate research bursaries each year, 'allowing students across the UK to experience first-hand what it would be like to be a scientific researcher'.[7] Approximately 10 per cent of these awards were given to students of information or mathematical sciences in the period 2004-2008, with mathematics students receiving slightly more than half of these.

[6] www.bbsrc.ac.uk/funding/studentships/vacation_bursaries.html

[7] www.nuffieldfoundation.org/go/grants/nsbur/page_412.html

We contacted around 170 academics who had received a Nuffield award to ask about their projects, and the experience supervisor and student experience. As with BBSRC, student and staff responses were generally extremely favourable and a large number of positive comments were received from supervisors (table 2) and students (table 3). Further details are provided in the snapshot case studies thereafter and also at the project website.[8]

Institution	Department	Supervisor comment
University of Cambridge	Computing	This was the main advantage of the Nuffield funding - the way that it was the student's 'own' funding rather than simply acting as a short-term contributor to an existing project, as is more often the case in undergraduate research.
University College London	Computing	The student really benefited, and that is the main point. They saw what research was like. Liked it, and then went off to do a PhD.
University of Kent at Canterbury	Computing	The student in question got a real experience of research as it is done (at least in computing): the messiness as well as the excitement. He also got experience of technical writing and presentation.
University of Nottingham	Mathematics	I believe the student learnt what it was like to work on a non-trivial (open) problem using his own strengths and gave them confidence that they could work independently.
University of Glasgow	Mathematics	It gave her a reasonable idea of what working as a research student was like. It also gave her an opportunity to take a bit of mathematics and explore it in a much more open way than you normally would in a lecture course.
Imperial College London	Mathematics	I think the student learnt a lot and benefitted considerably from the experience.... He also learnt how research was not the smooth path from hypothesis to conclusion of the popular literature, but rather a question of overcoming a series of hurdles.

Table 2: Nuffield undergraduate research bursary: examples of supervisor feedback

[8] www.computing.dundee.ac.uk/rtl/casestudies.asp

Institution	Department	Student comment
University of Stirling	Computing	I learnt a lot about working in an academic situation, where the day's work and finite targets are set by myself. This is much different from normal university life where deadlines are given for assignments and worked towards. I feel more competent in personal time management more than ever now.
Cardiff University	Computing	I found that producing a piece of software that solved a real scientific problem whose solution might be useful to someone else was especially rewarding.
University of York	Computing	I appreciated being able to concentrate on only one problem for a time, in contrast to the projects within my degree course where time spent on project has to be balanced with modules.
University of Glasgow	Mathematics	The summer bursary project has given me an invaluable experience in mathematical research which I could not have gained from the lecture theatre.
University of Liverpool	Mathematics	The bursary has broadened my perspective about what research is about. It also increased my interest in doing a postgraduate degree after I finish my honours degree.
University of Bristol	Mathematics	The experience of working independently on a project has greatly improved my motivation and independence towards my work, and has definitely been something that I have used in current undergraduate studies and elsewhere. I discovered that although it can be de-motivating when things do not seem to be going well, that I also enjoy the challenge of trying to fix problems that may occur.

Table 3: Nuffield undergraduate research bursary: examples of student feedback

Case studies are presented in chronological order, beginning with information and computer sciences (ICS) and concluding with mathematics.

University of York: Computing 2004

Contact	Dr Gerald Luettgen
Institution	University of York
Email	gerald.luettgen@cs.york.ac.uk
Discipline	Computing science
Project	Nuffield student research project 2004: Integrating databases into the synchronous paradigm for reactive-systems programming
Student	D White

Project details

A current limitation in embedded/reactive systems design is the lack of database support integrated into design tools. This project has researched and developed mechanisms for accessing the relational database mySQL within the synchronous language Esterel, which underlies the popular Esterel Studio tool. The focus was on providing an as general as possible Applications Programmer Interface (API) for database use inside Esterel. Due to the variety of ways for passing back results from the database to the Esterel program, two APIs were defined to take account of different situations. Both APIs were tested in a case study modelling a warehouse storage system, in which a database is employed to retrieve information about customer orders and item locations. A robot uses this information to automatically pick a customer's order from the items in the warehouse. The system was implemented in the Lego Mindstorms Robotics kit and programmed in Esterel.

Supervisor feedback

The student's work has recently been accepted for publication in a journal (www.hindawi.com/journals/es/aip.961036.html). The project has helped the student to find out that he really likes research. As a consequence, after finishing his undergraduate studies, he enrolled in the PhD programme at the University of York.

Student feedback

I greatly enjoyed my research over the summer; this was because of the interesting subject I was able to pursue and also having the freedom to approach it in a way that suited me. I appreciated being able to concentrate on only one problem for a time, in contrast to the projects within my degree course where time spent on project has to be balanced with modules. I learnt a great deal from the bursary experience, expanding my knowledge of computer science both in the mainstream fields (Linux, databases, C programming and communications protocols) and the specialist field of synchronous reactive systems programming (Esterel). The knowledge I have gained in Linux, C programming and general communication protocols will be useful for my 4th year. This is especially true for my 4th year project which requires me to implement a solution to the parallel reinforcement learning problem.

University of Southampton: Computing 2004

Contact	Mr Quintin Gee
Institution	University of Southampton
Email	qg2@ecs.soton.ac.uk
Discipline	Computer science
Project	Nuffield student research project 2004: Entity location Services
Student	O Snowden

Project details

The project was a study of object orientation for the conceptual structure of the internet.

Supervisor feedback

We have an internship scheme where students between their penultimate and final years are given the opportunity to work alongside our current researchers for the summer, contributing where they can. We are offering 10 for this summer at about £1,000 for three months.

Student feedback

The Nuffield bursary scheme has given me an opportunity to gain some research experience. I have greatly increased my knowledge in the subject area and have without doubt improved my research techniques and documentation skills.

My reading from these scientists' works has inspired me to tackle more challenging problems. I have since decided to cover aspects of the Realms concept as part of my final-year dissertation.

University of Stirling: Computing 2005

Contact	Dr Rachel Norman
Institution	University of Stirling
Email	ran@cs.stir.ac.uk
Discipline	Computing science
Project	Nuffield student research project 2005: A host-host pathogen model with vaccination and its application to real systems
Student	K Marshall

Project details

This project involved building mathematical models of diseases which infect more than one host. For example rabies in foxes and dogs, or bovine tuberculosis in cattle and badgers. The aim of the project was to look at the effect of vaccination on our ability to control these diseases. In particular we wanted to look at which of the two species we should vaccinate or whether a joint vaccination policy was more sensible. We found results for the general case with any disease and then applied them to the specific example of red and grey squrrels and a parapox virus, and rabies in dogs and Ethiopian Wolves. Both of which are important systems because of the conservation of endangered species.

Supervisor feedback

The work done on this project brought to light some very interesting results. Kathryn analysed the general model which could apply to a wide range of systems analytically and looked at all of the possible results. This in itself was challenging mathematically and was an extremely useful exercise. She then went on to apply the results to a number of different systems. This required her to read the literature about these systems and to extract the data which allowed her to parameterise the model, again this is a challenging thing to do and was done very well.

I do think the student found it a useful experience although she did not go on to do research. I find vacation studentships useful for giving potential PhD students a taste of research although they are quite time consuming to supervise.

Student feedback

I found this experience to be both challenging and rewarding. Throughout the placement I was able to develop both my modelling skills as well as my data interpretation and analysing skills. I worked on field case study data, and was able to gain a better understanding of the abilities required and the work involved in research. Also I learned how to use new software packages such as Mathematica, as well as further developing my competence level on other packages such as Excel. This will be advantageous later on in my career.

