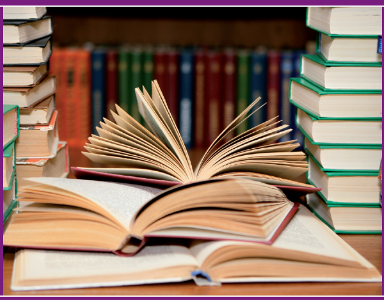
Student Research Projects:

Guidance on Practice in the Biosciences

Martin Luck




Teaching Bioscience:

Enhancing Learning Series

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Student Research Projects: Guidance on Practice in the Biosciences

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Teaching Bioscience Enhancing Learning is a series of guides intended to be an accessible introduction to good learning and teaching practice within the context of competing research and institutional pressures. The aim of each publication is to provide a persuasive overview of the pedagogic reasons for adopting a particular practice and support these reasons with sufficient practical guidance and information to turn ideas into reality. The guides are structured around a common format; Chapter 1 provides a general introduction to the topic, Chapter 2 advice on how to implement the topic and Chapter 3 more in-depth information on the topic and the opportunity to investigate it further. In addition, each guide contains a collection of bioscience case studies highlighting how others have introduced the topic into their teaching practice. It is intended that the guides will be useful to academics in their first year of lecturing, particularly those who are studying for Postgraduate Certificates in Learning and Teaching in Higher Education, as well as to those with many years of teaching experience.

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Introduction

The purpose of this Guide is two-fold: firstly it is intended to provide useful insights into current thinking about pedagogically sound provision of student research projects, and secondly to showcase examples of how student research experience is incorporated within UK HE-level undergraduate bioscience programmes.

Chapter 1 explores the key pedagogic advantages associated with research projects and the main benefits for students and staff.

Research projects are of value to undergraduate students in several important ways. Research work gives them ownership of their subject and allows them to experience the limits of confident knowledge, consistent with their approaching status of graduate. Research offers a taster of real science, which may inform career decisions, and allows the development of valuable skills. Project students encounter a new level of independence in their studies and should find the experience both motivational and enjoyable. For academic staff, projects provide an immediate link between teaching and research. The research may be intrinsically productive but it can also be a chance to test ideas and take controlled risks, provided these aims are consistent with educational objectives.

Chapter 2 takes an in-depth look at the variety of forms of research project, the management of research project provision, and the nature of student supervision.

The types of work which may be appropriate for research projects are numerous and are limited only by the imagination of staff and their educational context. Conventionally, the project is a practical, experimental investigation but, as illustrated by several detailed case studies, it may take diverse other forms provided certain characteristics and objectives are met. In fact, diversity is a feature of bioscience education, as of bioscience itself, and this is nowhere better illustrated than in the project topics and styles which colleagues use. However, a crucial feature of research provision within in any department must be the assumption that all projects are of equal educational value.

Departments make certain practical decisions about how to incorporate research projects into their programmes and about how to manage them. Both ‘set aside’ (calendar time devoted solely to the project) and ‘multi-tasking’ (project runs in parallel to other studies) models are used, but there is also variation in the extent to which students receive pre-project research training or are expected to work in teams. The choices made often reflect pressures from class sizes, limited availability of resources and local approaches to funding. However, case studies again demonstrate that with a little imagination and resourcefulness, impressive results can be delivered. In terms of funding, students should be expected to appreciate the cost of their research but not to take responsibility for it.

Project management starts with topic allocation (a departmental activity) but then rapidly becomes personal. At the scientific level, the supervisor’s role is to give the student gentle but secure guidance in how to understand and define the question, manage their expectations and set realistic targets. Underlying all this is the heuristic objective of instilling an uncompromising approach to enquiry. This can be best achieved by a proper application of the scientific method and by the adoption of a discourse appropriate to the subject area. Projects carried out this way carry limited educational risk but retain the potential for great excitement and genuine discovery. Some projects may require an ethical appraisal, and this too can be part of the educational process. Mock grant applications provide a way of getting students to think objectively and constructively about the work they are about to undertake.

It is a singular privilege to be a project supervisor. A unique relationship develops between supervisor and student but this entails a set of mutual obligations, best described as 'amicable professionalism'. The supervisor needs to plan in anticipation of need, but must also prepare for the unexpected. Regular meetings, diarised and recorded, are the bedrock of successful supervision and should be a natural aspect of the shared endeavour. It is helpful to establish from the outset a framework for writing which will carry the student through to the report or dissertation. Writing is tough, and the supervisor has a direct and unavoidable responsibility to be both literary coach and stylistic guide. Few projects are problem-free; when difficulties arise, it helps to distinguish between those which stem from the project itself and those which concern the personal circumstances of the student. Supervisors should be resourceful in offering assistance but must also know their limits and call on others when appropriate.

Chapter 3 highlights some of the key principles of assessment and considers the range of outcomes and outputs which may be produced from student research projects; again drawing on examples from subjects within the biosciences.

Projects are primarily educational in aim and need to have an assessable outcome. The traditional dissertation has advantages and disadvantages when compared to a research paper, and other forms of final report may be appropriate for certain types of project. Length and content need to be broadly defined to ensure parity between students but there should be individual flexibility and discretion in the way rules are applied. Because undergraduate research projects should always be realistic, not contrived, it is to be expected that publications will sometime result. This is icing on the supervisory cake and a chance to celebrate student achievement. Besides conventional journals, an increasing number of local and national vehicles are becoming available for the publication of undergraduate research.

Bioscience Case Studies: the second part of the Guide provides 10 case studies of student research in the biosciences. They cover a wide range of research project formats; conventional laboratory or field-based projects, group projects, and a diversity of alternatives involving data-mining and analysis, and commercial, communication and education-based investigations.

All of the case studies show practice which offers lessons for others and may be applicable or translatable to other contexts and subject areas. Each is written with enthusiasm and passion and gives insight into the problems or issues associated with implementation as well as the successes. Together the individual case studies encompass the theoretical concepts covered in the earlier chapters. Expanded versions of the case studies, further bioscience case studies, and supporting materials are available from the accompanying web site to this guide (www.bioscience.heacademy.ac.uk/TeachingGuides/)

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Chapter 1

The value of student research in the biosciences

Introduction

Most undergraduate students are expected to do research at some point during their university education. This Guide discusses why this should be so, what's in it for students and staff, and how to go about making the experience as valuable and productive as possible for all concerned.

There is no doubt about the importance attached to research and its centrality in the undergraduate curriculum. Survey responses from 58 UK bioscience departments (Cowie, 2005a) indicated that all offered some form of practical project in the final year and many also offered projects involving data analysis and literature review. The value of the project in the undergraduate curriculum was indicated by its weighting of between 25 and 30% in the final degree mark and the expectation that students would spend an average of 240 hours over 16 weeks working on their projects. The Quality Assurance Agency considers research to be a required component of undergraduate programmes. This is made explicit in each of the QAA subject benchmark statements of relevance to the biosciences (QAA, 2002 and 2007a and b).

Why is research so important for undergraduates? What do they stand to gain from it and what can be done to ensure that the experience is a positive and productive one? As teachers of bioscience, we need to address these questions head-on so the right research environment is created and adequate supervision, resources and support are in place. It also helps if the experience of supervision can be positive for staff.

What's in it for students?

Here are four good reasons for enabling students to do research.

i) Ownership: a philosophy of higher education and 'graduateness'

What's so special about higher education? Before they come to university, most students' educational experience has been centred on the acquisition of knowledge. Those coming through the conventional school system have studied a proportion of mankind's collective wisdom, divided into subjects and arranged into a curriculum. Success has depended on the ability to demonstrate the possession of facts, broad understanding and personal skills. Those who come to higher education after a break or for a change of career possess a good deal of 'life experience' but are also expected to be knowledge-aware. All students arrive with a chosen field (science, humanities, arts etc.) in which they feel broadly confident or have a potential interest.

At university, study continues in the chosen field, but there is a difference. Subjects develop depth as well as breadth, information becomes more detailed and concepts become more challenging. But this is not just a change of intensity. A key characteristic of successful degree study is that the student comes to appreciate the full extent of their subject, of how far it has developed and of where it might be going next. They also move from being a passive observer of the scene to becoming an active participant. For further discussion of this topic, see Hounsell and McCune, (2002) and McCune *et al*., (2003).

This view of higher education leads to a definition of what it means to be a graduate. By obtaining a degree, a student should feel not only that they can speak about a subject with some authority and confidence but also that they have a sense of where the border between certainty and uncertainly lies. They should know something of the background to what they have learned but also possess the skills to appraise and interpret new information or discoveries. University study could therefore be described as the point where students experience the limits of confident knowledge. It should be the time when they are able to reach from the realm of the known to the realm of the unknown. By arriving at this point, they should feel ownership of their subject.

For academics, the question is how to create the right educational environment for this to happen. Encouraging students to take part in research has long been seen as a route to specialist enlightenment. In a practical scientific field such as the biosciences, knowledge, understanding and advancement come from practical investigation and the evaluation of observations. What better way could there be to turn students into competent, rational, professional bioscientists than by offering them the true scientific experience? This Guide suggests some ways of making this happen.

One further educational point should be made here. Bioscience students arrive at university expecting, quite rightly, to learn through experiment. However, their previous experiences may have given them a utilitarian rather than investigative perception of the experimental sciences: experiments were used to demonstrate what is known, not to discover something new (Collis *et al*., 2007). The best way to change their view is to allow them to design, perform, analyse and interpret their own research (Garde-Hansen and Calvert, 2007; Hurd, 2008).

ii) A taster of real science

Many bioscience students go on to academic and research careers in academia, the state sector or industry. A few may find that a particular skill or knowledge of a topic, obtained in the course of their project, leads directly to a PhD position, but this is rare. For most, the project represents a unique chance to experience research in a relatively secure and supportive environment. They can decide if they are suited to it, whether they can accept its intensity, focus and frustrations, and whether they are likely to enjoy it. Student research lacks the absolute requirement of productivity - the emphasis is on process rather than outcome - so an element of anxiety is removed from the experience.

For graduates entering bioscience-related jobs or professions where research is not the main preoccupation, there is value in having experienced the scientific process. They will find themselves working with information supplied by others; they need to understand how science works and how information is gathered and evaluated. They will also need to know when to be trusting and when to be sceptical, how to separate fact from presentation and how to distinguish importance from fashion. Many of these attributes apply equally to those moving out of science. The experience of research should prove to be valuable for all graduates, whatever career they enter, and not just those with the higher classes of degree.

Ryder (2004) conveniently distinguishes *Knowledge of Science* and *Knowledge about Science* as distinct learning outcomes of final year research projects. The former relates to the scientific content of the project and the opportunity for directly engaging with and owning a number of concepts and ideas. The latter has to do with understanding methods of scientific enquiry, appreciating the relationship between claimed knowledge and real data, and appreciating the culture of science and its professional, institutional and social contexts. When formulating ideas for investigation it may be helpful to reflect on the extent to which a particular project may support these two learning outcomes.

iii) Skill development

A previous survey of academic colleagues (Luck, 1999) generated a list of some 46 ‘adaptable’ skills a student might acquire by doing a research project (Table 1). These were roughly divided between four headings: Process skills; Presentation skills; Management skills; and Personal skills. Similar skill audits are available elsewhere (Cowie, 2005b; Ryder, 2004).

Projects are valuable, not just for their intrinsic content or outcome, but for the skills obtained by the student. Here is one way of categorising some of these skills. Recognising skill development in this way can help the student to value their project and recognise their achievements.

Table 1 Skills obtainable from projects (Adapted from Luck, 1999)

Process skills	Presentation skills	Management skills	Personal skills
Problem formulation	Effective use of language	Project planning	Independence
Problem solving	Data awareness	Setting objectives	Self-confidence
Assessing information	Oral communication	Project management	Self-reliance
Sifting and balancing evidence	Audience awareness	Progress review and evaluation	Self-discipline
Research techniques	Debating and arguing	Time management	Self-enquiry
Literature searching and sourcing	Persuading an encouraging	Working to deadlines	Imagination
Reading scientific information	Effective use of display technology	Working with others	Originality
Developing arguments	Report writing	Person management	Ability or learn
Designing investigations and experiments	Writing for different audiences	Coping with crises	Making decisions
Analysing data	Writing for different purposes	Entrepreneurship	Being adaptable
Attention to detail			Accepting criticism
Numeracy			
Literacy			
Computing skills			
Lab skills			
Safety awareness			
Writing for different purposes			

The QAA Benchmark Statement for Agriculture and related sciences (QAA, 2002) gives a detailed list of skills associated with its degree programmes, divided amongst Intellectual skills, Practical skills, Numeracy skills, Communication skills, ICT skills, Interpersonal and teamwork skills, Self management and professional development skills. About 75% of these can be associated directly with research work, as may many other skills.

In addition there are 'subject-specific' skills, associated with the research work itself and learnt in order to carry it out (for example, a specific lab procedure, machine operation, mathematical model or statistical technique). Some of those may also turn out to be unexpectedly adaptable to other situations.

It has been fashionable for some time to specify skill development as a learning objective in course descriptions. In the case of research projects it may indeed be helpful to define certain target skills, although with such a long list to select from one might debate whether accurate specification is necessary or indeed possible. The development of skills could, by itself, probably justify the inclusion of research in undergraduate courses. It is certainly valuable to be able to offer them as a tangible outcome to students, especially to those who may be less academically inclined or sceptical about the value of getting involved in research. In the end however, skill development is inevitable: any student completing a project will have acquired a valuable set of life- and career-enhancing experiences, whether or not they have been deliberately sought or explicitly identified as skills.

iv) Independence, motivation and fun

Undertaking a research project represents a radical change in learning style for most students. They move from the organised security of formal teaching situations (lectures, practicals, tutorials etc) to an individual investigative study for which they need to develop their own learning environment. The project topic belongs to them and progress depends uniquely on their input. The progress they make will be a measure of their self-reliance and their ability to convert enthusiasm into productivity. This is personalised learning.

Many students find this independence motivating and energising. They enjoy the change of focus and respond positively to the newly acquired responsibility for their own learning. These are valuable aspects of the research experience and they will contribute to the student's personal, scientific and professional maturity.

As in most areas of life, motivation, independence and pleasure are closely linked, so there is every reason to expect the project to be a pleasurable aspect of degree study. The following quotation is attributed to Benjamin Jowett (1817-1893), a Greek scholar and Master of Balliol College, Oxford: "We have sought truth, and sometimes perhaps found it. But have we had any fun?"

What's in it for academics?

In view of the cost of undergraduate research in time, effort and resources, it is reasonable to expect a payback. The research itself is being done for two separate reasons: for its educational value and for its intrinsic scientific worth. Because the student doing the research is concurrently learning how to be a researcher, there can be no guarantee that the research will be productive or valuable. So, what else can staff expect to get from the experience?

i) Linking teaching and research

In recent years, there has been much debate about the link between teaching and research in higher education (Sears and Wood, 2005; Jenkins *et al*., 2007). Do teachers need to be active researchers? Should research-focussed academics be expected to teach? What is the nature of scholarship? Are teaching and research linked or separate parts of academic life? These questions come to the fore whenever the Research Assessment Exercise is mentioned and whenever comparisons are drawn between institutions with different academic priorities.

More importantly, every academic is forced to address these questions for him or herself. We each need to set our own priorities and adjust to the competing demands of what can feel like an impossible job. These issues have been discussed elsewhere (Luck, 2006) with the conclusion that teaching and research need to be integrated components of academic professional life; they influence each other in a variety of important, often subtle ways.