University of Wales, Aberystwyth: Computing 2005

Contact	Dr Amanda Clare
Institution	University of Wales, Aberystwyth
Email	afc@aber.ac.uk
Discipline	Computing
Project	Nuffield student research project 2005: Fault detection in grid-enabled laboratory automation systems
Student	C Foulston

Project details

We have designed and produced a framework for grid-based failure detection to monitor and report on our automated laboratory equipment and the Robot Scientist. Its features are distributed agent-based monitoring, selective reporting and report dispatch brokering. Monitoring and reporting agents can be distributed due to the loose coupling of web services, enabling a large environment of parameters to be monitored. Reporting is via different mediums such as email, instant PC alerts and text messaging, though any type of agent can sign up for new reports, making the system expandable to a variety of needs. Dispatch brokering allows agents and humans to sign up for the latest reports for further analysis.

Student feedback

It was very interesting to work with other researchers in similar and also completely different areas. It has shown me research is very diverse and a lot gets learnt very quickly between groups, and the available information is phenomenal. Computing all this information can be very time consuming, with the amount and the time given and knowledge of others to get the best result. Talking to friends of the same knowledge level here, I got to work with people that picked up what I was trying to say very fast and pointed me in the right direction of the material and offered their views and understanding.

University of Cambridge: Computing 2006

Contact	Dr Alan Blackwell
Institution	University of Cambridge
Email	alan.blackwell@cl.cam.ac.uk
Discipline	Computing
Project	Nuffield student research project 2006: Cognitive dimensions analysis of code level security vulnerabilities
Student	L Church

Project details

The main focus of the work that he carried out with Nuffield funding was to apply the methods of psychology of programming research to the study of computer security. This was a novel combination of concerns that had not previously been investigated, and was inspired by Luke's own interests. There is both a computer security research group and a psychology of programming research group in Cambridge (the latter my own), but the two perspectives had not been applied together. The availability of the Nuffield scheme meant that Luke was able to pursue his own interests in combining the two, acting as a relatively autonomous young researcher using advice from more experienced researchers as he needed it. I would say that this was the main advantage of the Nuffield funding - the way that it was the student's 'own' funding rather than simply acting as a short-term contributor to an existing project, as is more often the case in undergraduate research.

Supervisor feedback

The student has now proceeded to a PhD position, with funding from a commercial sponsor, under my supervision. I would say that the Nuffield student research award had a significant influence on his development as a researcher, and was instrumental in establishing his current area of research. Luke's PhD research is now focused more on psychology of programming, but he maintains research links that were developed during the Nuffield-funded project on computer security. He has been able to help support himself by doing paid work as a consultant to an international security technology company. He was also been invited by Google to fly out to their California headquarters last year to discuss his security research. He has regular contact with the Cambridge security research group (who also offered him a funded PhD studentship).

I would say that the real benefit has been to Luke himself, rather than in developing my own research. However, this was extremely valuable, in establishing early experience for him to gain status as an innovator and authority in a specific area. Funding for a student that was independent of prior research groups also opened up important research questions at the intersection of different established approaches.

Imperial College London: Computing 2007

Contact Dr Krysia Broda
Institution Imperial College London
Email kb@doc.ic.ac.uk

Discipline Computing
Project Nuffield student research project 2007: Re-engineering of the Pandora Natural Deduction Tool
Student A Raad

Project details

The project was one of two that together formed a project concerned with a teaching tool for programme reasoning. The other bursary was awarded to Dr Broda's colleague, the late Dr Gabrielle Sinnadura. Many of the ideas used in the tool were Gabrielle's. Two second-year students and one first-year student worked on the project. They took as a starting point a tool used by Dr Broda in teaching for several years that teaches natural deduction. This project was to design a completely new tool that integrated standard first order logic rules with the rules of Hoare logic, used in reasoning about imperative programmes. The result of the project was a prototype tool that with some more work could be used for programme reasoning, including logical reasoning where necessary.

Supervisor feedback

Although the students had used these rules informally, to understand their formal application was quite difficult for them. The project also required use of various tools for writing compilers and managing last projects, which they had not used before. I have since employed another student during last summer to extend the tool. The tool can be downloaded from www.doc.ic.ac.uk/pandora/newraptor. It is still not perfect, but it can be used to prove many examples that we use in teaching our first-year course.

I believe the students learned several things through the project. They experienced how to work in a team and to share knowledge, and became more self-confident in their technical knowledge. All of them have gone on to become members of our undergraduate tutoring scheme and all of them wish to pursue a PhD. I think they all enjoyed the experience of working on a much larger application than they had tackled before. Personally, I believe involving undergraduates in research is very beneficial. They gain experience of working on their own and of being an independent thinker.

Student feedback

Working on Pandora was challenging but enjoyable; it allowed me to develop Java skills and gain confidence in submitting my work to criticism. The daily supervision ultimately led me to produce a working programme. Working as part of a larger team was a good learning experience. The experience of working in the bursary project has been very positive. My second-year studies have been made easier by my improved communication and implementation skills.

University of Stirling: Computing 2007

Contact	Dr Bruce Graham
Institution	University of Stirling
Email	b.graham@cs.stir.ac.uk
Discipline	Computing science and mathematics
Project	Nuffield student research project 2007: Computer simulation of the growth of neurons in 3D space
Student	C Riddell

Project details

Neurons in the nervous system form complex tree-like branches known as dendrites and axons. Different types of neurons can be identified by their morphology (tree-like structure). The way that neurites (dendrites and axons) grow and form their typical branching patterns is still far from completely understood. One approach is to use mathematical modelling and computer simulation to explore different mechanisms that might influence and control neurite outgrowth. In this project we have used 3D computer graphics and collision detection technology derived from computer games to investigate how neurons growing closely packed together influence each others' branching patterns due to collisions between growing branches constraining where they can go in 3D space. The results indicate that such collisions will certainly play a role, but are also unlikely to be the sole determinant of outgrowth patterns.

The starting point was a basic simulator written in Java that implemented a simple statistical model of neurite outgrowth. This model produces trees with a realistic branching structure, but takes no account of how the branches grow in 3D space. The student used the Java 3D graphics library to visualise the outgrowth of neurons in 3D space. A key aspect of this was to use Java 3D's collision detection capabilities to enable growing branches to detect when they ran into each other and change their growth accordingly, such as stopping growing or changing direction.

Student feedback

If this research were to be continued by myself for example, I would look into a technology which could provide better collision detection capabilities for the branches. I would implement the 3D objects in openGL and run the back end, which controls the number of neurites grown, the type of neurite to be grown etc, in C++. I learnt that certain technologies may not be suitable for the job, but at the same time I expanded my skills and programming competence. I learnt a lot about working in an academic situation, where the day's work and finite targets are set by myself. This is much different from normal university life where deadlines are given for assignments and worked towards. I feel more competent in personal time management more than ever now, and feel no matter what type of work I go into later on in life, if the employer asks for something just to be done, I can assess what needs to be done specifically first before tackling the job.

Cardiff University: Computing 2008

Contact	Frank Langbein
Institution	Cardiff University
Email	f.c.langbein@cs.cardiff.ac.uk
Discipline	Computing science
Project	Nuffield student research project 2008: Density-controlled low-discrepancy sampling and meshing of 3D geometric models
Student	K Sullivan

Project details

High quality point samples are crucial for measuring and representing continuous data for computational applications. To cover a data set well, the samples must be uniformly distributed, but must not exhibit high regularity, such as present in a regular grid, to avoid sampling artefacts. For this project, a sampling algorithm for 3D domains to represent CAD models has been devised by generalising an approach to sampling surfaces in 3D. Experiments show that the resulting samples are of high quality, close to the theoretical limit, as indicated by a discrepancy measure. Furthermore, 3D meshes were generated from the point samples using Delaunay triangulation. Measuring the tetrahedron quality of these meshes to evaluate their suitability for finite element simulations indicates that the mesh quality is better than expected, but requires improvement. Especially at the 3D domain's boundary the tetrahedrons are of low quality, which we intend to address in future work.

Supervisor feedback

The student developed a piece of useful software that we can use within the context of our research. He particularly interacted well with one of my PhD students and a paper combining their work is currently on the horizon.

It gave him the opportunity to participate in our research and not just the lectures, which, as far as I can tell of course, he enjoyed a lot; in particular the advanced programming and related maths.

Student feedback

I enjoyed the flexible working hours as it gave me the freedom to work when I wanted to and it allowed me to explore specific ideas in more depth to evaluate how well they worked.