Creating, running and supervising undergraduate projects can be a straightforward way of integrating teaching and research, helping to overcome the problem of competing pressures. Moreover, if student project work is viewed as part of one's research activity, as much as a part of one's teaching, it can increase the motivation and reduce the burden considerably. The following paragraphs look at how this can happen.

ii) Testing ideas, risk-taking

Be reassured: it is OK to take (calculated) risks with student projects! It is perfectly acceptable to get students to investigate speculative ideas, to test hunches and to work on a small scale, always provided that the educational environment and the scientific framework are sound and well managed. All research is risky – otherwise it wouldn't be research – and student research is no different in that respect. The outcome of any research project is uncertain: if it were already known, the project would not be worth doing.

Where student research does differ is in its purpose: because it is part of learning, the emphasis is on process rather than outcome. A project can be deemed a success if the student emerges from it with understanding, enthusiasm for science and a greatly increased portfolio of skills. In fact, whilst a very few students are fortunate enough to make important discoveries, the vast majority of projects never generate anything remotely publishable. But if this is the case, how can student research be looked on as a valuable part of one's research activity?

One answer is to make use of students as test pilots. Get them to try out ideas which are too small to give to a PhD student, which might be away from the main focus of your interests, which might be following up a hunch or tying off a loose end, or which you might otherwise find hard to get funded. As discussed below, student projects can be 'wet', 'dry' or literature-based, or have a commercial or educational context. In all of these situations, they offer an opportunity for you (the teacher/researcher) to engage with your own imagination, without the need for external justification.

Be clear this approach is not one of reckless risk-taking. Quite the opposite is true: any project needs to be properly thought out, designed, resourced and managed otherwise it is not justifiable and the student will be let down. Be prepared to take risks in topic and concept, but be clear about the nature of the work. Give the student attainable goals and adequate resources and know what you will do if problems arise.

iii) Surprises and dead ends

Although the value of most student research lies in the experience of the student, some projects do turn out to be scientifically valuable as well. Student data can contribute to publications including papers, books and conference presentations. It is exciting when this happens and a cause for celebration. In Chapter 3, we look at some ways of publicly recognising student research and increasing its value.

In addition to this be prepared for the odd surprise. Occasionally, research ideas which you may have thought to be unlikely will turn out to be inspired and far-sighted. Other ideas, thought to be routine and a safe bet, will prove to be dead ends and not worth pursuing further.

Students themselves spring surprises too. Given the opportunity to think for themselves, students can often bring a fresh imagination and an uncluttered perspective to a problem, and other productive suggestions or new interpretations. If this happens it is indicative of a successful conjunction of circumstances: project, student, supervisor and resources all coming together in a conducive intellectual environment.

And a further even more rewarding surprise is when a student starts to flourish unexpectedly, for example, when someone who has struggled in the face of conventional coursework and exams turns out to have a real aptitude for lab work or complex modelling or literature analysis. These moments, which are sometimes life changing for both the supervisor and the student, are to be savoured.

iv) Fun

Supervising a project student inevitably means getting to know them particularly well (Chapter 2, page 26). Whilst it remains a professional interaction, it is a deeper interaction than occurs elsewhere at undergraduate level. This adds immensely to the pleasure of the job. Project work is a collaborative effort, even if the types and quantities of input are unequal, and strengths and weaknesses on both sides can be brought into sharp focus. Each supervisory experience is unique and each project assumes its own personality and flavour for this reason. At the end of the project, an experience has been shared and it should be possible to reflect on it with pleasure. Jowett's question (above) should be posed at regular intervals.

Chapter 2

Ways of implementing research projects

Types of project

Cowie (2005b) found that all the HE bioscience departments which responded to his survey (58, representing pre- and post-1992 universities) offered practical research projects based on laboratory or fieldwork. Over half (52%) also offered literature-based projects and 43% offered projects based on data analysis. A fifth of departments offered projects not falling into one of these categories, suggesting that there is an extensive pool of alternative possibilities, designed and supervised by imaginative staff with a broad range of research skills and experiences to offer.

In this section we look at a range of types of project, both conventional and unconventional. We identify six broad types of research project commonly used in the Biosciences (including the Life, Food, Agricultural and Biomedical areas) and consider the essential characteristics of each. Case studies, kindly provided by colleagues, are presented to illustrate how these projects operate. The aim is to indicate the variety of research experiences which can be offered to students and to provide ideas and inspiration.

Subsequently, we consider the more abstract but important questions of whether different types of project offer equivalent educational experiences and of what needs to be done to ensure all students engage with real research. As a general principle, all types of project can be investigatory and involve the application of scientific techniques, even though individual contexts, methods and outcomes vary widely. An educationally successful project is defined by process as much as by outcome and so all students should be expected to work within a rigorous scientific framework. We therefore emphasise an overtly experimental approach, grounded in a clear perception of and application of the scientific method. A discussion of the importance of the scientific method and of ways of getting students to engage with it is given later (Chapter 2, page 23).

i) Laboratory

Laboratory projects are traditional in many bioscience disciplines. They are the most obviously experimental in nature and it is straightforward to build them around the testing of a hypothesis. The project will probably fall naturally into three phases: a period of practical experimentation, preceded by a reading of key literature and followed by data analysis and interpretation. Because of the complexity and resource requirements of most practical bioscience research, these projects may require the application of standard procedures. Methods of data analysis may also be well established. The student will probably be working as part of a well-established lab or research team.

Despite joining an established research environment, the student has several important tasks: a) to get to grips with the background material, b) to produce a sound experimental design, c) to become a responsible laboratory worker, d) to learn the required techniques, e) to generate and analyse data or observations, f) to interpret data and reach an informed conclusion. Each of these can be a significant challenge, even where the bench work itself is routine and reliable data is likely to be produced.

For the supervisor these types of projects can be the most expensive and resource-intensive. The student needs to be provided with lab space, consumables and machine time, and it will be necessary to devote academic, researcher or technician effort to induction, training and trouble-shooting. None of this input has a guaranteed return in terms of lab output. The experimental design stage will need to be carefully guided so the student retains reasonable autonomy, avoids known pitfalls and ends up with a workable scheme. Also, students vary considerably in their aptitude for practical experimentation, so a good deal of patience, tolerance and support may be needed from others in the lab.

The main advantages of lab projects are that they lead directly to practical skills and they fit easily into a conventional investigative framework. They are also reasonably straightforward to write up, either as a thesis or in the form of a research paper. The main disadvantages can be cost, the difficulty of providing access to adequate facilities and resources, and the need for close supervision.

Chaffey (case study 1) provides a typical example of a lab-based project built around a straightforward and easily adaptable set of microbiological procedures. A key feature here is that the simplicity and reliability of the technique allows the student to be imaginative and to suggest and test their own independent variables. A tried and tested structure like this also means that appropriate emphasis can be placed on rigorous attention to experimental design and the application of scientific method.

Partridge and Murphy (2004), and Latham (2008) are published examples of lab-based experimental projects. Other high quality research reports from bioscience projects can be found in the Bioscience Horizons journal (http://biohorizons.oxfordjournals.org/).

ii) Fieldwork and surveys

In many respects projects involving field-based observations or collection of samples from the field (followed by analysis in the laboratory) are similar to laboratory projects, and represent the traditional student research project in field-biology and environmental biology disciplines (agriculture, ecology, conservation, zoology, and marine and freshwater biology). The field-based element of such projects may take place within the UK or overseas (the latter may be particularly attractive to many students (and prospective students). The logistics of organising field-based projects (particularly overseas) can be complex and issues surrounding student supervision and health and safety may be heightened. In addition to the constraints posed by larger student cohorts and research costs, the accessibility of suitable field sites and the inherent nature of field-based projects (involving observation of biota and dynamic systems) can make project timing more problematic. As a result, it is common for the field-based or sample collection element of the project to take place in the summer vacation preceding the student's final year of study, which can sometimes give rise to questions over parity.

According to Downie *et al*., (case study 2), they have found linking field-based projects to 'undergraduate expeditions' to be a particularly successful strategy for overcoming such difficulties; enabling greater numbers of students to undertake projects overseas. Their solution has been to create fieldwork opportunities during the summer vacation (for which students in any year may apply) and to allow final year students to use these as the basis for their final year research. Projects may be based in the UK or abroad and in the latter case are linked to 'undergraduate expeditions' organised jointly by staff and students. The key feature of this approach is that the final year students take part in a larger endeavour which can be properly funded and academically managed. The university retains oversight of the experience and expedition staff can ensure the correct scientific approach is being taken. Staff (and students) in the department recognise the inherent diversity of the projects carried out and the flexibility permitted in terms of timing and input, but find the resulting studies are equivalent (in terms of time, effort and intellectual rigour) with other types of final year project. An additional advantage of this approach is the opportunity for students in earlier years to gain research experience and learn alongside senior students, and staff undertaking research activities.

Bryant (2005) concludes bioethical topics can be the basis for 'dry' projects; with such projects embodying similar elements to traditional projects, namely: defining a research problem, designing appropriate methods to investigate the problem, and collecting, analysing and presenting data/observations. Ethical approval is essential for this type of project, which typically involves surveys/questionnaires or structured interviews (methods more common to the social sciences), and can therefore represent a steep learning curve for biologists. In common with 'wet' projects, such projects may lead to publishable outputs (e.g. Bryant and Morgan, 2007).

iii) Data analysis, bioinformatics and modelling

Many areas of modern bioscience, for example those based in genomics, proteomics and metabolomics, generate vast amounts of data requiring devoted and specialist analysis. These can generate abundant material for student research. Many bioscience departments have specialist bioinformatics staff who can provide links to colleagues with suitable data sets as well as offering support and supervision.

Such projects, built around data analysis and modelling, are characterised by the fact the student is not responsible for the generation of the data. Their role is to understand its origin, design and structure and then to mine it for valuable information. In this sense the ownership of the project is somewhat different from a conventional experimental investigation. The student needs to be clear about the level of responsibility they may have for the hypotheses being tested, the type of conclusion they are expected to come to and the extent to which they are responsible for the analytical methods to be applied.

A further issue to consider is the extent of the mathematical and statistical challenge associated with the work. Most bioscience students are numerically competent to a lesser or greater extent, but a significant proportion express a dislike or insecurity over numerically-based work (and may even have chosen biology in preference to other sciences for that reason). In fact, with patient supervision and good specialist support when required, the concepts and analytical techniques needed for data-based projects are well within the grasp of most students. Furthermore, once the methods are set, the analysis will be carried out by computer and the student's role will be to manage rather than manipulate it. Thus projects of this kind may need to be proposed and sold to students with care, perhaps placing the emphasis on the biological outcome itself, rather than on the methodology.

James (case study 3) and Hejmadi (case study 4) provide projects based on bioinformatics topics which will specifically encourage the development of key research skills. Wagstaff (case study 5) finds that bioinformatics projects, if carefully designed and supervised, can have equivalent intellectual and experimental attributes to those of wet or lab-based investigations, although students may need initial guidance on the relationship between large-scale data analysis and real biological systems.

iv) Literature review

Pressure on staff time and resources mean that literature-based projects are becoming increasingly popular. On the face of it they seem a simple way of avoiding costs and dealing with large numbers of students. However to be effective they need to be properly structured investigations and must be carefully managed. They should be more than just an extended essay.

A useful guiding principle for literature projects is that the whole should be more than the sum of its parts. Published information needs to be read, reviewed and summarised, but the result should be a synthesis which provides a new interpretation, gives a new perspective or offers a novel explanation of the topic being discussed. This is not easy and it provides a significant and valuable educational challenge.

Such projects can be firmly grounded in the experimental method and the key to this lies in the way the topic is set. The initial idea for the project might be a purely descriptive enquiry, based on a question starting with 'What', 'Where', 'When', 'How' or 'Who' and using solely the existing literature to provide answers. The way to render these questions scientific is to turn them into testable hypotheses (as suggested in Table 2), and then to use the literature as evidence for the test.

Once this is done, all the usual requirements of sound critical science come into play: determining the validity and reliability of information, examining assumptions, identifying misinterpretations, spotting gaps in explanation, suggesting new experiments and developing new hypotheses.

Table 2 Turning investigations into questions
(Adapted from Luck, 1999)

Nature of investigation	Structure of question
Find out about something	Is it true that …? Where is X located? What does Y look like?
Measure something	What is the size of …? Is X significantly different in size from Y?
Find out how something works or why something happens	What is the cause of …? Does X have a significant effect on Y? Does Y depend on Z? Do X and Y respond independently to Z?
Model a possible event	What would happen if …? Could X be the cause of Y? Is Y a necessary consequence of X?"
Solve a practical problem	How can X be achieved? How can difficulty Y be removed?
Create a useful product or practical solution	How can X be done, or done better? How can Y be made?
Investigate an historical event	When and why did X happen? Why did Y happen when it did?
Investigate an historical character	Who caused X to happen, or what was their role in the course of events?
Investigate a significant event	Where did X happen? Why did it happen here?
Test public opinion	What do people think about X? Which of X, Y and Z do people prefer?
Study a process or policy	What is the mechanism of X? How can Y be improved or made more efficient?

Initially, the student may find this approach unfamiliar, unnecessary, uncomfortable or even irritating. However, if done in a structured fashion, they will quickly find that it guides and focuses their reading and gives secure purpose to their investigation. Until this point they may have used published information as a reliable point of reference. Their principle challenge is to realise that literature is subjective, fallible, incomplete and open to re-interpretation. When used in this way, literature-based projects can be exciting routes to discovery.

Projects often begin with a general idea of what needs to be investigated. An essential early step is to turn this idea into a focussed question. It helps to categorise the nature of the investigation and to phrase the question accordingly. Once this has been done it is generally straightforward to develop hypotheses and apply the scientific method.

The challenges for the supervisor include:

- Training the student's attitude and language towards a critical investigation;
- Keeping account of the balance of the work as it proceeds;
- Pointing the student to key sources at appropriate points in the investigation; and
- Encouraging them to use their imagination and helping them to find new points of view.

Writing up a literature-based project presents a further challenge, and departmental guidelines for the structure of the thesis are likely to need adaptation. Although a conventional experimental framework is inappropriate, it is still important to identify questions and hypotheses, to present evidence and evaluate it and to come to clear conclusions. The literature review section will probably be greater in extent and it may be appropriate to have a separate section, analogous to the 'Results', where key items are evaluated in depth. The 'Methods' section will probably be short but could contain a brief account of the literature search strategy (sources and databases used, keywords, levels of search, threads followed) and of any meta-analytical or data assembly procedures employed.

Equally, it is usually necessary to design a specific marking strategy for these kinds of projects rather than force the assessment to fit that applied to a conventional, experimental project (for example, see University of Nottingham, School of Biosciences). It is important to understand the requirements of the work and explain these clearly to the student at the outset of the study.

v) Commercial; Product development

Some departments exploit links with industry to provide both ideas for project topics and the material for investigation. This approach recognises that many students will develop careers in industry and commerce. They can benefit enormously by seeing how a business operates, whilst at the same time working on a research idea of direct interest to the company. From the university's point of view, it adds variety to the project options available but also helps to ease pressure on resources.

A key determinant of the success of these arrangements is the clarity and effectiveness of the link between the supervisor and the business partner. The supervisor retains educational responsibility and may need to guide the partner over matters such as expected achievements, workload and timescale, as well as the need for a carefully structured and objective assessment of student performance. The partner's agenda will be centred on the product and its commercial value or importance to the company. They may have a mutual interest in the science underpinning the research and will need to establish an ongoing dialogue to ensure that their interests and those of the student are sufficiently catered for.

Tatner and Tierney (case study 6) exploit links with local bioscience companies to develop sponsorships for individual students. The topic for research is suggested by the company and the work itself is done on the company's behalf, although the student has a university-based supervisor with responsibility for the underlying science. The student's performance is assessed by a conventional project report and a technical document, the latter becoming the property of the company. Students taking this type of project undergo an intensive two-week business orientation course to prepare them for the commercial environment they are about to enter. Similarly, Przyborski (2005) describes a year-long 'enterprise elective' offered by the School of Biological and Biomedical Science at the University of Durham, with input from the University's Business School. Students generate an idea for a business opportunity based on a scientific discovery, and then apply their knowledge and understanding of science to develop and research their idea into a technology that can be readily commercialised. They work and are summatively assessed both in groups and individually; producing an extended essay, a presentation and a business plan.