I found that producing a piece of software that solved a real scientific problem whose solution might be useful to someone else was especially rewarding. I also found that viewing the results was also very interesting.

I also found that viewing the results was also very interesting due to the graphical nature of the problem. I also found evaluating these results an interesting process and learnt that it is very important to be able to accurately describe how you obtained them. Because of this I had to record carefully what I did. I saw that evaluation happens during the development of an algorithm and it is crucial to understand how to generate better results. In particular when measuring the quality of the generated tetrahedral meshes I saw that comparing experimental results to theoretical results helped me debug the program, but more importantly investigate how to improve the quality of the mesh with respect to the specific quality measures. Viewing the 'bad quality' tetrahedrons using the software also gave some useful insight into the regions where they occurred the most.

University of Durham: Computing 2008

Contact Dr Shamus Smith
Institution University of Durham
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Discipline Computer science
Project Nuffield student research project 2008: Evaluation of peer-to-peer routing strategies for distributed storage
Student D Trenholme

Project details

Project abstract: 'This project will investigate the reuse of computer game development tools to rapidly prototype virtual environments (VE). We will explore how reusing game development technology can simplify the 3D modelling of virtual buildings and the generation of effects that are difficult to program, such as fire and smoke. A training-based VE will be constructed and evaluated to test fire evacuation procedures of a simulated real world building'.

Supervisor feedback

From this project I have published two journal articles with the student as co-author:

Smith, SP and Trenholme, D (2009) Rapid prototyping a virtual fire drill environment using computer game technology, *Fire Safety Journal*, vol 44, no 4, pp 559-569

Trenholme, D and Smith, SP (2008) Computer game engines for developing first-person virtual environments, *Virtual Reality*, vol 12, no 3, pp 181-187

This month, when the second journal article was released, Durham University issued a press release on the project - Violent computer games have role in fire safety - which can be viewed at: www.dur.ac.uk/news/newsitem/?itemno=7525&rehref=%2Fnews%2Farchive%2F&resubj=%20Headlines and www.dur.ac.uk/shamus.smith/fire

This resulted in a number of radio interviews, an appearance on ITV News and numerous web articles:
BBC News - http://news.bbc.co.uk/1/hi/technology/7867861.stm
Guardian - www.guardian.co.uk/technology/2009/feb/05/videogames-fire-safety

Over 100 other web articles can be found at: http://delicious.com/shamussmith

This has provided my research with unprecedented national and international exposure. I have used it as a case study to attract more students to work on game technology-based UG projects. It has opened up new collaborations in Durham to work with colleagues in psychology who are interested in using game technologies to run experiments.

I encourage all my UG (and taught PG) students to undertake new research. Students are typically up to the challenge and in addition to completing first class projects; I use the potential to publish as a motivating factor. In addition the two publications above, I have published research based on final-year UG projects:

Smith, SP and Du'Mont, S (2009) Measuring the effect of gaming experience on virtual environment navigation tasks, *Proceedings of IEEE Symposium on 3D User Interfaces*, LaFayette, USA, 14-15 March 2009

Smith, SP and Hart, J (2006) Evaluating distributed cognitive resources for wayfinding in a desktop virtual environment, *Proceedings of IEEE Symposium on 3D User Interfaces*, Alexandria, USA, 25-29 March 2006

Student feedback

During the project, I have learned some useful skills in research techniques. For example, the research has helped to increase my ability to establish targets and work on my own initiative while still meeting deadlines in some aspects of the project. During the first phase of the project, I learned how to search for and review relevant literature and include the pertinent information in a final report, as well as keeping in mind the issues raised in the literature that are relevant to the research in later phases. The evaluation phase of the project required that a number of user studies be carried out to evaluate the realism and usability of the virtual environment. From this, I gained some experience in carrying out user studies and from the pre and post session questionnaires that were designed, I have learned what sort of data is appropriate to acquire for this type of project.

When writing the final report for this project, I learned how to collate and interpret all the information and data that had been gathered previously during the research. A large amount of data had been collected during the evaluation phase and I learned how to interpret it so that answers to specific questions could be found that were also relevant to the research.

The research project has increased my interest in scientific research and made me more aware of the scientific research opportunities that exist in other areas. For instance, I have also become interested in research carried out in areas similar to the games industry, such as the research and development that is carried out in media production. After I have completed my current degree, I had been thinking of enrolling on an MSc course and afterwards going straight into employment. However, after completing this project, I have now also begun considering the possibility of postgraduate research for a PhD related to one of my interest areas.

University of St Andrews: Computing 2008

Contact	Dr Graham Kirby
Institution	St Andrews University
Email	graham@cs.st-andrews.ac.uk
Discipline	Computer science
Project	Nuffield student research project 2008: Evaluation of peer-to-peer routing strategies for distributed storage
Student	B Birt

Project details

The project involved the design and implementation of Liskov's Zero Hop Routing proposal. This proved to reduce access costs by avoiding the need for any inter-node communication in order to discover where a particular piece of data is currently stored.

The principal objective for the bursary was to develop a practical implementation of the Zero Hop Routing scheme originally proposed by Liskov. In the first phase of the project the student designed and implemented the scheme in Java. This was initially tested using a number of virtual nodes running on a single machine, and then on a distributed network.

One novel aspect of the work addresses the detection of failed nodes in the network. The network is split up into a number of 'watch groups' in which each node 'watches' for failure of the other nodes in the group. If a failure is detected, the suspecting node reports this to the Configuration Service, and once the Configuration Service receives a sufficient number of failure accusations against a node, that node is added to the Configuration Service's list of nodes that have left the network during the current epoch.

Work is now ongoing to incorporate the software developed during the project into the ASA storage project at St Andrews. Documentation and full source code are available at: www-systems.cs.st-andrews.ac.uk/wiki/Software

Supervisor feedback

Overall I am very much in favour of including undergraduates in research. It is potentially, one hopes, beneficial to the students in terms of sparking interest and reinforcing understanding of concepts in the curriculum. It is certainly beneficial to the research group in bringing in fresh enthusiastic minds. And pragmatically such internships are useful in identifying potential future research students.

Student feedback

I learnt a lot during the summer studentship experience, much of which I am finding very useful in my current third year of studies, especially an understanding of peer-to-peer networking and distributed systems. The research that I was involved in over summer has captured my imagination so well that I am now very much more interested in continuing research into distributed systems after I gain my degree, perhaps as a PhD. The experience was highly valuable in other ways too; I experienced working with some very intelligent people in the computer science field, improved my information retrieval and analysis skills, and gained some practice in brainstorming as a team. Playing a major part in this project was an invaluable experience in understanding in order to work with others in order to keep track of project progress and direction.

It was refreshing to work as a student, yet on a project that will actually be of use as opposed to projects that are useful for learning but will not be used for practical purposes once I have created it.

Cardiff University: Mathematics 2004

Contact	Professor Paul Harper
Institution	Cardiff University
Email	Harper@cardiff.ac.uk
Discipline	Mathematical sciences
Project	Nuffield student research project 2004: Mathematical modelling of NHS booked admission systems: exploring the relationship between bed capacities, length of stay, variability and booked admissions
Student	G Gill

Project details

There is considerable interest within the NHS for booked admission systems whereby patients pre-book their operation date. Working with a number of hospitals, this project has used mathematical modelling techniques to explore the feasibility of the proposed system and to provide general guidance on suitable strategies. We have used computer simulation to mimic booked patients arriving at hospital (for different specialties, such as orthopedics and general surgery) and have fitted statistical distributions to capture the variability in length of stay. We also account for emergency demand for beds and have evaluated the impact this has on number of required beds per specialty, and the benefits of ring-fencing beds for electives (booked admission beds) which we are able to quantify for different scenarios. The results of the flexible tool, which can be populated with data from different hospitals, shows the impact of user-defined inputs: bed numbers (for booked admissions and flexible bed stock), number of admissions (emergency and electives) and patient length of stay; on model outputs of bed occupancy and waiting times/refusal rates. This is of key importance to participating hospitals to have the correct bed configuration in order for the booked systems to function efficiently and effectively.

Supervisor feedback

I believe that the work was of real importance and of value to the Trusts. As for comments regarding the involvement of UG students in research, one of the biggest barriers is limited time and the steep learning curve of the student to meet expectations of the project and in this case the client (NHS). However, for the student it is a valuable insight in to the world of academia and research, and the experience will hopefully generate interest resulting in a much needed next generation of researchers.

Student feedback

I really enjoyed this project in healthcare modelling, which I am very interested in. It has broaden my view into what kind of work is involved by a PhD student as well as providing me with an opportunity to learn new modelling skills on how to apply these to a real-life challenging problem. I have become confident in building computer simulation models and data analysis and data handling skills. These I'm sure will hold me in good stead for my final year as an undergraduate student and beyond if I pursue postgraduate study.

I also learnt about self-discipline in a research-led environment, which is different from the experience on a taught undergraduate degree programme. I noted that being a research student was very different from an undergraduate student. Lots of freedom was given to me. After being given instructions it was largely up to me when to do the work and I enjoyed this freedom whilst recognising the responsibilities to finish the work in the tight timescales of 10 weeks.

University of Liverpool: Mathematics 2004

Contact Dr Alexei Piunovskiy
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Discipline Mathematics
Project Nuffield student research project 2004: Study of optimal immunisation policies for a deterministic epidemic model
Student S Nietiadi

Project details

We considered the following model: a closed population consists of susceptibles (their number always decreases due to infection) and infectives that can recover and become immunised thereafter. The dynamics was described by a couple of rather complicated nonlinear ordinary differential equations recently analysed by other researchers. The distinguishing feature was the ability to immunise susceptibles at an arbitrarily enough chosen rate. This rate of immunisation is the control (action). Under a fixed control strategy, we were interested in the two perfomance criteria: the total amount of newly infected susceptibles and the total amount of immunised susceptibles. Both criteria should be minimised. We considered the linear combination of the criteria mentioned, stated and studied the optimal control problem. It turned out that, for a given number of susceptibles, there is no need for immunisation, if the number of infectives is small, and one has to select the highest possible immunisation rate if the number of infectives is big. We elaborated the algorithms for the calculation of the threshold in the amount of infectives, for a number of qualitatively different situations dependent on the relations between the parameters of the model.

Student feedback

I am very much grateful for the opportunity this bursary gave to me. I learnt to absorb new knowledge in short amount of time and was able to improve my understanding in one of my weakest areas. This work has added to me the skill of using computational software to do calculations and plotting the appropriate graphs illustrating each different case in the project. During the research, I also picked up a skill of adapting with my supervisor and was able to quickly adjust with the way he structured the work. This skill surely will help me in my future career, despite any type of career chosen. The bursary has broadened my perspective about what research is about. It also increased my interest in doing a postgraduate degree after I finish my honours degree. Overall, it has given me a great opportunity to use and add to what I have learnt during my degree, and also to give a great positive impact on my future career.

University of Southampton: Mathematics 2004

Contact	Dr Christopher Howls
Institution	University of Southampton
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Discipline	Mathematics
Project	Nuffield student research project 2004: Mathematical modelling of spread bets
Student	M Kabelka

Project details

The project was aimed at working out fair values of the centre value of a range of time-dependent spread bets. We wanted to see if we could:

- evaluate them
- check the theoretical values of simple bets against the actual values offered by online bookies.

The second point was to check if bookies might be incorrectly evaluating the bets (which they appeared not to be), or whether there might be arbitrage (opportunities to have a greater than zero probability of making an instantaneous profit).

Supervisor feedback

The work was written up and published:

Fitt, AD, Howls, CJ and Kabelka M (2006) The Valuation of Soccer Spread Bets, *Journal of the Operational Research Society*, vol 57, no 8, pp 975-985

The work was original and one of the first papers in the literature on the quantification of spread bets. This work has proved a basis for further ongoing research work by my collaborator Professor Alistair Fitt in the area of portfolios of bets:

…when freed from the constraints of a UK undergraduate degree syllabus, he was almost unstoppable in his enthusiasm for learning the new mathematical techniques that were required in the project.

…he thoroughly enjoyed the opportunity to undertake research. Very few undergraduates have the opportunity to publish a research paper before they have even got their first degree. The skills he learned would certainly be applicable in his chosen future career.

At Southampton we see this as a vital way of exposing undergraduates to the experience of the research environment, and a springboard into recruiting them for PhD work...

One colleague this past summer had a mature student working on a project in relativity. The option to "try out" research was welcomed by this mature student: given his age, he felt he could not afford a false start in his future career. The project has broadened his career horizons and he is now actively seeking to stay on with us for a PhD after he has graduated.

University of Southampton: Mathematics 2004-06

Contact Professor Tim Sluckin
Institution University of Southampton
Email www.soton.ac.uk/maths/people/profiles/applied/tim.html#emailFrm
Discipline Mathematics
Project Various Nuffield student research projects

Supervisor feedback

...interesting project for the student to have been involved with, showing all the difficulties of the research process.

...experience was enhanced...to realise that there was more to doing research than just doing as one is told.

University of Bath: Mathematics 2005

Contact Dr Peter Moerters
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Discipline Mathematical sciences
Project Probabilistic proofs for tail estimates of branching trees

Project details

In the project we found elementary new proofs for results about asymptotic probabilities related to the martingale limit of a supercritical Galton-Watson tree.

Supervisor feedback

The student is now my PhD student, we proceeded to add some less elementary results, which use the same basic insight, and wrote a very nice joint paper about it. He wanted to find out about the process of mathematical research, and the experience was positive, so he proceeded to do a PhD.

With undergraduate programmes in this country reduced to the bare necessities, and typically not very research orientated, this is only possible under very exceptional circumstances. You need a good project which needs to be elementary and relate to undergraduate material. You do not have this very often. And you need an exceptional student to really provide a significant input. Only the best two or three students in a cohort here could do this. Therefore, in my view, people talk far too much about these undergraduate bursaries, extending the programme (as it happened recently with EPSRC) will bring a lot of less suitable students and projects and is not a good way forward. At the end of the day, to start with meaningful research you need to do a PhD, and there is not enough funding for this in this country.

University of Glasgow: Mathematics 2005

Contact Professor David Fearn
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Discipline Mathematics
Project Nuffield student research project 2005: Evolution of a freezing mixture
Student D MacTaggart

Project details

When a mixture is cooled at a boundary and starts to freeze, the composition of the solid that forms differs from that of the fluid. As freezing proceeds, the fluid composition evolves. This affects the freezing process since the freezing temperature decreases as the solute concentration increases. We have investigated a simple parameterised model that aims to elucidate qualitative features of this fascinating system. In particular, we have focused on the effect of the evolution of the fluid composition. This has largely been neglected in previous work. Our study is motivated by the Earth's core which is a mixture of iron and some lighter elements. The solid inner core is mainly iron. The lighter elements, released as the inner core freezes, are an important source of buoyancy, driving motion in the outer core and so generating the Earth's magnetic field. We find that, when convection is vigorous, the fluid composition evolves to the so-called eutectic composition at which point convection ceases. Developments of these ideas should lead to a better understanding of how long the Earth's field can be maintained.

Supervisor feedback

David has worked very well, shown initiative and independence, and described the project and its results in a well-written report. This project has presented an important opportunity to kick-start an idea I have had on the back-burner for some time. Excellent progress has been made in a short time and the results should be publishable with a little further work.

Student feedback

The bursary experience has been highly stimulating and thoroughly worthwhile. It has given me an appreciation for the way mathematical research is conducted and has cemented my intentions of doing a PhD. Over the summer I was introduced to new and interesting topics such as metallurgy and geophysics. Through the work, I read several published academic papers on the subjects concerned. This increased my knowledge of the subjects and I used information from the papers when analysing the model results in my report.

The summer bursary project has given me an invaluable experience in mathematical research which I could not have gained from the lecture theatre.