Jellings (2003) describes Technology Transfer projects, designed to strengthen the links between research literature and vocational graduate destinations. The use of these projects was encouraged by discussions with employers, and they were found to substantially increase the employability of students who completed them. Each project is structured around an assessment of recent developments in an organisation which exploits technologies associated with specialised areas of the student's degree programme, coupled with a targeted analysis of a particular business. The project is thus directly relevant to both the student and the business.

The challenge for the student is to probe the links between technology and its application and to understand how communications between and within technology-using organisations actually work. It was found possible to assess project performance by adapting standard criteria to include both the business analysis and the student's ability to design systems for the communication, transfer and embedding of new technological information.

vi) Educational resource development/ Communication projects

Students often express an interest in the way science can be communicated and taught. Many will go into teaching where there is a clear need for well-developed communication skills coupled with an ability to describe complex topics in a straightforward and understandable manner. Others may be attracted to careers in journalism, public relations or as science writers in commercial, industrial, government or charity settings. Even those who enter more conventional academic, scientific or research careers, are increasingly required to be able to justify their work to lay-assessors or describe what they do to non-specialists (for example when applying for research funding or patents).

Like all bioscience students, students following any of these paths need to have a good understanding of their subject and to have experienced research first hand. However, there is an additional advantage if the research they carry out for their degree has an explicit clear communication element. Several departments have developed projects offering this combination of experiences. The challenge in designing and running them is to ensure that the student engages with the scientific process at the same time as developing suitable styles of presentation.

Lloyd (case study 7) offers 'science communication projects' as one option amongst a variety of project types and styles. Project topics are often drawn from topical and controversial areas in the public eye (of which there is seldom a shortage given current developments in bioscience, biotechnology and biomedicine). The outcomes of the project are a dissertation and an oral presentation, together with a communication piece in a format suitable to the nature and context of the topic. This combination ensures ample opportunities for the student to demonstrate their communication skills, but also allows them to show that they can engage deeply with a scientific issue, undertake in-depth research and deploy the crucial tools of critical judgment and analysis. The assessment scheme is explicit in terms of achievement in each area. (See also, Whittle (2003).)

Grady (2008) similarly offers projects tagged as 'Education'. These often lead to the development of a teaching resource relevant to school biology and may require the student to make contact with or seek advice from a teacher. The project learning outcomes specify that original research must be undertaken and that there must be some experience of scientific and investigatory techniques. Thus the research work is in every sense equivalent to that being carried out in more conventional bioscience projects. The added attraction, especially for students interested in a career in education, is the targeting of research towards pedagogy and the chance of developing communication skills and awareness.

In both of the above cases the requirements and learning objectives are specified in such a way as to ensure that academic and scientific rigour are maintained. This ensures parity with other projects and prevents students from seeing it as a soft option. It also dispels any uncertainty amongst academic colleagues about the equivalence of the research challenge.

Broadley (case study 8) has developed the use of teaching experience as a final year research project. Students taking part in the Undergraduate Ambassadors Scheme (www.uas.ac.uk/) engage in lesson planning as the basis of their final year dissertation. Alongside the development of a teaching resource, they undertake research into aspects of pedagogy and are required to reflect critically on the progress of their own learning and development. Thus, rather than gaining technical scientific skills, their research skills relate to communication and pedagogy, coupled with an understanding of their own area of bioscience. The project is marked to a rigorous scheme which ensures equivalence with more traditional types of research project. Students taking this option have previously followed a module called *Communicating Biosciences* which provides them with some basic skills and raises their awareness of the styles of communication required for different audiences.

Wakeford and Miller (case study 9) and Hollingsworth *et al.*, (2004) describe projects involving the development of e-learning resources, which have been an option for a number of years, for final year students at the University of Manchester. Students produce e-learning resources for undergraduate use, such as data-driven activities, or virtual experiments to support laboratory classes. As part of these projects each student is involved in designing, creating and then evaluating their resource and its suitability for their intended audience.

Adams (2008) describes the development of an information website as the outcome of a research project in plant biotechnology. The aim was to provide a vehicle through which information about the selenium fortification of bread, arising from government-industry sponsored research on fertiliser-based agro-fortification, could be communicated to scientists, health professionals, industry and the public. Adams' task was both to understand the biotechnology and nutritional science underlying the topic, and to consider the most effective way of designing and constructing a dynamic and informative website. Thus the project combined a need for sound evaluation and understanding of scientific information with an appreciation of effective design and communication.

vii) Relative values

Students only get one chance at a research project, so it is essential that all are given an equivalent educational opportunity. Given the enormous variety of possible topics, it is reasonable to ask whether some types of project may be inherently more valuable than others.

There is certainly a view amongst some academics that all bioscience students should have the opportunity to carry out conventional, lab- or field-based research and that any other type of project represents second best. In fact, this need not be the case: the value of a project lies principally in the experience it provides of the scientific process, not in its factual or methodological content. Furthermore, given that about 50% of biosciences graduates go on to get employment outside the subject area (Brown *et al.*, 2005), it would be hard to argue that specific lab or field techniques should be experienced for their career value.

Each of the project types discussed above will facilitate a proper experiential engagement with science, provided they are constructed, performed and supervised in the right way. Wakeford and Miller (case study 9) acknowledge the need for all students to experience realistic research, whatever type of project they carry out. They promote investigative and critical thinking in virtual laboratories, using a "language of enquiry" model and a carefully structured and supported learning environment.

As a matter of practicality, large class sizes and the availability of funding and staff resources demand that a flexible approach is taken to project design. Furthermore bioscience education, like bioscience as a discipline, thrives on diversity and so the range of available projects should reflect this. All students should receive an equal chance to demonstrate their skills and abilities and it would certainly be wrong to pre-select them on the basis that some projects are inherently more difficult or intrinsically more valuable than others. It is notable that the journal Bioscience Horizons (http://biohorizons.oxfordjournals.org), which publishes expert-reviewed and fully citable articles derived from student projects, reports not only traditional-style lab investigations but also fieldwork reports (e.g. Crompton, 2008), ecological surveys (e.g. Worster, 2008), literature-reviews (e.g. Kaczmarczyk, 2008) and web resource development (e.g. Adams, 2008). It is clearly realistic for all students to be offered a full research experience, and for expectations to be set high, whatever the nature or type of the investigation.

Students may express particular preferences or interests and this can be reflected in the allocation of topics, provided a fair distribution system is used (see below). However, experience suggests that students will demonstrate their level of ability whatever type of project they do, provided the project itself is designed to afford them that opportunity. Aptitude, ability and skill are unpredictable attributes.

Strategies for project management

i) When to do it

Undergraduate research projects in the biosciences normally take place in the final year of a three year BSc degree course (or four year Scottish equivalent). An alternative strategy, currently more common in the physical sciences than the biosciences, is for a three year BSc degree to be converted to an MSci by an extra research year. Traditionally, the inclusion of research within a three year course distinguished an honours degree from an ordinary degree, although this distinction has been blurred since the massification of HE began in the second half of the 20th century and the widespread adoption of credit ratings and modular course structures in the 1990s. Research projects are also available to many students taking medical or veterinary courses at the end of the pre-clinical training period or as part of intercalated degree studies.

The credit weighting applied to research within the overall degree assessment varies considerably across universities, colleges and departments, reflecting variation in the amount of time allocated to research within the degree programme. Cowie's (2005a) survey indicated projects contributed on average 26.4% to the degree mark (higher for practical and data analysis projects and lower for literature-based projects) but with a likely range of between 10 and 50%. This variation is to be expected given the autonomy of universities to create their own degree programme structures and the avoidance of time specifications in QAA subject benchmark statements.

ii) Two models

There are also two distinct models for including research in the degree programme. The 'multi-tasking' model (by far the more common; Cowie, 2005a) requires students to take a project module(s) alongside their other studies and the research may therefore be extended over one, two or even three terms/semesters. The 'set-aside' model allows for a period of study to be devoted entirely to research. The amount of calendar time may be substantially less under this model (say 8 - 10 weeks or one semester) but the hours of study should be proportionate in terms of credit weighting and assessment. In the end, the department will decide which model is adopted and will build the project appropriately into the rest of its teaching and assessment programme.

Projects which are based on seasonally-dependent resources (for example, in applied land-based or environmental subject areas) or which involve vacation or placement work, may have to be run on a multi-tasking basis simply to allow access to the necessary material. Such a project may be designed to have distinct periods of time devoted to experiment or data collection, with the rest of the time assigned to literature review, data analysis and write-up. In general the multi-tasking approach allows for a diversity of project types to be made available within a single department. The set-aside model lends itself well to lab-based projects and can be particularly efficient to run where groups of students need to be taught a common set of techniques or given devoted access to resources, for example in molecular, biochemical or cell culture laboratories.

Although 'multi-tasking' and 'set-aside' are equally valid approaches, the project experience of students under each model may be quite different. Under 'multi-tasking', the student is exposed to the research topic for an extended period and there is time for their thoughts and ideas to develop. The opportunity to separate background reading from practical research activity may be exploited to allow the student a significant influence over project design. On the other hand, 'multi-tasking' students may need to be particularly well-skilled in time management and will probably need to negotiate constantly with supervisors and members of the research group over timing and access to resources. 'Multi-taskers' typically show variations in motivation and enthusiasm over the course of a long project and can require flexible supervision and sensitive encouragement.

'Set-aside' students have the advantage of single-minded devotion to task but may have less opportunity to think about the investigation before it gets underway. With devoted resources and lab time, the opportunity to develop practical skills is high but there may be little time for false starts or repeats. Overall, the limited period available means the project must be carefully tailored to allow for each element of the work and for a proper write-up to take place. The 'set-aside' experience may be more realistic as a representation of life as a career researcher, if that is the student's intention. On the other hand, the eventual sense of success or failure may be exaggerated, simply because the research experience has been compressed.

iii) Preparation for research

We have already acknowledged that students do not come to their projects as skilled or experienced researchers. The project is thus as much a chance to learn as a chance to research. However, to make progress students need some basic skills. So, how do they acquire these?

Williams (2004) identifies two approaches to the development of research skills and competence. In a "Nature" approach, students are immersed in a research culture and gain their research experience from frequent practicals and small projects embedded within their course. They have contact with research active staff but the rate and extent of skill acquisition depends to a great extent on self-motivation and the student's innate curiosity. In a "Nurture" approach, the student follows a series of structured sessions (lectures, tutorials, workshops) on aspects of research methodology including qualitative and quantitative methods, experimental design, ethics etc., explicitly designed to prepare them for project work.

There are advantages and disadvantages to each approach. Williams advocates a mixture, recognising that there are constraints on staff time and financial resources. The advantage of this is that students can be motivated to develop their own ideas and take responsibility for project design whilst also receiving adequate and comprehensive amounts of research training. Structuring the preparative activity also makes it open to both formative and summative assessment, if this is considered to be a necessary part of project preparation.

Davies and Cotter (2008) describe a Level II course, designed to develop research skills and encourage student-driven learning. Students work in teams of six and follow a structured framework to define project aims and investigative approach. Assessment emphasises groups' responsibility and is designed to ensure that all participants fully understand the project.

Huxham (case study 10) requires students to take a 3rd year preparatory "dissertation and statistics" module during which they also produce an assessed literature review. His students are also expected to have acquired key research skills from modules taken earlier in the course.

Reader (2008) introduces Level II students to project work in behavioural ecology through a two-week field course. Students plan experiments before they go and then work in teams to generate data based on the local resources. The emphasis during the field course is on the systematic collection and statistical analysis of data as well as on the development of work management and organisational skills. Many of the projects carried out generate publishable material. This high level of success is attributed partly to the focus achievable by relocating to a conducive location and having a large staff input for a short period of time, but also to a clear sense of student ownership and responsibility for the project work itself. Motivation is also provided by the good possibility of eventual publication. Work which does not reach this level is collected into an in-house volume which can be passed on to the next generation of students.

Lintern (2007) describes the use of lab workshops to train students in common laboratory techniques likely to be needed in their research projects. She reports good levels of satisfaction amongst students for this type of approach even though the skills being developed are fairly basic and despite not all students immediately appreciating their relevance. Jervis (Latham and Jervis, 2008) uses short, easily designed and inexpensive practical projects to introduce second year students to a particular area of bioscience they may not have encountered previously. They offer basic skill training and boost students' confidence in practical research. The project topics are linked to academic research going on in the department but are designed to be attractive and accessible. They are therefore realistic and purposeful tasters for what might be available in the final year project.

Yeoman (2008) leads an optional second year research skills module in which students undertake open-ended, heavily supported mini-research projects in small groups, which are designed to give them the basic technical, analytical and writing skills needed for final year laboratory projects. Students receive an introduction to the research environment and gain confidence from spending a sizeable amount of time in the laboratory (an average of 7 hours per week for eight weeks).

An alternative approach to supporting practical work is the provision of a bank of technical worksheets for commonly used techniques, such as that available at Bristol (Langton, 2007).

iv) Group projects

With pressure on staff time and ever-increasing class sizes it is tempting to allow students to do their research in groups. This can simplify departmental management of the research element of the degree programme and can bring about savings for the supervisor in instructional and support time. Generic research skills, in the lab or field but also for literature research and data analysis, can be taught to the group in a more structured or scheduled manner than may be possible when individual projects are being supervised. A team of students will be able to tackle a considerably larger project and if they work well together they can all benefit from the extended scope and depth of enquiry.

It may well be realistic to represent research as a collaborative activity in this manner: most professional researchers work as part of a team, or at least see their work as contributing to the effort of a larger group or lab-wide endeavour (Wright and Boggs, 2002). Students working as a group will start to sense how research teams operate and will be able to develop useful teamwork skills. They should also help each other to achieve greater breadth and depth of understanding.

However, some particular challenges need to be overcome if student research is to be approached in this way. These relate to the equality of experience, the assessment of individual performance and the absolute educational requirement that one student's performance should not be dependent on that of another. It becomes crucial to design the project in such a way that every student retains some autonomy and individual responsibility so whatever the final outcome of the research, their own abilities and skills are properly represented. Students may benefit by motivating each other and from sharing expertise and experiences, but it would be quite wrong for a student to feel that the final assessment of their performance depends on the efforts of their peers.

Saffell (2008) describes a research module in which students work in small teams (3 students/team) to propose, design and execute an investigation. Although the teams take responsibility for their research, they operate within a highly structured environment which ensures that the experimental work is properly executed and that the project develops through an appropriate sequence of phases. The students produce individual plans and reports for assessment. Hejmadi (case study 6) provides team projects (usually 2 students/team) with a less structured framework, although there is still emphasis on careful planning, a rigorous scientific approach and the development of skills. The achievement of some key skills (including problem solving, critical appraisal, team working, data analysis, experimental flair) forms an explicit part of the assessment process, alongside assessments of lab performance and a conventional research report.

Wakeford and Miller (case study 9) tackle the problem of large student numbers and limited resources by creating a framework of virtual laboratories in which groups of 7-10 students can carry out enquiry-led projects. Students design e-learning materials and contribute to the development or evaluation of educational resources. The projects are particularly attractive to students seeking to do non-laboratory research, but are designed to ensure that the investigatory experience is equivalent. The emphasis is on interaction between individuals rather than team working per se, and assessment is managed by locating each student's contribution to a number of organised tasks as well as through individual reviews and reports.

v) Single/joint supervision

In some circumstances, it can be useful for projects to have more than one supervisor. This may be for practical scientific reasons (for example, in the provision of resources or expertise) or to allow a junior colleague to obtain supervisory experience. Responsibility for guiding the work may change as the project proceeds, such as between a period of practical work and the write-up. This will not present difficulties provided one supervisor is recognised as being in over all charge of the project, and provided the student is clear about roles and responsibilities right from the outset.

Projects involving an external study placement will usually have a partner supervisor who guides the off-site work. These individuals will be working outside the academic environment and will need to be properly briefed about the home institution's requirements and conventions. The project needs to be designed so that the interests of the partner are compatible with those of the student in terms of the time available and the quantity of work to be performed. The home supervisor will retain academic responsibility and it is best if the roles of each individual in the partnership are explicitly agreed at the start of the project. The student needs to be absolutely clear about whom to refer to for guidance at each stage of the work. It would also be unfair to allow them to become embroiled in disputes over, say, resources or costs.

In the case of collaboration with commercial partners, the home supervisor should ensure that no conflicts of interest are likely to arise, that data ownership is clear and that any intellectual property rights are clearly established. It can be hard for a student to write up their dissertation or consider publication of exciting findings if they are hampered by what they are permitted to report.

It is often useful to assign a student to a non-academic colleague for guidance and day-to-day supervision. Post-docs and experienced technical staff, if carefully chosen and properly briefed, may relish the opportunity to take on a student. They may even be in a position to suggest research topics or propose particular approaches to an investigation. It is seldom appropriate to look upon the student as just an extra pair of hands. Nonetheless, a properly trained and reasonably competent student may prove to be a valuable addition to the research team, to the extent that this is compatible with the overall educational purpose. Academic responsibility in these circumstances must remain with the supervisor, and it is essential the student also appreciates this.

The use of postgraduate students to run or oversee undergraduate projects is more controversial and best avoided unless it is part of a carefully planned programme of postgraduate training. The main difficulty is that postgraduates, however willing, have their own study agendas and can find it difficult to share their time and intellectual energy with another student. They should also be protected from the risk of feeling responsible should the work go wrong or mis-understandings occur. Furthermore, if the undergraduate and postgraduate work closely together, a problem of ownership of results and data can easily arise. Postgraduate input can be extremely valuable but is probably best limited to demonstrating methods, providing occasional informal guidance and offering friendship.

vi) Location: research labs, teaching labs, working with others

In planning and designing practical projects, supervisors need to give some thought to the location of the research. Some departments allow their project students to use teaching labs as a base (e.g. Hejmadi, case study 6), particularly if non-specialist equipment is needed. Others will offer space in a specialist lab, possibly for a limited period of time or to accomplish a specific set of tasks.

Issues to consider in making these decisions include the need for specialist guidance, physical access to buildings and time taken to move between locations. Specialist labs typically have access restrictions for safety or security reasons, and the student may require some additional training before they can use them. They will need clear guidance on all aspects of lab policy, on responsibilities for resources and on access rights and booking of equipment. In a research lab where everyone else is fully trained and well established, it can be easy to forget that a project student is still a novice and a guest.

A further consideration is the extent to which a student may be socially isolated: this will be determined by the nature of the investigative work and the physical locality, but it can be advantageous for students to be in contact with their peers or to have a day-to-day support network in the shape of friendly postgraduates and full time researchers. It might be helpful to set up a VLE or social network site for the research project module, so lab-based students can emerge from a hard day at the bench to the more familiar environment inhabited by their peers.

vii) Funding

According to Cowie's survey (2005a), about two thirds of departments offered funding to support undergraduate research projects and the median amount available for practical projects was £145. It is clear from this information and from discussions with colleagues that, despite the recognised importance of research in the undergraduate curriculum, there is no consistency between departments or universities in the extent to which project work is seen as a funding priority. A great many colleagues receive no direct funding and are forced to support projects using marginal sums scraped from other budgets. Even where direct support is available, it is likely to be considerably less than the true costs of the research and may cover little more than photocopying, local travel or a couple of simple reagents.

Given this background, supervisors are constantly expected to come up with imaginative, efficient and cost-effective ways of allowing students to undertake real research. In highly research-active departments, with rolling programmes of grant support from public or commercial sources, it may be possible to incorporate student work within the margins of larger projects being carried out by full time researchers and postgraduates. However, even in these cases, resources need to be carefully accounted for and there will need to be a delicate assessment of the likely contribution which the student effort may make to the overall research programme.

Evidently most supervisors do not find themselves in this position, and furthermore, student projects should really fall under an educational budget heading rather than being subsumed within the supervisor's research budget. An absence or inadequacy of funding places a severe constraint on the type of research which can be undertaken and will also influence the extent to which students are offered non-practical rather than practical projects. 'Dry' projects, such as those based on literature or data analysis, or involving survey work or external collaboration, may be less expensive than laboratory or fieldwork projects but may still come at a price (information access costs, photocopying, computer hardware and software, travel and accommodation expenses, etc.). These costs also need to be realistically assessed at the start of the project. In general, it would be wrong to expect the student to contribute from his or her own resources.

There is every reason to make students aware of the costs of their project, to encourage them to be economical with resources and to bring realistic financial considerations into their planning. This, after all, is a key aspect of all research and should be part of the undergraduate research experience. As a supervisor, you need to assess whether the investment in time and precious resources is likely to be rewarded by robust results, or whether you risk spending lots of money finding out you have a weak student who cannot produce anything useful. If possible, it can be helpful to retain a level of generality in the project description to allow for flexibility until you have assessed the capabilities of the student you have been assigned.

Remember, however, that the student does not have any absolute responsibility for the cost of the project or for the provision of resources. It would be quite wrong to involve them in disputes over funding or to make them the scapegoat for problems. Most difficulties of this sort can be pre-empted with good planning. Unexpected problems, and strategies for dealing with them, can be shared as part of the research experience but only to the point where the supervisor assumes final responsibility. See also the suggestion of a mock grant application (page 25).

Structures and processes

i) Proposal and allocation of topics

Departments adopt two main approaches to the allocation of projects. They may ask staff to describe possible topics and ask students to select from a list, or they may ask students themselves to think of ideas for research (for example, see Gallagher *et al*., 2008). Given that students vary widely in their understanding, knowledge and enthusiasm, a combination of these approaches often emerges in which the majority respond to staff ideas whilst a few have particular interests or a desire to get involved in particular subject areas.

Most departments invite students to select from a list of projects by indicating their preferred titles in order (Cowie, 2005a; Huxham, case study 10). Some departments also ask students to identify projects they particularly do not want to do. About half of departments report that they take students' previous academic performance into account when resolving the allocation of popular projects. A very few departments make the allocation entirely randomly.

The decision on which approach to adopt has to be a departmental one but in essence it depends largely on the ratio of topics (and staff) to students, the diversity of subject areas covered by the department and how much flexibility is to be allowed.

The advantages of working from staff-suggested projects are that staff workloads can be evenly distributed, projects can be designed to be realistic and feasible, resource requirements can be predicted and projects can be integrated with the overall work of a research group. A disadvantage of this approach is that students have to take the value of the research on trust and do not immediately own, or perhaps even feel an affinity for, the topics they are given. This can be a genuine problem, especially in a class with a variety of ability levels: strong or enthusiastic students might miss an opportunity to demonstrate their skills or aptitude for a particular type of work and weaker students might quickly find themselves out of their depth. Students may also be forced into projects or topic areas for which they have no particular enthusiasm.

These difficulties can be avoided provided the allocation is skilfully managed and there is a flexible and sensitive approach to individual student needs. The reasons behind student choices are diverse (Harland *et al*., 2005): besides topic interest and the attractiveness of the title, they may include the challenge of the topic, personality issues to do with staff, practical considerations (timing, type of research), the potential for skill development and career aspirations. Students may express some very particular preferences when making their choices (for example: preferring lab-based or literature work; wishing to avoid particular animals, plants or tissues; possessing or lacking necessary mathematical skills; availability for seasonal work that clashes with vacations; the need to develop a particular job-related skill; having a preference for or antipathy towards individual members of staff, etc.).

Students should be given an opportunity to express these preferences and explain them to whoever is arranging the allocation. However, once these have been taken into account, there is value in not extending the flexibility too much and in not overdoing the negotiation. Students need to get on with their work and they need a final decision on what they are to work on. Exerting a little discipline at this stage helps to emphasise the rationality and objectivity of the allocation processes and can prevent excessive and irrational discussion.

In attracting students, it often helps to give a brief outline of the main question to be addressed, the type of work to be done, the principal techniques to be used, and some indication of the sort of outcome in terms of results, skills, or understanding. It can also be helpful to suggest one or two key papers to read for background information, but make sure these are easy to read, relevant and accessible: a research paper which is technically challenging or obscurely written, however important it may be to the topic, can have the reverse effect from the one intended and frighten students away. Table 3 suggest some key information that will help students decide if a project is right for them.

Table 3 Suggesting projects: Information needed by students

Students need at least the following information in order to make informed decisions about the projects they wish to do.

- A concise, accessible **title**
- The name of the **supervisor**
- Any particular **modules** the student should have taken or **skills** they will need to possess
- Short descriptions of
  - **Objectives**
  - **Background**
  - **Content**
  - **Expected outcomes**
- The types of **methods** to be used
- **Skills** which are likely to be acquired
- **Timing:** the likelihood of irregular hours, vacation work, periods of intense investigation; external constraints on when work must be done
- A brief summary of or link to **previous work**
- A small number of key **references**
- **Contact details** for further information or discussion

Keep the information short, concise and accessible to a non-specialist. A long-winded or over detailed project description will deter selection.

Inviting students to suggest their own project topics has the obvious advantage of immediate ownership and high levels of interest and enthusiasm. Equally obvious perhaps, is the risk that suggested topics will be unrealistic in scope, that resources will not be available or that there may be no one with sufficient knowledge to act as supervisor. Experience suggests however that students showing initiative of this kind respond well to sensitive and constructive guidance: their initial ideas may lack focus but with a little discussion it is usually possible to shape their ideas into workable and interesting project material.

Supervisors often report that when supervising projects at the edge of their own current experience, they expand their own understanding and may even develop new research interests themselves. As always, it is a matter of balancing the interests of the student and the supervisor against the educational value of the project and the risk of failure.

In any kind of allocation there will be students who do not get to work on their preferred subject and who feel hard done by. To wrap up the allocation process it is well worth explaining to all students firstly that all projects are of equal merit and secondly that, whatever the topic, if they put sufficient effort into their work they will become fascinated and absorbed by what they are doing. They might also be reminded of the obvious point that making a choice excludes comparison.

It is a common experience that students enjoy their project work. Even those who get their first choice frequently find that the topic turns out to be rather different from what they expected.

ii) The first meeting: Setting the question and managing expectations

After project titles have been allocated, it essential supervisors sit down with each of their students to work out in some detail what their projects are about. Some skill is needed in making this first, detailed conversation productive: the student needs to be inspired by the overall concept, but also leave with enough detail to know what their immediate practical goals are. They need to get their reading of the literature off to a good start, but not feel so swamped that they suffocate under a blanket of unfamiliar terminology or complex methods. They need to see their contribution will be valuable and also to feel what you are asking them to do is within their grasp and has a good chance of success.

An essential outcome of this first meeting must be a clear formulation of the research question. Encourage the student to use active and scientifically meaningful verbs (‘to measure’, ‘to test’, ‘to compare’, 'to evaluate' …) and to avoid a retreat into targetless generalisations ('to consider', 'to look at', 'to wonder', 'to describe'). Table 2 suggests some ways of turning different types of enquiry into focussed research questions. The acid tests of whether this has been successful are:

- The ease with which the question can be reformulated into a testable working hypothesis, and
- Whether the nature of the outcome can be successfully predicted (see iv).

The other central purpose of this meeting must be to establish a good working relationship. The student needs to feel they have your support, that they can ask ignorant questions and that you will able to guide them safely as their knowledge and understanding increase and as they get deeper into the study. They need to know how and when to contact you and what your offer of 'an open door' really means in practice. You can find out what the rest of their study timetable looks like and find out how they plan to distribute their project work over the working week (and beyond).

Now is also a good time to introduce them to other members of your research group, including the technicians, post grads and post docs they will see around. They may also find themselves working alongside other students with whom they have not previously had contact.

iii) Setting feasible targets

Having agreed the project topic, discussed its context and decided on its aims, it is time to plan a detailed way forward for the research. The student is suddenly faced with a lot to do: as well as needing to read some literature and understand the topic, they have to plan investigations and learn the methods they will need. At the same time, they need to get to grips with their new working environment and get to know key people.

This phase of the project needs careful and sensitive handling. The student will feel enthusiastic and keen to get going but probably won't know where to begin and might easily feel overwhelmed and confused. Rather than presenting them with an extensive and daunting list of references, it is better to give them a single research paper or review to read: offer something which will hold their interest and which they will feel able to discuss next time you meet.

On the practical side, it can help to set them going with a single, relatively straightforward investigation or an experiment which has a high chance of generating results. If it is necessary to train them straightaway in a particular technique, this is best done using real biological material or live data if at all possible. This approach will make them feel empowered and capable of making progress; it will help to raise and maintain their confidence.

An intellectual challenge faced by bioscience students as they move through their degree course is in coming to realise that experiments are for real, that the observations they make are intrinsically correct and valuable. Their experiments at school, and possibly also at first year university level, were seen as a way of demonstrating known facts rather than of generating new knowledge. Thus a 'successful' experiment was one which achieved an intended outcome (or had an unintended outcome which could be explained away). Now, as they take on their own research and do experiments for themselves, they are exposed to real investigative science for the first time. Suddenly, success is to be measured not by reassurance and fulfilment of expectation but by having sound processes and confidence in the outcome, whether the result is expected or unexpected. Interviews with students (Ryder, 1999 and 2004; Collis *et al*., 2007) show that they are aware of these changes in the purpose, context and scope of their work; their perceptions of science as a whole evolve significantly.

Experience suggests students emerge from this crucial early phase of the work at different rates and with different levels of confidence in their own abilities. It may well come as a surprise to a new project student to discover that not even their clever supervisor knows what the result of an investigation is going to be! For the first time, they are working at the edges of confident knowledge. There is a new insecurity to be faced, but the potential for great excitement as well.

iv) Setting a scientific context

Students carrying out research in biosciences, like those in other scientific disciplines, are heirs to a long and extraordinarily successful human endeavour. In guiding their research projects, we expose them to the disciplines and rigors of the scientific process in the hope and expectation that they will achieve scientific literacy and philosophical awareness. Some will go on to become professional bioscientists and academics, eventually making a direct contribution to the corpus of human understanding about the biosphere. Those who disperse to other professions will retain an informed view of bioscience and of science in general, and will bring this to bear in other areas of life and culture.

Underlying everything we do and teach is the philosophy of our subject and the set of procedures, conventions and assumptions called the scientific method. Applying the scientific method makes for sound research; being able to do so amounts to a professional skill. In giving students the experience of research, how far should we go in educating them formally about the scientific method?

It seems unreasonable to expect bioscience students to become fully-fledged philosophers of science, much as we might wish them to have some grasp of the history of bioscientific ideas and a passing acquaintance with key figures in its development. Much of the literature on the history and philosophy of science is hardly bedtime reading and we might prefer our students to be concentrating on more immediate matters. On the other hand, we want them to be properly aware of what they are doing and to understand why science works in the way it does.

Experiential learning will be the key to this awareness and understanding (Shearer, 2007). In designing their investigations they will be forced to confront some deeply fundamental concepts such as the testing of a hypothesis, the distinctions between independent, dependent and explanatory variables, the use of controls, the meanings of accuracy and precision, the importance of variability and the use of discriminant statistics. They will also come to understand why progress in science can be slow, why results and analyses need to be exposed to public scrutiny and why interpretations are subjective and culturally contextual.

Some undergraduate courses explicitly teach the scientific method and expose students to these ideas in a philosophical or historical context. Most bioscience courses will also include some study of statistical methods in which the theoretical basis of experimental design is likely to feature prominently. Other departments set up support resources designed specifically for project students (for example, the University of Reading's, CETL-AURS website *ENGAGE in research*). Whilst these are valuable learning opportunities, it is probable that students achieve a deep understanding only when they set out on their own research and start to generate and analyse their own data.