Keele University: Mathematics 2005

Contact	Dr John Preater
Institution	Keele University
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Discipline	Mathematics
Project	Nuffield student research project 2005: Stochastic modelling of hydrocarbon reservoirs
Student	S Pearce

Project details

The project was in the context of hydrocarbon reservoir modelling and in particular the creation of commercial software called Reckonnect (which was finally 'launched' last year: www.reckonnect-software.com). His results were important to my understanding of some theoretical issues in relation to simple models of the software. In particular, his simulations indicated clearly that one simplified model was inadequate but that another gave very good agreement with the Reckonnect software.

Supervisor feedback

The student who undertook the work is now studying for a PhD in applied mathematics at Keele. On the project he gained valuable experience in writing (VBA) code, carrying out simulation studies, grappling with some rather intractable analytical problems and reporting both orally and in writing.

University of Ulster: Mathematics 2006

Contact	Dr Mark McCartney
Institution	University of Ulster
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Discipline	Mathematics
Project	Nuffield student research project 2006: Stability and instability in mathematical models of traffic flow

Project details

This was an eight-week summer project investigating, both numerically and analytically, a set of time delay differential equations related to traffic dynamics.

Supervisor feedback

The student worked pretty much 'by himself', that is, there were no relevant post grads around. It built on earlier work (by a previous PhD student) and resulted in a paper which has just been accepted for publication in Physica A, so real questions were answered in terms of research.

It gave the student a good feel for what it was like to do research, and a sense of achievement when he was able to come up with results which were new. It was good for his CV and self-confidence, and will help him make up his mind if post grad research is 'for him'.

University of Bristol: Mathematics 2007a

Contact	Professor Guy Nason
Institution	University of Bristol
Email	g.p.nason@bristol.ac.uk
Discipline	Mathematics
Project	Nuffield student research project 2007: Modelling and analysis of infectious disease time series using novel locally stationary time series models
Student	E Kershaw

Project details

Locally stationary time series models are currently undergoing a period of intensive research development at a number of centres worldwide. Classical time series models involve a concept, stationarity, which assumes that the statistical properties of a time series do not change over all time. This assumption is often unrealistic in practical situations, for example, in financial time series the limitations of stationarity are becoming all too apparent. We propose to use new locally stationary methods to assess the stationarity, or not, of time series of numbers of cases of infectious disease patients (for example, measles, influenza). Either outcome will be interesting.

Supervisor feedback

In my view, the main benefits of this project are that Emma is now extremely keen on the idea of research and she has now some mature view of what that might entail. She has learnt some very useful things, both for her future undergraduate and potential postgraduate work. I think she really liked the idea of dealing with real epidemiological time series and this has really fired her up with enthusiasm.

Student feedback

Personally, the experience I gained from this opportunity has been very valuable to me since completing my project in the summer.

The experience of working independently on a project has greatly improved my motivation and independence towards my work, and has definitely been something that I have used in current undergraduate studies and elsewhere. I discovered that although it can be demotivating when things do not seem to be going well, that I also enjoy the challenge of trying to fix problems that may occur. In my academic life so far, I have always found it very easy to be taught rather than to find out for myself and doing this project has reinforced my interest for learning. I have found that since the project, my enthusiasm for my studies and in particularly those that interest me has increased in a way that has been very beneficial.

My knowledge of time series analysis before this project was very limited, so this project allowed me to branch out into an area of statistics I had not encountered before, and I felt learning the subject alone felt very satisfying and has greatly helped in one of third-year units in the subject. Another very useful outcome has been that I developed my skills in the software package, R, to a much greater degree. Having already come across the package in my studies, I found the knowledge learnt over the summer has assisted me in my undergraduate work this year.

University of Bristol: Mathematics 2007b

Contact Dr Timothy Browning
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Discipline Mathematics
Project Nuffield student research project 2007: The equation of A+B=C in powerful integers
Student R O'Connell

Project details

The solubility in integers of the equation A+B=C is well understood, and one can easily write down an asymptotic formula for the total number of solutions in the range max{|A|,|B|,|C|} < X for which A and B are coprime. The main focus of this project was to count the number, M(X) say, of such solutions in which A,B and C are all 'square-full'. A number N is said to be square-full if p^2 divides N whenever the prime p divides N. Note that M(X) counts all primitive Pythagorean triples (such as (A,B,C)=(3,4,5)) in the appropriate range, and so has size at least cX^(1/2), for some constant c>0. In our investigation we developed heuristic arguments to show that it should not grow much faster than this, and tested the hypothesis with extensive numerical investigation. This project fits into a much broader framework concerning integral points on Campana orbifolds.

Supervisor feedback

I think it gave her a first taste of research work (rather than mostly spoon-fed lectures and the associated exercise sheets). In mathematics it can be quite hard to really involve them in the process of creating mathematics at this level (I fear that anything they do produce on this line will be of little academic interest). However, many undergraduates are very adept at computer programming and this is where a real contribution can be made, especially as most mathematicians leave this 'experimental' side relatively unexplored.

Durham University: Mathematics 2007a

Contact Dr Herbert Gangle
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Discipline Mathematical sciences
Project Nuffield student research project 2007: Explicing the coproduct for multiple zeta values
Student S Belcher

Project details

It concerned an algebraic structure (the 'coproduct') for objects which are intensively studied ('multiple zeta values') and which occur in many different contexts (like number theory, knot theory, Feynman integrals in quantum field theory, and so on). Goncharov, one of the most prolific experts in the field, has given a construction of the corresponding algebraic structure in a rather general setting. It proved to be a quite non-trivial task to understand Goncharov's construction, to make it more explicit in the case at hand, and to implement it on a computer.

Supervisor feedback

Steph presented her results during a workshop in Durham with two top researchers in the field who showed lots of interest in her results and encouraged her to write them up and publish them. The new description should give new insight into how one should combine the objects in question (that is, multiple zeta values) in order to produce families of relations for them.

My impression was that it enhanced her experience a lot. In particular she found results which are not - at least not explicitly - in the literature, and those experiences of 'ownership' of results constitute an important part of the drive for research. So I believe she has experienced a rather good glimpse into research life, and she seemed to get very much 'hooked'. Furthermore, since she had shown so much talent for research I suggested her to apply for a PhD position at a research institute which she actually was awarded.

In my opinion this opportunity is one of the best and satisfying features of the British system for undergraduate studies - I can only warmly recommend that experience for both students and advisers. Admittedly, I was very lucky in finding such a gifted learner, and with lesser talented students it may turn out to be more of a burden, but typically only the best ones actually do step forward. Moreover, such a research experience is more fun for the lecturer than the concentration on teaching material which can get somewhat tedious (the second and third time around, say).

Durham University: Mathematics 2007b

Contact	Dr Jochen Einbeck
Institution	Durham University
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Discipline	Mathematical sciences
Project	Nuffield student research project 2007: Analysing speed-flow diagrams with local principal curves
Student	J Dwyer

Project details

In 2005, Dr Einbeck co-developed and published a nonparametric technique (local principal curves) for approximating complex data structures via (non-linear) smooth curves. A useful application for this technique seem to be speed-flow diagrams, in which the average traffic speed (typically over intervals of 30 seconds to 5 minutes) at a certain location of a freeway is plotted against the traffic flow. When collected over a longer time span, this typically gives half-moon shaped data clouds.

Jo Dwyer's job was to extract a large number of such speed-flow data from the Californian database PemS (https://pems.eecs.berkeley.edu) then fit local principal curves through them, and, in doing so:

- test the code
- create a 'catalogue' of types of speed-flow patterns
- suggest and implement methodological improvements.

Supervisor feedback

Jo found the work on the project extremely rewarding, and she learned a lot which was useful for her 4H project (Latex, for example). From my perspective, the main benefit was to have somebody (other than me) testing thoroughly our code with real data. This indeed led to some improvements of the original implementation.

University of Nottingham: Mathematics 2007

Contact	Dr Stephen Coombes
Institution	University of Nottingham
Email	stephen.coombes@nottingham.ac.uk
Discipline	Mathematical sciences
Project	Nuffield student research project 2007: Mathematical modelling of thalamo-cortical oscillations
Student	R Nigmatullin

Project details

'to investigate the generation of basic brain rhythms, such as that of the 10Hz alpha rhythm (associated with periods of eyes-shut relaxation) seen in electroencephalogram (EEG) recordings. This will be done using coarse grained models of neural tissue that include a representation of both the cortex and the thalamus (the gateway to the cortex). Previous mathematical work on cortical neural field models (lacking a thalamic component) has proven remarkably successful in understanding the dynamics observed in brain-slice experiments. With the inclusion of slow ionic currents, known to dominate the rhythms generated by the interaction of the cerebral cortex with the thalamus, we will develop a more appropriate framework for describing macroscopic brain EEG signals. In particular we are interested in event-related desynchronisation/synchronisation (ERD/ERS), associated with a decrease/increase of the amplitude of the EEG alpha rhythm, and in particular how performing certain motor tasks can lead to patterns of "focal ERD/surround ERS"' (Suffczynski et al, 2006, *International Journal of Psychophysiology*, 43, pp 25-40).

Supervisor feedback

I believe the student learnt what it was like to work on a non-trivial (open) problem using his own strengths and gave them confidence that they could work independently.

University of Oxford: Mathematics 2007

Contact	Dr Ruth Baker
Institution	University of Oxford
Email	baker@maths.ox.ac.uk
Discipline	Mathematical sciences
Project	Nuffield student research project 2007: A mathematical investigation of the mechanisms underlying the vertebrate segmentation clock

Project details

Somitogenesis is the process via which the head-tail axis of vertebrate embryos becomes segmented. Present mathematical models for somitogenesis do not explicitly consider the mechanisms underpinning the segmentation clock. Previous mathematical models have investigated the phenomenon of oscillating gene expression which appears to underlie the clock. They have typically concentrated on one component of the clock.

A long-term goal is to extend such models to take new experimental evidence into account and then to integrate these new models into our current theoretical framework.

Objectives for the project included to review the current experimental and mathematical literature on the segmentation clock and to use analytical and numerical tools to further explore the models in the literature.

Supervisor feedback

The project duration is probably too short to gain a great understanding, but enables the student to learn computing skills, data handling. Involving undergraduate students within the research process is a great idea but incredibly time consuming!

University of Durham: Mathematics 2008

Contact	Dr Veronika Hubeny
Institution	University of Durham
Email	veronika.hubeny@durham.ac.uk
Discipline	Mathematical sciences
Project	Nuffield Student Research Project 2008: Geometrical properties of higher dimensional black holes
Student	M Carlton

Project details

Understanding geometrical properties of solutions of general relativity, especially of black holes and their higher dimensional generalisations, often yields crucial insight for further developments. While stationary black hole solutions in four spacetime dimensions are well known and have been well studied for decades, the five dimensional black ring solutions have only recently been found. The goal of the present project was to study the geometry of the doubly-spinning black ring.

Supervisor feedback

I should say at the outset that the entire project was fuelled by Matt's own initiative: he approached me when he was taking my General Relativity course with a request for me to supervise his summer project, and he decided to apply for the Nuffield bursary; when I suggested the research topic he studied the review papers even before he received the response from the Nuffield Foundation; he carried out his project diligently and largely independently; and he wrote it up in an original and well-written paper, which I have no doubt will get published in a refereed journal.

Overall, I think it was an excellent learning experience for Matt: by doing the project from start to finish he not only acquired a useful set of tools, both theoretical and computational, for tackling other research problems, but he also got a glimpse into what doing research is like. He had a chance to interact with other physicists, not in a role of a student, but as an equal, discussing various developments and outstanding problems in a particular area of physics. Having done three such undergraduate summer internships myself as an undergraduate, I strongly believe that it provides an invaluable perspective to any serious student, especially those contemplating an academic career.

Matt's paper is available at: http://arxiv.org/PS_cache/arxiv/pdf/0902/0902.4641v1.pdf

University of Southampton: Mathematics 2008

Contact	Dr James Anderson
Institution	University of Southampton
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Discipline	Mathematics
Project	Nuffield student research project 2008: Characterizing circles in families of curves

Project details

The basic idea of the project came from the following observation: if you consider the family of circles of radius t>0, then the length of the circle C_t is the derivative of the area of the disc inside C_t. So, the question I set the student on, does this property of length of a curve being the derivative of the area of the region inside the curve characterize circles? It turned out that the answer was well known, and is emphatically no: if you take any simple closed curve in the plane and let C_t be the outer boundary of the t-neighborhood of C_t (perhaps only for small t), then the length of C_t is the derivative of the area inside C_t. I shifted the emphasis to considering other natural families of curves, such as the level sets of a function; for which functions does the length of the level set S_t equal the derivative of the area inside S_t.

Supervisor feedback

I believe the project greatly enriched the student's experience, and I believe this in part having discussed the experience with the student. He saw first hand what mathematical research entailed, even with the changed project, and he was forced as well to pull together his own knowledge from a variety of different and disparate sources to address some of the questions. It may have been the first time that he realised the truth of the statement that the division of the undergraduate curriculum into different modules is highly artificial.

I believe that getting undergraduates involved in research projects is an extremely powerful way of engaging them. The only reservations I have are that, as a pure mathematician, I see that great care needs to be taken to ensure that the project is both a reasonable project for the student to engage in, and also carrying sufficient heft to require the student to do something beyond the standard things they have done. This is very possible to do, and it will not always result in a measurable outcome such as a paper or conference presentation, though it is nice when it does. It is the grappling with an actual problem and having to find ways in that is important.

University of York: Mathematics 2008

Contact	Dr Alet Roux
Institution	University of York
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Discipline	Mathematics
Project	Nuffield student research project 2008: Analysis of high frequency financial data

Project details

The aim of this project was to investigate some of the features of high-frequency (tick-by-tick) data of transactions on financial exchanges, and the ways in which it differs from what is conventionally assumed in financial theory. For example, it is discrete, it is bursty, it has fat tails, and it exhibits heavy short-term seasonal trends (for example, daily and weekly patterns). This was done by means of a dataset of manageable size containing trades of LIFFE futures and options data.

Supervisor feedback

The student realised first hand that the well-polished version of mathematics taught at university is really the result of a very long and difficult (some say tortuous) process, and had a taste of what the research process is really like. I hope to think that this has strengthened his interest in pursuing mathematics at graduate level.

I am not convinced that undergraduate students can contribute to meaningful theoretical research in mathematics, because they simply lack the necessary mathematical background. Nevertheless, this doesn't mean that they should be excluded - as in this case, they can contribute through more empirical study.

5 Discussion and recommendations

It is clear from our brief study that research is alive and well around Scotland as a component, exemplar and even driver for teaching in information and computer sciences (ICS) and mathematics, statistics and operational research (MSOR). The diversity of opinions and practices which has emerged is healthy and to be encouraged and we see no need to promote a uniformity of approach. What is clear is that, where research is appropriately and effectively embedded in the curriculum, its effects are overwhelmingly positive, contributing significantly to enhancing the student experience and the breadth and depth of their learning.

Research is clearly seen by most staff and students as an important part of the learning experience if it is appropriately placed. Academics in some fields and at teaching at some levels have pointed out that research linkages are sometimes neither appropriate nor practicable but universally acknowledge the motivational potential where they are. The next sections identify some challenges, and offer a set of recommendations for consideration by directors of learning and teaching, programme conveners, and module coordinators.

5.1 Challenges in information and mathematical sciences

Three challenges exist to be addressed if research-teaching linkages are to be further used to enhance ICS and MSOR graduate attributes.

Challenge 1: students are particularly excited by research that can be related to an application or real world problem. It can be inspirational and aspirational for some, with less tangible but still valuable benefits to others, even where it is not directly motivating for all students.