Because of this, there is a responsibility on supervisors to engage students properly with the scientific method and to expect them to acknowledge it in their dissertation or final report. Here are some ways of achieving this:

- Establish an appropriate discourse during the design stage of the project. Force the student to set testable hypotheses, state them explicitly and express them precisely.
- Get the student to anticipate all possible outcomes to an experiment and think them through in relation to analyses and interpretations.
- Make the student aware that they are working within an established paradigm. Get them to read the literature with critical eyes, a sense of history and a sharpened awareness of assumptions.
- Encourage the student to think laterally about the observations they make and their possible causes, then to make a balanced and informed appraisal of the most likely explanations.
- At the end of the project, get them to reflect on
  a) the extent to which their hypotheses and assumptions were adequately tested,
  b) the effect of their work on the subject paradigm,
  c) any new and testable hypotheses their research has exposed.

Many of these thought processes will arise naturally during the development of the research and some elements will be discussed when the project is being written up. The essential point is that they are expressed in such a way that the philosophical basis and scientific context of the study is brought into focus (Cotton and Scalise, date unknown).

The following discuss the scientific method, at practical and philosophical levels, and are valuable as guides for both staff and students: Gauch (2003); Ladyman (2002); Luck and Wagstaff (2003).

The following are practical research guides for students which apply the principles of the scientific method in a manner appropriate to projects in biosciences: Barnard *et al*., (2007); Jones *et al*., (2007); Luck (1999); McMillan and Wyers (2007); Reed *et al*., (2007).

v) Setting ethical guidelines and frameworks

Much bioscientific research involves human and animal experimentation of one kind or another. Whilst undergraduate project students will not be directly responsible for such work[1], they may find themselves associated with it or being expected to use material or data derived from it. They may also have to build delays for approval procedures into their project planning. It would be sensible to encourage them to think about the ethical implications of their work at an early stage. This is partly because it is an aspect of their training and education (Downie and Clarkeburn, 2005; QAA, 2007b), but also because it will give them a realistic view of what is scientifically permissible and give them the confidence to defend their work in the face of criticism.

Ethical questions can be usefully incorporated into a wider realm of thought which includes the legal, social and environmental implications of the research. This may be a good way of raising the matter with students because it can be turned into a routine part of the planning framework for all projects. Table 4 offers a checklist of questions which all students can be asked to consider. The questions fall under the natural headings of Informed Consent, Confidentiality, Anonymity and Legality, plus a further set related to the scientific professionalism and personal integrity of the researcher.

Table 4 Ask ELSI: Ethical, Legal and Social issues

Informed consent

- How can I be sure that my subjects are willing to be involved?
- Am I exerting any pressure on my subjects to take part (e.g., use of family members, colleagues; reciprocal agreements)?
- Do they know what to expect by taking part in the study?
- Do they have a clear statement of their rights and obligations?
- How much background information should I give them; will this affect the quality of the data?
- Are there any personal risks that they need to be made aware of?
- Do they have the opportunity to withdraw from the study at any time without giving a reason?

Confidentiality

- Are my subjects happy for information about them to be made public? In what form?
- Will they be telling me things which would normally be kept private?
- Can subjects ask me not to use, and to destroy, particular information if they so wish?
- Will my subjects be able to confirm that the information I have recorded is factually correct?

Anonymity

- Have I ensured that my subjects are not individually identifiable to anyone outside the study team?
- Could any circumstantial information uniquely identify one individual?
- Will the recruitment of subjects to the study serve to identify them as belonging to a particular (social, medical, ethnic) group?

Legality

- Does the study raise any legal questions?
- What will my attitude be to information which appears to result from or reflect criminal activity?
- Could the data I obtain expose any of the subjects to legal risk?
- Have I obtained approval for my study from my local Ethical Committee?
- Is my supervisor fully aware of everything I intend to do and prepared to take responsibility?
- Who will own the information or final report which is produced?

Professionalism

- Does the study need to be done: am I sure that the data I want does not exist already?
- Is the study properly designed and have I got the analytical techniques I need?
- Have I got the right number of subjects: will I have sufficient data to justify my conclusions, or alternatively, will I be involving more subjects than I require? (Have I obtained adequate statistical advice?)
- Am I prepared to treat my subjects with courtesy and respect, even if I find their views or habits personally objectionable?
- Have I arranged appropriate emergency support if things go wrong?

(Adapted from Luck, 1999)

[1] Some student research using human volunteers, for example in non-invasive physiological studies or psychological surveys, may require specific approval from an ethical committee. The supervisor will have formal responsibility for the work but the student may well be able to take the lead in formulating the application.

Table 5 The ethical matrix

Interest groups	Beneficence	Non-maleficence	Autonomy	Justice
Who is affected by this project? Who does it depend on? Are animals involved?	(What benefits will come from the project?)	(How will harm be avoided?)	(What rights are available and how will individual integrity be maintained?)	(How will benefits, risks and costs be fairly distributed?)

These lists of questions (Table 4) can be used to help your student identify issues associated with their project. The list is designed for projects involving human interaction (as experimental subjects, as providers of data, in surveys, or in product testing etc.) but could be easily adapted for work with animals. Use it as part of the dialogue with your student during project design, either by itself or as a way of completing an ethical matrix (Table 5).

Although not all questions will be relevant, the experience of considering and openly discussing them will prove valuable in getting students to place their research in context. Even projects which are remote from biological material or human involvement can benefit from this type of scrutiny, for example regarding rights of access to information sources and the uses to which new information may be put. In the case of environmental biology, guidance on responsible fieldwork is provided by the British Ecological Society (Smith, 2002).

A complementary, slightly more philosophical approach is to apply an Ethical Matrix (Table 5) to the study. This was originally developed within a bioscience context (Mepham, 1996 and 2005) and has proved to be instructive in teasing out the essential costs and benefits of ethically-sensitive research work of all kinds (Forsberg, 2005 and 2007). A wider view of the incorporation of ethics education in science courses is also being considered by the Inter-disciplinary Ethics Applied (IDEA) Centre for Excellence in Teaching and Learning (www.idea.leeds.ac.uk/).

The Ethical Matrix provides a framework for evaluating the ethical questions associated with a research project. It does not provide answers but it helps in formulating the right questions to ask. Its purpose is to raise awareness and identify issues.

The columns in the matrix need to be completed according to the nature and context of the project. The student can do this but will need guidance. Completing the matrix can be part of the dialogue of project design.

The Interest Groups column should be completed first, using as much imagination as possible. Each interest group should then be assessed under the other four columns.

vi) Mock grant applications

An interesting approach to getting students to prepare properly for their research work is to ask them to write a mock grant application. This can form the basis for the research work itself and can also be used for summative assessment.

The main purposes of this exercise are:

- To identify the main question(s) to be addressed in the project;
- To formulate testable hypotheses and present them in a formal manner;
- To begin the process of experimental design;
- To predict the nature of the data to be obtained and the need for statistical analysis;
- To identify the key methods to be used;
- To identify the resources that will be needed;
- To give the student a realistic appreciation of the costs of the project;
- To consider any ethical implications and seek approvals;
- To anticipate the kinds of outcome which might be achieved;
- To start the process of literature review, and above all;
- To justify in the student's mind what the research is really about and why it is worth doing.

In addition, the student will develop valuable skills such as writing to a word limit, reading and summarising literature, designing and formulating experiments and identifying outcomes. The relative emphasis to be placed on these skills and the scientific content of the project can be decided according to local circumstances, and the grant application can even be used as the project itself (Henderson, 2003).

Students will require some guidelines for this activity – perhaps a proforma with specified sections resembling those of one of the major grant awarding bodies (Wellcome, BBSRC, MRC etc.), together with clear guidance on length, content and focus. It may be possible for them to cost the research as well, although this can be rather difficult unless some specifically identifiable kit or materials are to be purchased. They can certainly anticipate costs by thinking about replication and identifying the quantities of materials they are to need. (E.g. Davies, 2002.)

For those students who eventually seek careers in academia or research, the experience of having developed a grant application will prove invaluable. For all students there is significant value in getting them to justify, to themselves and others, what it is they are about to do. This will also pay dividends in terms of focus and organisation of material when the research is written up. Eventually, when the project is finished, there will be chance to reflect constructively on how the reality compared with the intention.

The art of supervision

Being a project supervisor is a singular privilege. You have the chance to guide a student as they take their first steps in real science. Suddenly, your teaching becomes personal. The experience will probably be unforgettable for you and your student; this section looks at ways of making it a positive one.

i) Student-supervisor contract and mutual obligations

The relationship between student and supervisor may often become a close one, academically-speaking. This is to be expected and may even be desirable. The closeness stems largely from the fact the student, probably for the first time in their formal education, has an opportunity to bring their own thoughts and ideas to bear on a detailed and undecided issue. This can be an unfamiliar, perhaps unnerving experience. The supervisor's role is to encourage the student and to provide a supportive, secure and risk-free environment in which ideas and thoughts can develop. If this works effectively, the student will mature intellectually. One of the great privileges of being a supervisor is to be present as this happens. In ideal circumstances, it would be surprising if closeness and a certain degree of friendship did not result.

Despite this, the student and supervisor need to retain their respective positions within the educational context. At the very least, the supervisor will be required eventually to assess the dissertation and the student's overall performance. Objectivity will be called for, and this will depend on, and may even challenge, the supervisor's academic professionalism and personal integrity. During the conduct of the project itself, the relationship has also to facilitate guidance, support and a mutual respect for the work in hand. Emotions and extraneous influences can challenge this, possibly very seriously. Problems and difficulties need to be pre-empted if possible, or dealt with as they arise.

There is also an important sense in which the supervisor acts as role model for the student. The supervisor represents academia: they are the voice of wisdom and knowledge, and the student expects them to be a source of experience on how research is carried out. The student will watch and be influenced by the supervisor's behaviour, their personal values, their attitude to students, and their approach to facts, knowledge and ideas. Prior to the start of the project, the student's only interaction with the supervisor may have been across the impersonal spaces of a lecture theatre or teaching lab, or through the highly contextualised medium of comments on an essay. This relationship changes rather suddenly when the project begins.

With these complexities in mind, it is plain to see that the student and supervisor need to work at their relationship to make it productive and harmonious. Some mutual obligations, rights and responsibilities naturally emerge (and anecdotal evidence from a handful of bioscience departments indicates they may be communicated explicitly in module handbooks and associated codes of conduct). There are also some implied obligations, such as offering career advice or writing references, which extend beyond the project itself and may continue some time after graduation.

Table 6 summarises aspects of the student-supervisor relationship which should be considered. Some are also discussed in more detail below.

To be a project supervisor is a singular privilege. It carries obligations and responsibilities, but the rewards can be many. The relationship works best on a friendly but professional footing. (Table adapted from Luck, 1999.)

Table 6 The student-supervisor relationship: amicable professionalism

Student's attitude to supervisor	Supervisor's attitude to student
Acknowledge greater knowledge and experience	Acknowledge patiently the need to learn
Accept advice and guidance	Offer constructive advice and guidance
Show increasing independence as the work proceeds	Give support and encouragement, and recognise progress and development
Avoid being defensive in the face of criticism	Give objective criticism in a constructive but sensitive manner
Respect existing work practices and conventions	Provide a safe and secure working environment
Don't waste resources	Anticipate requirements and provide appropriate resources
Respond to communication and keep appointments	Respond quickly and fully to requests for help
Keep appointments	Be available, within reason
Don't hide unresolved problems	Anticipate problems as far as possible
Recognise when help is provided	Deal with problems rapidly
Complete agreed work on time	Moderate and return work swiftly
Use research time as effectively as possible	Acknowledge time limitations
Take responsibility for the work schedule	Give space for reflection as well as learning
Use imagination but recognise limits	Encourage inquisitiveness but set boundaries
Be frank and honest about progress	Encourage and recognise success; point out deficiencies
Don't be afraid to ask stupid questions	Answer all questions fairly and fully
Invite friendship but respect its limits	Encourage friendship but respect its limits
Seek support when considering jobs and careers	Freely offer career advice and act as referee

ii) The research environment

As a supervisor, it is wise to remember that students do not arrive with a ready-made toolbox of personal or research skills. Practical classes are being reduced in many undergraduate courses (ABPI/Biosciences Federation, 2007; Biosciences Federation, 2005; Collis *et al*., 2007) and even fundamental techniques such as making solutions or organising data may be unfamiliar (Lintern, 2007). You might reasonably expect to have to teach a student how to run a gel or how to apply a statistical test, but you might be surprised to have to show them how to use a pipette, write up experiments in their lab notebook, or book their use of the ultracentrifuge. Similarly, with a project based mainly on literature assessment, the student may initially have little idea about how research libraries work, how journals are organised and published, about the importance of peer review or about the relative values of and reliabilities of different types of information source.

The only response as a supervisor in these situations is to shoulder the responsibility and teach the student what they need to know. This is now your role, irrespective of whether anyone else should have guided or trained the student previously. Giving any sign of irritation or frustration at a student's lack of ability must be avoided at all costs: it creates a despondent atmosphere and helps no one.

At the lab or group level, students will need to be inducted into safe ways of working and the conventions of the local research environment. They need to be introduced to the senior technician or lab supervisor and to understand that they fall under that person's jurisdiction as far as use of facilities and resources is concerned. They should be expected to take on responsibility for the tidiness of their own work area and to dispose properly of any biological, chemical or hazardous waste they may generate. They should be encouraged to attend lab/research group meetings and be given guidance about contributing to preparing stock reagents and buffers, if that is the way the lab operates. If their work involves lengthy or time-consuming procedures, they need to know if they can be alone in the lab or field and whether they are permitted to work beyond normal hours or at weekends. It helps if they know who the other users of the lab are whom they can call on for advice or in emergencies.

As a supervisor, you cannot anticipate every eventuality but it is best to be proactive rather than reactive as far as possible. It helps to treat the student like any other member of the lab and involve them in responsibilities like ordering stock, cleaning benches and washing up glassware. The goal to aim for is independence and it makes sense to treat lab awareness as a key transferable skill.

In one sense, students on practical projects need to make the transition from junior technician to independent scientist. In other words, they need to progress from being told what to do to using their initiative and taking responsibility. Some will do this rapidly, others may never achieve it, and their position on the ability scale will eventually be reflected in a summative assessment. Clear indications of aptitude will emerge: whether they need to be shown how to do things more than once, whether they can anticipate the next step in a complex procedure or whether they can think on their feet when unexpected difficulties arise.

As in any one-to-one teaching situation, you need to be responsive, patient and adaptable to individual need. In deciding when to watch over and when to disappear, when to manage and when to allow freedom, one feels a bit like a parent. There is no correct way to do it, but with sensitivity, patience and humour it is usually possible to allow both the student and the work to flourish.

iii) Regular meetings and project management

Regular meetings are an indispensable way of maximising the success of a project. They can be used to set short-term targets for work, to encourage the development of ideas, to maintain a good working relationship and to monitor progress. In the case of practical projects they are an opportunity to check and sign the lab book and make sure that proper records are being kept. For non-practical projects they are a chance to make sure that the student is getting the data they need, that references are available and that they are making appropriate judgments and evaluations of information. More importantly, regular meetings ensure that the student feels valued in their work, that what they have to say is being listened to and that there is some formal and professional respect for what they are doing.

A good way to operate is to hold weekly meetings but with explicit flexibility in duration and content. Start by negotiating a mutually suitable time in the week, say Tuesdays at 2.00. However, put only the next meeting in the diary and agree you will work from week to week in finding the best time. Explain to the student that they must come to every agreed meeting, but that sometimes they will have much to report and sometimes very little, that in some weeks you may meet for half an hour and discuss detailed matters whereas in others the meeting may last a minute or so and contain little more than pleasantries.