> It is rare that a research problem can be successfully reworked (some would say watered down) so as to be accessible to undergraduate mathematics students. Either the original concept is too deep requiring a sophisticated knowledge of mathematics to appreciate its importance and meaning or else the analysis used to solve the problem is beyond the scope of most undergraduates. Yet, it is important that undergraduates get exposure to real research not only because it should be a bona fide part of their undergraduate degree but also because they can then make informed choices as to their career paths on graduation. It is also surely beyond doubt that students are better able to absorb abstract techniques/methods if they are employed on a real problem. (Ward, 2006)

This is a first challenge for academics teaching pure mathematics and pure computer science: the subjects are often very linear and research in these areas requires a considerable amount of knowledge. **How can these departments provide students with a proportionate experience of research that is relevant to the programme of study, without distorting the curriculum?**

A number of academics strongly advocate facing this challenge. The synopsis below is from a talk given by Professor Chris Budd, Department of Mathematical Sciences, University of Bath. Professor Budd's talk is provocatively entitled 'Whoever tells you that teaching and research don't go together is talking rubbish':

> It is natural in maths to link teaching and research; that is, extremely difficult, theorem proving, model developing mathematical research. Indeed, a common myth surrounding maths is that research is too complicated for students to understand. However, maths is a subject that is best learnt by doing, which in turn means solving problems. The best problems in maths are open-ended and require creative and investigation, i.e. research. Another potential problem is that, if you teach without introducing new research, however difficult, there is the potential that students may go into industry and try to use (and tell others to use) standard methods for solving real-life problems that they learnt at university but which are not relevant or do not work in practice.
>
> Good teaching also provides a useful basis for good research. Exposure to different subjects and ideas can often lead to new research insights, as does thinking hard about how to explain a problem to undergraduate students. Furthermore, a significant amount of undergraduate maths is very close to leading end research, such as the P-NP problem, number theory and applied maths itself. Even more so, many new discoveries are being made in contemporary mathematics research. I argue that students enjoy being exposed to what is out there. Research develops a sense of awe, wonder, play and excitement in students of all ages. Research (especially in applied maths) leads to fantastic examples in lectures, plagiarism-free project subjects, and contributes to greater public understand of science. Maths is the only experimental subject that you do not need a laboratory for.
>
> To conclude, I believe it is necessary to be aware of, and to develop the latest, research methods and be prepared to use them in teaching practice. This involves introducing students to use the latest techniques. Students can therefore compare and analyse different methods to find which is best for their own problems. As a result, students use far stronger and more relevant methods that can be used after graduation.

Challenge 2: a key benefit of linking research and teaching is to enthuse a future generation about the excitement of exploration; understanding the research process itself is as important as comprehending the detail of the discipline's current cutting-edge research, which may be either too dynamic to keep up with, or too cumulative in nature.

> 'Undergraduates are usually a long way from research. It is not just introducing research into teaching but, rather, making the students aware of what research is and that it exists. This is, perhaps, more important. Nobody forbids introducing "real" research into teaching - it just rarely happens in this area' (Professor, MSOR).

A second challenge is to raise awareness of research already taking place in departments, and show either real world examples of applied research or the relevance of pure research. **How can students' awareness of different types of research and research processes be raised?**

Challenge 3: it is important to demystify research at an early stage and this can be done through exposure from day one to what excites teachers about their research. Direct student participation in research projects is most common at final-year undergraduate and taught postgraduate levels. It is particularly appropriate to applied subjects.

> 'If students can be exposed to research at any stage of their learning, it's likely to be valuable - at least to the keener students. I am more doubtful that weak students would benefit significantly since they appear to be very readily confused by "extra" information' (Lecturer, MSOR).

> 'students would benefit from research being introduced at year 1, if we can give them a foothold to contemplate the excitement and benefit of research' (Senior Lecturer, ICS).

There is enthusiasm to link research and teaching typically at undergraduate level 4 and postgraduate students. However, research may not be motivating or easy for all students. This is the third challenge: **to develop opportunities that can be offered at all levels, that are meaningful to students with a wide range of abilities, especially if in the circumstances of service teaching.**

5.2 Recommendations for subjects and departments

The following is a summary of our recommendations, based upon our findings about the extent and type of research-teaching linkages within the computing and mathematical sciences, and observations about how those linkages can be built up further. Case studies are provided in this report as potential sources of insight and stimulation for those seeking to engage with these recommendations:

1 Learning and teaching directors and programme coordinators should examine the range of identified graduate attributes to consider if programmes should be designed to enhance a richer set of attributes than those most commonly quoted (that is, critical understanding and ability to analyse problems):

> 'Students see that we (staff) are just more than established students...they then hopefully recognise that learning is more long-term than the collection of modules' (Lecturer, ICS).

2 Students at all levels should encounter research processes and practices, even if the subject content itself is not related to contemporary research:

> 'Research mindedness and challenging knowledge should be pervasive in any programme of study' (Lecturer, ICS).

> 'Our teaching at undergraduate level does not aim to be at the "cutting edge" of research and cannot be, given the cumulative nature of maths. However we do try to educate our students to a level where, at graduation, they are qualified to begin doing research or read research papers' (Professor, Mathematics).

3 Ensure students are made more aware of the academic community they inhabit, to ensure that they understand the nature of research and to make informed decisions in terms of their future careers.

This could be achieved by encouraging researchers within the department to make contact with students:

> 'Contact between PhD students and UG students is crucial...PhDs improve their communication; UG get exposure to people with very high technical skills who can still remember being a student!' (Lecturer, ICS).

4 Where possible, teaching content should be related to 'real world' examples, to assist students to relate concepts to their everyday experiences and to excite them with the prospect of research involvement and gaining research skills. Such examples should be genuinely and proportionately integrated within programmes:

> '[There is a] need to emphasise a link between research and practice - undergraduate students may not be interested in research as such, but they are interested in progress' (Reader, ICS).

5 Departments should emphasise to their students the importance of being able to stay at and to contribute to the forefront of knowledge. This corresponds to the need to demystify research to students; that is, to convey to them that not all research is concerned with obtaining a PhD, but is regularly expected within the working environment:

> 'Software engineering moves so fast that, even for undergraduates, it isn't enough to teach them the state of the art. They have to understand how to keep up, which involves at least a basic understanding of research' (Reader, ICS).

6 Ensure teaching staff are aware that introducing research or research methods into their teaching practice does not necessarily mean introducing their own specialist area of knowledge and should include subject-relevant research skills:

> 'In mathematics and mathematical physics, undergraduates are usually a long way from research. It is not just introducing research into teaching but, rather, making the students aware of what research is and that it exists. This is, perhaps, more important' (Professor, MSOR).

5.3 Strategies of departments and institutions

Examination of the case studies reported herein indicates that the great majority were initiated by individual staff or small groups of staff. It is evident that universities across Scotland are only now starting to develop institutional strategies. This situation may well change in the next few years, but presently there are few case studies of this nature to examine. Three exceptions are therefore worth considering here: each is featured in section 4.4 of this report but as an individual case study. In reality, the prompt for these developments - one from the United States and two from Scotland - were from the institution or the department.

Firstly, consider the case of Mathematics at Ithaca College, New York (see page 59). A description of the department's strategy is provided elsewhere: Healey and Jenkins (2009) outline how the department 'over some 7-8 years radically changed its course offering, its culture and organisation to make "research with students, designed as part of the curriculum...a distinguishing characteristic of mathematics at Ithaca College'. This includes a first-year course and a second-year course for all students, and a sequence of two junior-year courses featuring research methods and team work in which students work on research questions.

Secondly, consider the case study of Computing at the University of Glasgow (see page 47). For computing science and related honours students, the Department has set as mandatory a level 1 undergraduate course (Free Programming Projects) that supports creativity and free-thinking, ownership of work, independent learning and enhancement of problem-solving skills. Dr Cutts has made an important comment about such fundamental graduate attributes: 'The earlier they can be fostered, the better'.

Finally, consider the case of Computing at the University of Abertay (see page 52). Graduate attributes underpin the University's strategic plan 2007-2011. Attributes that define an Abertay graduate are conceptualised in four categories: confident thinkers, determined creators, flexible collaborators and 'challenging complexity, driving change'. An admirable set of bullet points was itemised for each of these categories, often featuring some that are not emphasised particularly strongly elsewhere, such as:

- an awareness of the stable, the new, the provisional, and of significant shifts in knowledge
- understanding the interdependence of ideas and their development
- working with ambiguity, uncertainty and error.