Explain to them that you recognise the complexity of their life but you expect the project to be given the attention and time it deserves. Explain also that you expect the progress of work to be uneven. There will be periods of intense activity, when the project takes over their life and others when it recedes to the background. Sometimes, other coursework will need to take priority. At other times, a lot of background reading will be needed and practical work or data analysis may have to be postponed. Writing will need a special effort and may need to be done in short bursts or in longer stretches involving midnight oil.

All of this is quite normal and needs to be built in to the way meetings are managed. The student's side of this flexible bargain is that they keep you fully informed about how they are doing, they act on the agreed outcomes of meetings and they bring any problems or issues to you as soon as they arise.

Time management is a particularly difficult and occult skill to learn. A few students seem to be naturally well organised and can envision the timescale of the project from the outset. More often, they seem to view the coming weeks and months in a kind of distant haze: they may never have set out to work on a large, time-consuming project before and may have no sense of scale. They may not know how to pace themselves or to make long term plans, and they may not see the urgency of getting on with tasks or using windows of opportunity.

It may be frustrating to have to deal with these issues as a supervisor but it is part of the job. It is easy to let your mind slip into critical mode and to subjectively devalue the student or their efforts, simply because of mistaken expectations. As a student, they are learning not just the material of the project but how to research, how to learn, how to study and how to manage themselves and their time.

iv) Recording meetings and keeping portfolios

A brief, written record of each supervisory meeting should be considered essential and obligatory. The student should come to view it as an automatic part of the supervision process and therefore of meetings in general. The record should summarise the outcomes of the meeting but also set targets for the next one and identify actions, in much the same way as committee minutes usually do. Encouraging the student to be the record maker and keeper, right from the start, is a particularly effective way of giving them ownership of the project. As you get to know your student better and to understand their work patterns and abilities, you can gauge how far record keeping needs to go and what works best. However, both student and supervisor need free and open access to the record at all times. If a particular student repeatedly fails to attend or needs excessive chasing, it can be reassuring to have a list of missed meetings as evidence. Problems and complaints are rare but there are times when records of activity can be crucial.

Meeting records can also form part of a more comprehensive project portfolio involving lab records, summaries of literature sources, visits to libraries or research centres, copies of key documents, ideas and data evaluations, interim reports and presentations. Some students are required to maintain portfolios as part of their project activity, to facilitate effective and objective assessment and to provide evidence for external examiner moderation (Wright, 2005). They can therefore be both a valuable heuristic aid for the student and a functional pedagogic tool for the supervisor and his/her department (Calvert *et al*., 2007).

v) Finding time and being around

As a supervisor, you have an obligation to be available to your student(s) and to set time aside to help them. It really is not acceptable to take on students in an atmosphere of resentment or irritation. Nor should it be viewed as a peripheral or trivial part of your work. Whatever your view of the burden of supervision, and even if there are unresolved issues of workload lurking in the departmental background, the only professional approach is to treat each student as a valuable individual and to give them the best support you can. From their perspective, the project belongs to them, you are their supervisor and they have a right to your time and wholehearted support.

Despite this, issues of time can be difficult to resolve. You need to manage your supervisory effort efficiently and there will be times when this is problematic. You are entitled to switch off at weekends, to use your discretion about, say, answering emails during the evening, to disappear for conferences and holidays at appropriate moments and to do all those other things that add to the joyful complexity of academic life. It is entirely reasonable to expect your project students to recognise this and to acknowledge it as part of the supervisory bargain. Indeed, it will aid the development of their own time management skills to realise that their interactions with you need to be respectful and reasonable.

vi) The framework for writing

The main outcome of the project will usually be some kind of written document: a dissertation or a report in the style of a research paper or review. It will probably be the longest and most complex document the student has ever produced and they will need a good deal of guidance, encouragement and support.

The starting point must be the departmental guidelines. (See for example: University of Nottingham, School of Biosciences.) These should be explicit and unambiguous regarding length, format, style and expected content (if they are not, campaign for them to be rewritten). They should also explain the assessment system. It is essential that the student has a copy of these at the start of the project and knows that they will be expected to conform. All subsequent supervisory discussions can then use them as a reference point. It will also be helpful for the student to look at some examples of dissertations and reports, so they can get a feel for what will be expected.

As a supervisor, there is advantage in being a disciplinarian over presentation. Because the writing process itself – putting thoughts into words, constructing sentences, achieving clarity and brevity, finding a suitable style and producing a coherent document – is inherently difficult, it helps if the presentational framework is solid and secure.

Table 7 lists ten elements of a framework which can be easily imposed on the student from the start. Everything in the list will be useful in the final write-up; none of it is a waste of time and much of it is obvious. It will help the student work efficiently and allow them to concentrate on the much tougher business of putting words together. When you meet the student to review progress, or if they send you draft material to comment on, you can easily refuse to look at their work if it is not in the correct format. This may irritate the student to start with but they will quickly conform (especially if they know that marks will eventually be lost for incorrect presentation). They will then be able to focus on what really matters. Good habits will be in place and you will both be spared much wasted time and effort.

Writing is hard. To make it easier, set your student a framework to follow right from the start. This small discipline will make life easier for both of you, save time and encourage good writing habits.

Table 7 A framework for writing: Ten instructions for students

- 1) Set up several word processor files with the correct default format (font, line spacing, margins, paragraph levels, page numbering, anything else required by the departmental guidelines) and use ONLY these for project work.
- 2) Keep a single electronic file of bibliographic details of all literature sources, properly ordered and in the correct format. Only record bibliographic details once. Throw away bibliographic notes written on scraps of paper.
- 3) Maintain a list of abbreviations and their meanings.
- 4) Write up methods and procedures as they are performed.
- 5) Keep a list of chemicals, equipment and other resources used, or be able to go straight to this information in your lab record book.
- 6) Analyse data and interpret results as they are obtained. Do this for every experiment or investigation whether preliminary, final, inconclusive or conclusive.
- 7) Use correct spellings and have an awareness of grammar.
- 8) Give every diagram, figure, table or other illustration a proper legend.
- 9) Keep a dated backup copy of everything.
- 10) Keep another dated backup copy of everything.

As well as providing a framework for writing, Table 7 includes instructions for ensuring that information will always be to hand. In addition, you might want to ask the student to send you electronic copies of their data (spreadsheets, gel scans, micrographs, survey results etc.) as they obtain it. This will give you direct access to their work, for checking and evaluation, but it will also mean that you have it stored for later access, after the project is finished.

vii) Reviewing the thesis: how much to correct? How to be fair to all.

Writing is difficult. Few of us find it straightforward and it takes a good deal of time, effort and practice to get it right. The biosciences have their own set of linguistic styles and the student will need to learn and develop an appropriate one in the course of writing up their project. It is also obvious to anyone who has written anything complex or technical, that expressing oneself clearly goes hand-in-hand with understanding what one is trying to say.

The supervisor has a crucial educational role in guiding and moderating the student's written work. What is unclear is the amount of supervision to be given: how much can the final dissertation depend on supervisory advice or editing? At one extreme, the student might be expected to work virtually alone and produce a write-up which perfectly reflects their independence, warts and all. At the other extreme, the supervisor could edit and correct every element of the work as it is produced, so that the write-up approaches some kind of academic perfection but only distantly reflects the student's ability.

The question of where to operate between these extremes is faced by all teachers. The answer, if there is one, is usually heuristic: allow for trial and error and give as much advice as required. The problem is different students need different amounts of support. This makes it difficult to be equitable to all. It is also particularly hard to ensure the final assessment remains fair and objective, even where mark moderation procedures are in place (Chapter 3).

Some departments try to get around this by specifying allowable levels of correction. For example, the supervisor may be permitted only one look at a draft text, or there may be certain parts of the dissertation (the Abstract, say, or the Discussion) which must be the work of the student alone. Such rules superficially suggest fairness but may be harsh on students whose first language is other than English or who require additional learning support. Nor do they allow for differences in life experience or educational or social background. They may also limit the chance that the student will learn and improve through experience.

It would be fair to say that most students develop and refine their writing skills considerably over the course of their project. This is encouraging because it suggests that supervisors can operate in response mode, gently guiding rather than slavishly correcting. Occasionally students have major difficulties with language and might need to be given extra attention or referred for professional support. In this situation, it becomes important to see beyond the language issue and ensure that the research work itself can proceed unhindered.

viii) Dealing with problems: personal issues

It is unlikely that any student project will run without a hitch; experience suggests they seldom, if ever, do. However, provided the project is well planned and conscientiously supervised, most issues can be dealt with as they arise and disasters will be rare. Most of the problems that a supervisor will face result from the unexpected, unpredictable variables in the scenario. These include the skill and enthusiasm of the student, the reliability of methods and the availability of materials. Difficulties arising for these reasons can be compounded by the limited time the student has available and the need to produce an assessed piece of work. And of course a backdrop to everything is the inherent uncertainty of the project itself: this is both a potential problem and an opportunity, for predictable research is scarcely worth doing.

There are undoubtedly difficulties which result from the action, inaction or competence level of the student. These must be faced but they can be the hardest to deal with because they require patience, sensitivity and the avoidance of personal accusations or blame. Some students will learn how to carry out a new technique the first time they are shown, whereas others may be shown it five times and still not be able to get it right. A keen but modestly skilful student may work diligently yet have little to show for their enthusiasm, whilst another may put in minimal effort but hit a rich seam of productivity which scarcely reflects their input.

It is impossible to predict the characteristics and qualities of the student before the project begins. Nor is it possible to predict the student's reaction to the work once it gets underway. A student's skill as a researcher may be at complete variance with their previous performance in the exam room or in coursework assignments.

The only wise strategy for a supervisor is to assume the following, until evidence indicates otherwise:

- The student is motivated and enthusiastic;
- The student is capable of learning tasks and of carrying them out effectively;
- The student will show reasonable levels of care and responsibility in what they do;
- The student has the literary, organisational and numerical skills to complete the project and write it up;
- The student is capable of balancing the requirements of the project against the other demands of their academic and private life; and
- The student is capable of bringing the project to a satisfactory conclusion.

Adopting this approach should also help to ensure that all students are treated fairly.

If a student is struggling or things are going badly, the supervisor has to take the lead in trying to improve matters. Students can become quite upset and defensive about what they perceive to be their own failure or incompetence, even when this is not the case. Similarly, a student who loses motivation or slips behind in their work may withdraw from contact or avoid meetings. Both these types of behaviour can compound the underlying problem and require sensitive handling. It is quite unacceptable to leave the student to flounder without showing interest or offering support. Similarly, resorting to blanket assumptions of 'laziness' or 'complete incompetence', whether thought or expressed, must be avoided at all costs.

Most academics will have a pastoral care element to their job and it is sometimes helpful to adopt this type of approach to a project student with obvious difficulties. Giving the student time and space to talk in a secure and non-judgemental atmosphere can help considerably. It may not of itself move the project forward but it will enable the student to take stock and face the reality of their situation. The supervisor's role then is to help them find an effective way forward. This may involve an adjustment of targets, a change of pace in the work or even, in very difficult circumstances, rethinking the nature and scope of the project entirely. In these situations, your obligations must be principally to the student rather than to the project.

If the student's difficulties arise from outside the project, the normal support mechanisms of the department and university should be engaged at the earliest appropriate opportunity. A confidential chat between the supervisor and the student's personal tutor or other staff might provide enlightenment. There will also be professional support services in the institution to call on, just as in any other circumstance where difficult issues of pastoral care emerge. Your duty of care to the student in making sure they seek the support they require is just the same as that of any other member of staff.

In the end, it is up to the supervisor to make a judgement about the best way to work with each individual student. A sensitive approach and optimistic atmosphere will allow them to reveal their strengths and indicate the most appropriate rate of progress. Expectations can be stated and targets must be set, but they should be flexible enough not to become overwhelming. Students should find their project work challenging and demanding, but only to the point where they prove to themselves what they are capable of.

ix) Dealing with problems: project issues

Student projects sometimes go wrong. Methods fail, resources run out, accidents happen, field sites are flooded, labs get contaminated and machines break down. Key literature may be hard to locate, data may be unavailable or incomplete, starting assumptions may prove erroneous or other groups may publish first. These types of unavoidable disaster befall all research from time to time and student research is no different. Even the best-planned and thought-out projects occasionally fall foul of inanimate mendacity.

Where a student project may differ is in the effect that a particular problem may have. As indicated earlier, there is always likely to be a certain amount of tension between the objectives of the research and the educational imperatives of the project, and this means that a single problem may have multiple consequences. On top of this, there is a limited amount of time available: it may just not be possible to repeat complex techniques, to wait for suppliers or to generate new archives of data.

Circumstances like these are frustrating and annoying for both student and supervisor, even though neither may be at fault. The student may feel obliged to take some blame for what has happened, even when this is completely unjustified, and it can take considerable supervisory skill to deal with the resulting combination of disappointment and feelings of responsibility. Even if they don't feel responsible, the student may lose motivation or become disaffected if the supervisor fails to intervene at the right moment or offer the right amount of support.

The supervisor also needs to devise a rescue plan, both for the project itself and for the educational predicament. There are no easy answers here and a certain amount of imagination and inspiration will be called for. It may be possible to alter the direction of the project, either by refocusing the objectives, changing the depth of analysis or modifying the scale of the investigation. If a practical project becomes completely unworkable it may be possible to recast it as a literature review or theoretical study, capitalising on and extending the background work the student has already done. If the problem lies with experimental material rather than methods, it can be educationally valuable to run the procedures and analyse controls, and then to make predictions about the possible outcomes that might have emerged. The student will then at least see the value and integrity of the experimental design and still have some contact with the investigatory process.

It would be trite to suggest that working through major problems gives the student a valuable lesson in life as a researcher, true though that may be. They are unlikely to see it that way, if only because the quality of their degree probably hangs on how well they perform in the project. They need to be completely reassured that their grade will not be affected by circumstances beyond their control. They need to know that they will still be assessed fairly and objectively and with just as much chance of a high mark as any other student. As a supervisor, and eventually as an assessor, you will need to distinguish clearly between failure and lack of success, and to make a fine comparison between what was achieved and what was possible.

Chapter 3

Project outcomes and assessment

The project report

i) Dissertation or research paper?

As discussed in Chapter 2, the product of final year research has traditionally been a dissertation or thesis. This is an extensive document, comprising a standard set of chapters and often resembling a mini-PhD thesis. Traditionally, copies may be expensively bound in hard covers and tooled in gold lettering, often finding positions of solid permanence on the shelves of both the student and the host department. More recently, ring-, spiral- or perfect-bound versions have been the norm. Cowie (2005) found that about 70% of departments set a word limit on the report, commonly around 8000-9000 words. At this length, the equivalent of a substantial monograph, the thesis is by far the longest document most students will ever have written.

In contrast, about 30% of departments (Cowie, 2005) require a shorter document, written in the form of a research paper for a specialised journal (e.g. Wagstaff, case study 5). This may present no less of a literary challenge to the student, given the need for focus and the adoption of a constrained style of writing. It is possible to see advantages and disadvantages in both approaches.

The creation of a thesis encourages a comprehensive literature review, the recording of methodological minutiae, the presentation of results in briefly summarised as well as fully analysed formats, and a detailed discussion. The discussion in particular can allow a strong student to use their understanding and creativity to develop ideas and demonstrate initiative. Equally, a less academic student may see the limitless expanse of the document as an insurmountable challenge or an opportunity for unfocussed rambling, as if assessment were based on weight or wordage rather than quality of content.

There is no doubt an able student will benefit enormously from the experience of writing, assembling and having editorial control over such a large document. If time permits, the privilege of being able to expound on a concept at length, attempt different solutions to problems, balance evidence and construct cogently written arguments is, at its best, about as profound an educational experience as one could wish an undergraduate to have.

The counter-argument, which is perhaps particularly applicable to students with no aspirations towards further research or in subject areas with a strongly applied context, is that the thesis is a false god: it does not train them in proper scientific writing, it does not really focus on tangible outcomes, it bears no resemblance to anything they are likely to read or write in future and it demands a set of literary and stylistic skills which they may neither possess nor really need to acquire. Furthermore, the production of a thesis takes time, energy and expense.

A research paper undoubtedly gets around the problems of length and lack of realism. It also offers a kind of natural symmetry in terms of subject development: the student completes their research by generating a document with exactly the same format as those they used to develop their knowledge and expertise. They need to write in a voice similar to the one they have been used to reading and they are forced to work at a level of detail and argument which is appropriate to the step-wise development of their subject. They add their brick to the wall and can immediately see that they have done so.

Yet this format also brings its own frustrations: a research paper pretends that the work proceeded in a certain way, logically and coherently, when it may not have done; preliminary investigations or unproductive methods may go unreported, despite having occupied significant amounts of time and energy; the summary of existing literature may have to be limited or curtailed; there may be inadequate space to present reasoned arguments and insufficient scope for speculation. Overall, the student may feel the paper does not adequately reflect everything they have done.

Both types of report will include an abstract. This is discussed below in the context of short reports.

ii) Length and content

Although departments usually specify their expectations in marking rubrics, it may be difficult to impose tight restrictions on report length. The main reason for this is the diverse requirements of different types of work. For example, a project based on data analysis may use a small number of tried and tested analytical methods requiring very little description and may lead to a predictive model which can be expressed in a few equations or lines of text. In contrast, a lab-based investigation may depend on the development of a complex, multi-step procedure, leading to many pages of detailed description, and result in, say, a qualitative account of a biological phenomenon. Equally, different topics start with widely differing amounts of published information, and the amount of background reading required of the student may also depend on the closeness of the subject matter to the course they have followed. In the case of a paper-style report, length and content may be governed by the conventions of the journal the student is expected to use as a model.

Thus it makes sense to build flexibility in to the system and to allow supervisors a certain amount of discretion in the way they impose the requirements. At the level of individual section or subsections, students frequently ask:

How long should it be?

They may feel that there will be a close association between length and intellectual effort, to a degree not appreciated by supervisors. The answer to this question is a matter of education and negotiation: it is really part of the guidance the student receives and is part of the way they learn and understand their subject. In the end, and notwithstanding attempts to unify expectations within departments or faculties, the only answer to the length question is:

As long as necessary and as short as possible.

At first sight, this response appears flippant or trite, but it contains the essential truth about all scientific reporting and possibly all kinds of writing. It certainly recognises the pointlessness of writing expansively just for the sake of a rule, and the danger of removing essential material if limits are over-restrictive.

iii) Short reports: oral presentations, posters and abstracts

Most departments require students to present their work in more than one format (Cowie, 2005a). These commonly include oral presentations and posters. Dissertations and papers will include an abstract and many departments also treat this as a distinct form of report. Such short reports offer opportunities for both presentational skill development and formal assessment, distinct from those of the main project report (dissertation or research paper). The principal characteristics of short reports are brevity and focus and they challenge the student to describe the key elements of their work in a particularly concise manner.

Because time (oral) or space (poster, abstract) are at a premium, the student is forced to confront the precise question they have investigated, the essentials of the experimental design and methods they have used, their most significant result(s), and the essential value of the outcome. These elements must be carefully balanced so the presentation has shape and structure. Unlike the dissertation, there is no room for extended scene-setting, for over-detailed methodology, for inadequately reduced data, or lengthy interpretation. Furthermore, the essentials need to be expressed in a way which is accessible to a non-specialist listener or reader.

In these respects, oral presentations and posters share many of the characteristics of the abstract and there may be value in getting the student to prepare them concurrently or by a similar process. Earlier (Chapter 2, page 23) we advocated the adoption of a rigorous investigative approach to project work, based on the scientific method. Experience indicates that where this has been done the construction of a talk, poster or abstract becomes an entirely natural, even automatic process. Whatever the project, and irrespective of ability, the student can return with some confidence to the security of the hypothesis testing framework: the key elements of the research process are specified and ordered and, at a minimum, all the student needs to do is draw in their own material. This is the scientific process in its quintessential form and the student will see immediately the extent to which they have engaged with it.

Despite the quasi-formulaic possibilities of short report preparation, there remain plenty of opportunities for summative assessment. On the one hand the content of the short report will reflect that of the project as a whole; the quantity, quality and importance of the work will be revealed and potentially exposed for criticism. On the other, the short report itself can be evaluated by the assessment criteria used for any other kind of coursework or presentation: the quantity and quality of the information given, the flow of the material, the accessibility of the content and the balance of the presentation as a whole. All these qualities can be measured against specified criteria for oral, poster and abstract formats.

Although generic assessment criteria can be set for most types of projects (e.g., Huxham, case study 10), it can be helpful to both students and staff if these are recast in greater detail for each type of presentation. For example, see University of Nottingham, School of Biosciences (2008). In this way, the student knows what is expected and has a target, and some objectivity in marking is achieved.

iv) Other forms of presentation

Other forms of report or outcome may be of value in particular circumstances (Cowie, 2005a). Projects involving the production of a useable object (for example, a website, an algorithm or piece of software, a device, a new analytical method, educational materials, etc.) can be judged by the tangible success of the endeavour and the extent to which the object meets the original brief. In these cases, as well as evaluating the product itself, it might be appropriate for the accompanying dissertation or other written report to discuss success or failure and to evaluate the developmental approach taken in the work (for examples, see Broadley, case study 8; Wakeford and Miller, case study 9; and Grady (2008). Local decisions will be needed to decide the relative importance of outcome and report. As with other assessment options, it is crucial the criteria are carefully constructed and as objective as possible.

An interesting way of assessing the student's intellectual development is the learning log or portfolio. This approach reminds us immediately that undergraduate research projects have a dual function (see Chapter 1): the completion of some research with intrinsic scientific value and the educational and skill development of the student. A carefully designed and managed portfolio can reveal process information about both of these; it can therefore be a specified outcome of the project and can be used as an element of final assessment (Calvert *et al*., 2007; Wright, 2005; Broadley, case study 8).

v) Publications?

This Guide has repeatedly stressed that undergraduate research should be real not contrived, that students should be experiencing bioscience at the edge of confident knowledge and that they should come to own their subject as a result of their engagement with its development. This view is widely shared (e.g. Hurd, 2008; Howard and Miskowski, 2005; DebBurman, 2002; see also a number of the case studies).

A natural consequence of this approach is that students will sometimes complete work of publishable quality. Several of the case studies in this Guide indicate this happens (Chaffey, case study 1; Downie *et al*., case study 2; Huxham, case study 10; Latham and Jervis, 2008; Murphy, 2008; and Reader, 2008) and there are a number of local (e.g. Biolog-e (Leeds); Origin (Chester); and BURN (Nottingham)) and national (Bioscience Horizons) journals devoted to undergraduate research reports and papers. Less easy to quantify are those occasions where student research has contributed to the published output of supervisors and departments, but there are surely numerous instances of this occurring every year.

The achievement of publication is something to be celebrated by everyone involved with the work. For the student, of course, it can be the pinnacle of their university education and potentially the foundation of a CV and a research career.

An important question, however, is the extent to which the achievement of external publication should be either an expectation of project work or should be used as an assessable element of it. Recalling that the purpose of the project is partly (mainly) educational, and also bearing in mind that students usually have little or no control over the wider significance of the research they are asked to undertake, it would seem essential on grounds of equitability of treatment that students are not expected to produce a publishable outcome.

Where internal publication occurs, departments and universities will make their own decisions about the extent to which submissions are selected or invited and the intensity of any peer-review. They will also decide how much research work each published article is expected to represent. In the case of Bioscience Horizons (the national level UK/Ireland journal devoted to undergraduate biosciences research), nominations of top quality research are invited from university departments at the completion of each academic year and the resulting manuscripts are subjected to rigorous and selective expert review prior to publication. The quality of papers published to date has been remarkable: in many cases the quantity, depth and quality of the research described has been indistinguishable from that published in many leading professional bioscience journals.

Despite these successes, most undergraduate research remains unpublished and hidden. Many projects, of course, would be unsuitable for wider dissemination but experience suggests a great deal of valuable work languishes on university shelves, gathering dust and hidden from critical view. This is a waste of effort and of good science. There is considerable scope for the development of further vehicles for external presentation.

Publication, whether internal or external, can provide several further advantages. It is a valuable resource for promoting the university and for illustrating to outsiders and prospective applicants what it is students actually do. It is also a great way of incentivising current students, particularly those who are about to start their own research: it shows them what can be done and will encourage them to achieve things they never imagined possible.

CASE STUDIES

The following section contains a collection of 10 bioscience case studies. All the case studies have been written by bioscientists with considerable experience of supporting the provision of final year projects to students and/or research modules in earlier years of study. The case studies are organised around common headings ('Background and Rationale', 'How to do it', 'Advice', 'Troubleshooting', 'Does it work?' and 'Further Developments'), but each study reflects the author's individual style and preference.

1
Traditional laboratory projects using tried and tested methodology create room for experimentation
N.J. Chaffey, Department of Biology and Food, Bath Spa University, Bath, BA2 9BN.
E-mail:n.chaffey@bathspa.ac.uk

2
Undergraduate Expeditions as a vehicle for final year projects
J.R. Downie, Joanna Smith and S. White, Division of Environmental and Evolutionary Biology, University of Glasgow, Glasgow G12 8QQ.
E-mail: j.downie@bio.gla.ac.uk

3
Analyses in Biology': an analytical alternative to traditional research projects
Helen James, School of Biological Sciences, University of East Anglia, Norwich NR4 7TJ.
E-mail: h.a.james@uea.ac.uk

4
Mentoring scientific minds through group research projects: maximising available resources while minimising workloads
Momna V. Hejmadi, Department of Biology and Biochemistry, University of Bath, Bath BA2 7AY.
E-mail: bssmvh@bath.ac.uk

5
Designing challenging 'dry' bioinformatics projects: exploiting public databases of genetic and post-genomic plant science data
Carol Wagstaff, Department of Food Biosciences, University of Reading, Reading RG6 6AP.
E-mail: c.wagstaff@reading.ac.uk

6
Commercial projects for final year students
Mary F. Tatner and Anne M. Tierney, Faculty of Biological and Life Sciences, University of Glasgow, Glasgow G12 8QQ.
E-mail: M.Tatner@bio.gla.ac.uk

7
Final year research projects in communicating science
Dan Lloyd, Department of Biosciences, University of Kent, Canterbury CT2 7NZ.
E-mail: D.Lloyd@kent.ac.uk

8
Implementing the Undergraduate Ambassadors Scheme (UAS) as a final-year project option
Martin Broadley, School of Biosciences, University of Nottingham, Sutton Bonington, Leicestershire LE12 5RD.
E-mail: Martin.Broadley@nottingham.ac.uk

9
A virtual laboratory for bioscience e-learning projects
Carol Wakeford and Ian Miller, Faculty of Life Sciences, The University of Manchester, Manchester M13 9PL.
E-mail: carol.wakeford@manchester.ac.uk

10
Research for real – an intensive honours research project
Mark Huxham, School of Life Sciences, Napier University, Edinburgh EH10 5DT.
E-mail: M.Huxham@napier.ac.uk

These case studies illustrate a range of approaches to supporting final year student research and preparation in earlier years of study. It is envisaged these case studies will provide guidance, inspiration, as well as practical advice on implementing final year projects for bioscience students. There is also an accompanying web site to this guide (www.bioscience.heacademy.ac.uk/resources/TeachingGuides/). The web site contains further practical material to aid the reader in implementing final year research projects for students. The site includes an electronic version of the full text of the guide, expanded versions of the case studies and supporting materials, and further case studies drawn from the biosciences.

Traditional laboratory projects using tried and tested methodology create room for experimentation

NJ Chaffey

Background and rationale

The project outlined is an example of one of many laboratory projects from our Biology Dissertation, a 40-credit final year project-based module, undertaken as part of degree requirements for BSc Biology or Environmental Science. Intended learning outcomes for the module are:

- Critically review relevant literature (essential preparation for the project, both as initial background in devising the project proposal and in informing the Introduction and Discussion of the thesis).
- Devise a goal and plan an appropriate study to achieve it (a research proposal with aims, objectives, project management plan, and completed risk assessment is submitted – and approved! – before work starts).
- Implement a study using relevant methodology and appropriate techniques (carrying out the proposal – with supervisor guidance, etc where necessary).
- Critically evaluate your own work (to encourage the student to criticise their project's shortcomings, etc. and suggest remedial action/further work, part of the Discussion).
- Produce an appropriately structured dissertation (a conventional bound thesis of 10,000 words).
- Communicate your work to a non-specialist audience (a short oral presentation of the investigation to their peers to develop communication skills other than written; takes place about 6 weeks before submission so feedback can inform and improve the write-up.

How to do it

In summary, candidate liquid plant extracts are applied to filter paper discs which are placed atop a microbial lawn growing on agar. The plant extract diffuses from the disc and either kills microbes or does not. The killing zone (zone of inhibition — ZOI) appears translucent relative to the rest of the lawn. The diameter of the ZOI is measured and compared between different extracts, control treatments, etc.

The project uses standard microbiological techniques and should be suitable for most bioscience departments. Where appropriate, students may be involved in all stages of the preparation of media, production of lawns, sterilisation of equipment, etc. Otherwise, a decision needs to be made regarding how much 'hands-on' involvement the student has in the — usually — 'behind-the-scenes' preparatory work. We encourage students to source details of techniques, etc. themselves — using past copies of undergraduate theses and published literature as inspiration. This is discussed with the supervisor before any practical work begins and in conjunction with project management planning and risk assessments.

Because of all the variables — plant/seaweed species, plant part, developmental stage of plant, harvest season, etc. that could be considered in any project, it is difficult to be too prescriptive regarding how to do it. The following is offered as a guide to the considerations that need to be applied in each study.

There are three main stages to the investigation:

i) Microbial cultures and preparation of agar plates

Choice of microbes is important and needs to be relevant to the investigation. For health and safety reasons, we generally use relatively harmless microbes, or non-pathogenic isolates of otherwise harmful ones. To cover a range of microbes, students generally use a Gram-positive bacterium, e.g. *Staphylococcus albus* (as a member of the same genus as the MRSA bug), a Gram-negative bacterium — e.g. *Escherichia coli B* (as a proxy for a major stomach-upset causing organism), and a fungus — e.g. *Saccharomyces cerevisiae*. Microbes are usually purchased from Philip Harris (Ashby de la Zouch, Leicestershire LE65 1NG).

Each microbe has its own preference for growth media and culture conditions (the supplier can advise on this). For those mentioned above we generally use:

Organism	Growth medium	Incubation temp. (^{o}C)
Staphylococcus albus	Nutrient agar	37
Saccharomyces cerevisiae	Sabouraud's agar	30
Escherichia coli B	MacConkey agar	37

Further details and formulations of the growth media can be found in standard microbiology texts, manufacturer's catalogues, or reputable internet sites.

Lawns are made by spreading c. 0.15 ml of microbial culture over the appropriate agar in a Petri dish and incubating overnight.

ii) Preparation of plant material and discs

In the past students have used fresh material (leaves, roots, stems, flowers, etc.), dried material, commercial preparations either solid (e.g. dried herbs) or liquid (e.g. essential oils). The goal is to get an extract that can be mixed/dissolved in an appropriate solvent so that it can be soaked up onto a filter paper disc, and made up in a reproducible formulation. This may take some experimenting (and can be both a fun and frustrating! part of the investigation); solvents routinely used include water, ethanol, industrial methylated spirit (IMS). Factors to vary include the time of shaking of extract and solvent, and the degree to which plant material is crushed or cut up before extraction.