Various corporate targets were set, including:

> 'Students will be engaged in enquiry and project-based work, individually and in groups, for 60% of their contact time'.

The campus-wide graduate attributes thus were to be developed at programme level and a requirement was established for student exposure to the research process. Undoubtedly those institutional goals and targets set therefore spurred and prompted a number of exciting developments, including those within computing.

5.4 Taking it forward - what is needed?

Robertson (2007) noted that 'blanket injunctions to adopt more "student-centred" or "inquiry-based" approaches to teaching and learning at undergraduate level are likely, in some instances, to founder'. However we have been impressed with the number of positive and honest appraisals from academics keen to engage with this debate, perhaps best summed up by one lecturer's final comment:

> 'such activities increase workload and prevent research. However answering this questionnaire has been provocative, and I think I could do more to give students a taste of research'.

What support can be given towards this effort? The majority of academics surveyed confirmed that some impetus or support currently existed within their university or department to incorporate more research into teaching practice. The following were cited as the discussion points (most common first): university-wide initiative; curriculum development or programme design group meeting; at the point of module design; department or committee meeting; and in research group meetings. However, few respondents commented on the nature of these discussions, and one-third of the respondents **did not** seek further support in this area, being concerned about lack of time or increased workload. Of those who would, the common factor in the method suggested most likely to be effective was funding: externally funded dissemination activities, externally funded exemplar activities or internally funded/supported dissemination.

One specific suggestion was for subject-specific training 'to help ensure that teaching drawing upon my own research can be successful...'. This training should cover how to incorporate research topics (not research results) into teaching and techniques or methods to do this in an integrated fashion.

It is clear from the responses received by the project team that Scottish institutions to date have emphasised the development of 'graduate attributes' by devising departmental strategies. It may be useful therefore for learning and teaching directors to reconsider parts of the Framing Tool[9] published in 2007 as part of this Enhancement Theme (Land and Gordon, 2007), not as an audit tool but as a prompt for ways forward. Of particular interest to ICS and MSOR might be the following extracts:

- How are research-teaching linkages visible in strategic documents and implementation plans for the faculty or individual schools and departments?
- Is personal development planning used in any way to foster research-teaching linkages?
- Are there informal opportunities for students to engage in research-teaching linkages outwith formal teaching? (for example research seminars, acting as observers in research teams, student conferences, student journals)
- Is there a developmental sequence or 'through line' for research-teaching linkages from first year to final year and postgraduate study?

(Land and Gordon, 2007)

Given the preponderance of attention given to the more able students - as evidenced by the case studies herein - the final point above is particularly thought-provoking. While the sponsored studentships provided by the Nuffield Foundation, EPSRC and BBSRC are evidently extremely successful and beneficial to both staff and students, they serve to highlight the absence of similar success stories for the average-ability student.

Another candidate question set suggested by Jenkins et al (2007) will be valuable for those departments ready to honestly appraise the extent to which research and teaching are genuinely linked - and for those seeking ideas for a way forward. Extracts of the question set are provided below as encouragement to read the full set:

Curriculum and research-based learning

- Can you clearly identify where research-based learning is integrated in the programme?
- Where are research methods/skills/ethics taught and practised? Is this progressive?
- How are research skills and the links between teaching and research embedded in monitoring and review of modules and programmes?
- How are students supported in making explicit how this research training/knowledge increases their employability?

[9] www.enhancementthemes.ac.uk/documents/ResearchTeaching/RTFramingTool.doc

Management, organisational structure and staffing at department level

- How does the department's learning and teaching strategy articulate research and teaching links?
- How does the department's research strategy articulate teaching and research links?
- How is the staff and student experience of the nexus monitored and the results fed back into policies and practice?

(Jenkins et al, 2007, pp 59-61)

Participants at the second workshop (April 2009) run by the project team were clear that the implementation of research-teaching linkages was a complex issue not unrelated to institutional drivers. It was generally felt that a single model was unlikely to apply equally well to all institutions - a point articulated succinctly by Jenkins et al (2007): 'allow for diversity'. One conclusion from the plenary session was that: 'There shouldn't be "rules" as such - it's about sharing ideas in terms of how research and teaching can be linked rather than forcing people who may find it difficult to do this in an abstract manner. The case studies are a starting point for this'.

It has been an exciting journey gathering and researching the background for this report. Overwhelmingly we have come across an enthusiasm for and engagement with the role of linkages between research and teaching, both from students and from the academic staff whose role it is to enthuse students about their subject. So the contribution of this document is, we hope, incremental and will help academics whose research-teaching linkages are already strong to consider other methods and motivations for making linkages. Where linkages are less strong, for whatever reason, we hope that the report will provide a new stimulus to ensure that there are no missing linkages which could be made in future to the benefit of academic staff and student motivation, and depth and breadth of learning.

No doubt the new theme in the five-year rolling programme of Enhancement Themes will be a further prompt and support for departments and for institutions. 'Graduates for the 21st Century: Integrating the Enhancement Themes' is intended to address two overarching questions - what should be the attributes of a graduate from Scottish higher education in the twenty-first century, and how can the achievement of these attributes best be supported? We hope that this report will be valuable to departments developing projects to enhance graduate attributes via appropriate research-teaching linkages.

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7 Appendices

7.1 Student questionnaire

The student questionnaire can be viewed at: www.survey.dundee.ac.uk/studentrtl

Acknowledgement: The content and structure of this questionnaire was developed at University of Gloucestershire in 2002 by Mick Healey, Fiona Jordan and Chris Short.

7.2 Staff questionnaire

The staff questionnaire can be viewed at: www.survey.dundee.ac.uk/rtlinkages

7.3 QAA subject benchmark statements

***Subject benchmark statement: Computing,* paragraph 6.5:**

On graduating with an honours degree in computing, students should be able to:

- demonstrate a sound understanding of the main areas of the body of knowledge within their programme of study, with an ability to exercise critical judgement across a range of issues
- critically analyse and apply a range of concepts, principles and practice of the subject in an appropriate manner in the context of loosely defined scenarios, showing effective judgement in the selection and use of tools and techniques
- produce work involving problem identification, the analysis, the design or the development of a system, with accompanying documentation, recognising the important relationships between these. The work will show problem-solving and evaluation skills, draw upon supporting evidence and demonstrate a good understanding of the need for quality
- demonstrate transferable skills with an ability to show organised work as an individual and as a team member and with minimum guidance
- apply appropriate practices within a professional, legal and ethical framework and identify mechanisms for continuing professional development and lifelong learning
- explain a wide range of applications based upon the body of knowledge.

***Subject benchmark statement: Mathematics, statistics and operational research,* paragraph 5.15:**

A graduate who has reached the typical level should be able to:

- demonstrate a reasonable understanding of the main body of knowledge for the programme of study
- demonstrate a good level of skill in calculation and manipulation of the material within this body of knowledge
- apply a range of concepts and principles in loosely-defined contexts, showing effective judgement in the selection and application of tools and techniques
- develop and evaluate logical arguments
- demonstrate skill in abstracting the essentials of problems, formulating them mathematically and obtaining solutions by appropriate methods
- present arguments and conclusions effectively and accurately
- demonstrate appropriate general skills
- demonstrate the ability to work professionally with a degree of independence, seeking assistance when needed.

***Annex to subject benchmark statement: Mathematics, statistics and operational research,* paragraph A18:**

A graduate who has reached the typical level for MMath...should be able to:

- demonstrate understanding of the main body of knowledge of the programme of study, which should provide a basis for originality in developing and/or applying ideas, often within a research context, and should extend and enhance the understanding associated with achievement at the bachelor's level
- apply knowledge and problem-solving abilities in new or unfamiliar environments within broader (or multidisciplinary) contexts related to the programme of study
- integrate knowledge and handle complexity, and formulate judgements with incomplete or limited information, where appropriate reflecting on social or ethical responsibilities linked to the application of that knowledge or those judgements.

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