Issues that can arise include pigmentation of extract solutions which can obscure identification/measurement of any ZOI, and difficulty of dissolving extracts (e.g. Aloe mucilage). If plant material does not dissolve, it should be possible to obtain an extract by shaking the plant material with a suitable solvent; again, some trial-and-error is almost inevitable here. In some cases it may be possible to use discs of plant material directly applied to the agar. An alternative to use of rather crude whole plant samples is to consider steam-distillation of plant material to release essential oils, which can then be tested. This may be done in an attempt to narrow down the range of potential anti-microbial agents.

iii) Incubation of plates and measurements of ZOI

Sterile discs (we routinely use 13 mm Whatman filter papers) are dipped in the plant extract, drained of excess liquid and dried in a sealed sterile Petri dish. Up to four discs can be accommodated in a Petri dish (but if the extract is highly active ZOIs can merge between one disc and another) and are applied to the surface of the agar containing the microbial lawn. The dishes are then sealed with tape (and not opened again — useful safety practice) and incubated for 24, 48 hours or longer at appropriate temperatures (depending on the investigation). Dishes are inspected for microbial death, which can be identified by a clear/translucent zone around the filter paper discs. The diameter of this zone of inhibition (ZOI) is measured and recorded and is the basis for comparison of effectiveness of anti-microbial activity of plant extracts/solvents.

Appropriate controls are essential: principally this is a disc dipped in the solvent used to extract the plant material. Another 'control' we employ is to use an alcoholic extract of garlic (3 g crushed fresh garlic and 10 ml IMS, shaken for 10 minutes) against the microbes to be tested. Garlic inhibits/kills all of those microbes mentioned above and is a good test of the student's aseptic technique as well as demonstrating a 'positive' result. Sufficient replicates are also needed to permit sensible statistical analysis of the results. This latter points needs to be borne in mind when designing the investigation — the demands on time for preparation of the large number of plates often needed, can be considerable! Subsequent analysis of results can then be undertaken using standard statistical tests.

- Refinements (these are but a few — encourage students to be imaginative!).
- Minimum inhibitory concentration (MIC) — how dilute can the plant extract be before it does not inhibit microbial activity? A series of doubling dilutions can provide useful information on this aspect of the investigation. Of necessity this is a relatively crude measure because the concentration of the active principle(s) is often unknown, but it can help to rank extracts' effectiveness pending further analysis of chemicals involved.
- Steam-distillation to release essential oils (see above), which can then be tested.
- Whether there is seasonal activity of any anti-microbial activity found.
- Whether anti-microbial activity is dependent upon stage of growth of plant.

Assessment of the Dissertion

Each project is written up as a standard scientific dissertation and submitted in duplicate. One copy is marked by the supervisor; the other independently by another member of staff. A table of marking criteria for the various sections of the thesis is completed; scores are given for each section and the scores discussed between the two markers. In the exceptional case where consensus is not reached on an overall mark, a third marker looks at the thesis. The agreed mark is reduced to a maximum of 85%; the remaining 15% of the final project mark is at the discretion of the supervisor having regard to the student's commitment and dedication to the project, adherence to agreed laboratory times, supervisory meetings, etc.

Advice on using this approach

- Ensure the students are thoroughly briefed on health and safety issues — get them to research and write the first draft of the health and safety/risk assessment for discussion with their supervisor — before undertaking the work.
- Impress upon the students the need to be organised and manage their time appropriately — there are potentially a lot of plates to work with!
- As with every project, things can go wrong and the unexpected can happen — part of the learning outcome of the module is how students cope with these matters.
- Depending on the plant material investigated/ microbes used, increasing levels of care/control/ containment may be needed in carrying out work/ disposing of used materials.

Troubleshooting

The commonly-encountered main problems are:

- 1) Not finding any anti-microbial activity. Make this a 'positive' result (not all plants are anti-microbial) by ensuring they do a 'dummy run' with garlic and microbes (that does work).
- 2) Poor aseptic technique. This should be overcome with practice.
- 3) Issues in finding the appropriate diluent for plant material. This issue requires experimentation to overcome it (which should be part of the fun of doing research!).

Problems specific to particular test organisms include getting the microbes to grow suitably (ideally, as a lawn) so that anti-microbial kills can be identified and quantified.

Does it work?

Although an important aim of any dissertation is for students to get experience of a proper research project, too many traditional laboratory investigations can get bogged down in trying to get the methodology to work, without generating results. This study uses proven methodology and should mean the student spends more time on planning the investigation, and obtaining and analysing their results. As a result, this sort of investigation is ideal for undergraduate projects. Not only is there the enjoyment and satisfaction of undertaking a project that works (usually!), it is an investigation that is highly relevant to topical concerns about the unexploited biomedical potential of plant resources. There is great scope for student imagination in selecting the microbes to use, the treatment combinations to apply, the plant/seaweed species to investigate, and then which parts and which solvent to use, determining MICs of extract, whether to investigate seasonal microbiocidal activity, etc.

The method is straightforward, and is tried-and-tested both within our department and the published literature - see Harding and Maidment (1996), Maidment *et al*., (2006); Maidment *et al*., (2001); Maidment *et al*., (1999); and Maidment *et al*., (1998). It also lends itself to students suggesting their own ideas of material to test (chrysanthemums against 'jock-itch' is one memorable investigation suggested by a student!), so they have 'ownership' of the project. Additionally, this investigation often has the bonus that — if done well — it may lead to publishable results (several of the above papers arose from such student projects).

Further developments

No significant changes are planned — it works very well as it is! However, with over 250,000 species of flowering plants there is plenty of scope to broaden plant material tested and microbes investigated. Having identified 'interesting' plant material, a logical step is to attempt separation and identification of active ingredients (those technical considerations are beyond the scope of this case study).

Additional materials

The gel diffusion assay technique has been used for many investigations of anti-microbial properties within undergraduate projects — e.g. New Zealand shrubs, Aloes, spice plants, Mediterranean herbs, commercial garlic preparations, essential oils, UK littoral seaweeds, and honeys. Some of the projects have been written up and published, while others are in preparation. Interested parties requiring further information are invited to contact the author for detailed instructions.

Undergraduate Expeditions as a vehicle for final year projects

J.R. Downie, Joanne Smith and S.White

Background and Rationale

The honours degree programmes we offer are in Zoology, or Marine & Freshwater Biology, but the scheme we describe could suit programmes in Ecology, Conservation Biology, etc.

Many students in these areas are interested in field-based projects and are particularly attracted to the idea of doing fieldwork abroad, in areas of high biodiversity. However, there are several difficulties associated with overseas fieldwork: a) cost, b) safety and supervision, c) timing i.e. it is not feasible to do the fieldwork for an overseas project at the same time as studying core modules at the home university.

Different universities no doubt find different solutions to these problems. For example, some may have rather short projects which can be tacked on to the end of an overseas field-course; some have a rigid separation in final year between a taught-module term or semester and a period entirely devoted to the project. It is also possible to devolve projects to organisations such as Operation Wallacea (www.opwall.com/), who provide excellent opportunities, but are rather costly to students.

At Glasgow, our pattern for laboratory-based projects is that they stretch over most of two semesters, concurrently with taught modules, and that they occupy about one third of a student's time over up to 20 weeks (including writing-up). This is a substantial time commitment, and field based projects are expected to be broadly equivalent.

Our scheme allows students to do the field-based part of the project (in the UK, or abroad, but this case history concentrates on projects abroad) during the summer vacation between the Junior Honours and Final years (3rd and 4th years of a Scottish degree). Overseas projects are linked to Undergraduate Expeditions.

How to do it

Our expeditions are jointly organised by staff and students, and must have a member of staff involved if they are to receive University approval and support. Expedition members can be undergraduates from first to final year, and postgraduates as well as staff. The general educational aims of an expedition are a) to give students experience of challenging fieldwork abroad that can generate worthwhile results; b) to give students the opportunity to be involved co-operatively in the logistical challenges of organising an overseas expedition. Our expeditions are not organised for the purpose of providing project opportunities for final year students, but it is generally possible to devise projects as part of the overall programme of work done on the expedition.

There are considerable advantages in this approach:

- Overseas fieldwork is costly, but we cover it through the fundraising effort needed to run the expedition. This develops the valuable generic skills of organising fundraising events and writing grant applications. Because students understand the considerable value to their personal development of participating in an expedition, they are very willing to spend considerable time on fund-raising.
- Since only a proportion of students on an expedition are working on final year projects, the others can act as helpers when they are not busy with other work. This has several benefits: it provides field safety; it helps with data collection; and junior students learn some of the skills involved in a fieldwork project before they need to work on their own project i.e. there is an element of peer-assisted learning.
- On the spot supervision, helps quality assure the process as far as the University and funders are concerned, and may be able to do some of his/her own research with the assistance of expedition members.
- It is common for our expeditions to be located in places where members of staff have one-off or long-term research interests. This means that the research-teaching link is strong for the student projects.

Troubleshooting

Three problems we have faced are:

- 1) **Equity** How to equate the project opportunities of students who have been able to work on their project abroad over the summer, compared to term-time projects at home? Our pragmatic solution has been to require summer project students to submit their reports just after the Christmas vacation, whereas term-time projects are submitted at Easter. We have not attempted to put limits on the amount of time a summer project student can devote to fieldwork. We have been pleasantly surprised that students have rarely complained that summer project students have an unfair time advantage over term-time project students. We suspect this is because students realise that projects are very diverse, and that the time any student chooses to devote to a project is a personal decision: and that these factors make summer/term-time difference insignificant, especially given that students fully recognise the value of allowing summer projects.
- 2) **Staffing** Not everyone wants to spend a substantial part of the summer vacation in the company of undergraduates! However, we can run staffing as a rota; and by linking expeditions to staff research interests, we reduce this problem.
- 3) **Health & Safety** Over the years, we have become more professional on risk assessments and safety precautions. Again, this is all excellent training and experience for students. The availability in many overseas locations of modern communication methods such as mobile phones has become a great help. However, accidents can happen and students can catch serious diseases, despite operating to the best available advice and practice. Since such events are likely to be more alarming overseas, it is vital to have effective procedures in place to cope with such problems, including communicating with parents etc. at home.

Does it work?

A growing number of our final year projects have been carried out overseas, since we began this practice in 1993. In 2008, we are running nine overseas expeditions, and over 10 students will do their projects under this scheme. Projects on expeditions have been of high quality, with many leading to publications in refereed journals, usually the first such publication for the students involved. Many graduates who have participated in expeditions have proceeded to fieldwork based research careers, and often comment that the opportunity to do a fieldwork project abroad was the best part of their undergraduate experience and influential in starting them on their career path.

The variety of projects undertaken has been very diverse. Most have been basic biology, ecology, or conservation related. We have also had human-based projects, using interview and questionnaire-based data.

Accompanying materials

The Exploration Society provides support to expeditions of various kinds: maintains a funding-source database; organises first aid training; organises briefings on field safety and safety assessment; ensures that reports of previous expeditions are available (hard copy in the University Library; increasingly also available on the web). The Exploration Society website is under development and will eventually provide a more comprehensive package of resources. In the meantime, please contact the first author for further details.

'Analyses in Biology': an analytical alternative to traditional research projects

Helen A James

Background and rationale

At the University of East Anglia (UEA), we pride ourselves in our strong commitment to research led teaching. In the School of Biological Sciences this is ultimately borne out in the final year (year 3/4) research project, where all our undergraduates have the opportunity to carry out their own piece of novel research. At UEA these projects have traditionally taken the format of the student spending 8 weeks (10-15 hours per week) on the data collection aspect in the laboratory or in the field prior to writing a report and giving a talk. Over the last few years a number of different pressures on traditional project provision have built up from both students' and supervisors' perspectives, as they have at other universities (Hollingsworth *et al*., 2004; Ryder, 2004). From the students' perspective a small, but significant, proportion of students each year do not want a practical-based project due to particular career aspirations or the knowledge that hands-on research is not for them. From the supervisors' point of view growing numbers of students have imposed increasing strains on the provision and supervision of the projects. These combined pressures led us to seek an alternative to the time and resource-consuming laboratory or field-based research project, but which maintained a strong research led approach to teaching. This resulted in the development of a new Year 3 module titled 'Analyses in Biology'.

'Analyses in Biology' is an alternative to the laboratory or field-based project with very similar learning objectives, which runs in tandem with the traditional project module. Its aims are to provide an introduction to biological analysis, the formulation of hypotheses, and appreciation of the processes involved in undertaking rigorous analysis of existing data and determining outcomes. Upon completion of the module students should have:

- Developed an understanding of the nature of scientific research and analysis;
- Developed key skills including an appreciation of experimental design and hypothesis testing, written and oral communication and the use of specialised analytical methods;
- Developed the ability to acquire, analyse and assess data and to critically test theories and concepts.

It is compulsory for all our students to take a project of some description. The choice between the two project modules is open to students on all of our degree programmes except Ecology, who take their own variant of the project module (Ecology Research Project). Students on our Biochemistry degree programme can choose either of the bioscience project modules, or a project module based within the School of Chemical Sciences and Pharmacy. Students make this decision in the spring preceding their final year. At registration in September they are provided with a list of supervisors and research areas and have two weeks to meet, chat and discuss possible projects with the supervisors. Students then submit their top four supervisor preferences. The module organiser then has the task of allocating students to projects, ensuring suitability of project for degree programme and an even spread of projects between members of faculty.

How to do it

'Analyses in Biology' is not an easy alternative to the traditional 'hands-on' research project nor is it an opt-out from research. Importantly, it is also not just a literature review. Instead it involves the student undertaking his or her own rigorous analysis of existing biological data. A variety of projects can be imagined; here are a couple of examples from UEA. One student looked at protease profiles in head and neck cancers and their correlation with certain risk factors. The project student was provided with real time PCR data generated by a PhD student from the supervisor's laboratory. The student interrogated the data to determine if there was a gene signature that correlated with gender or smoking status and tumour grade. They produced hierarchical clustering and heat map data alongside an in-depth literature search of gender and smoking in head and neck cancers. A similar sort of project was offered with data generated from microarrays (normal vs. pathological samples). Another example is to use online databases such as FlyBase and FlyAtlas and to ask questions about specific Drosophila genes. The student identified interesting expression patterns of a family of genes and postulated function from location. Comparisons were made to other species and phylogenetic trees were created. These sorts of projects therefore provide the students with a slightly different skill set, yet one which is of equal value to them.

The students will still 'own' the research and they will be producing novel findings. Examples of such projects from the previous two years include: protease profiles in head and neck cancers and their correlation with certain risk factors (using real time PCR data), simulated computer models of protein folding, analysis of microarray data to identify the patterns of gene expression within a tissue and investigating gene homologues and sequence comparisons for a number of species.

The students choose these projects at the same time as the laboratory or field-based projects (in September), so it is important colleagues have been reminded of the different types of projects to offer so they have had time to think about potential analytical projects. The students doing analysis projects are expected to spend a similar amount of time on the data analysis part of the project as the laboratory-based students spend in the laboratory. They are also assessed along the same lines as the laboratory-based students: on their conduct during the project, the written report and an oral presentation.

Advice on using this approach

It is important both styles of project are regarded as equally robust and scientifically equivalent by both staff and students. The value and importance of 'Analyses' projects must therefore be 'sold' to both groups, since the laboratory and field based projects are often considered the 'gold-standard'. It is important to be transparent about the objectives of both styles of project and their intended learning outcomes. Assessing students undertaking analytical projects by similar criteria to those doing the laboratory or field based projects is a useful quality control and ensures comparable standards.

In our experience both strong and weak students opt to take this module. Strong students can really excel at an analysis project — they can demonstrate independence, initiative and critical thinking. They are not handicapped by experimental errors or technical difficulties that can be common in laboratory undergraduate projects and, consequently, can achieve a lot in comparison to some more traditional projects. Weak students, however, can use this style of project to 'hide'. If, during the course of the project, the student is working 'out of sight' of the supervisor and only meets with the supervisor once a week, for example, then the student could put little effort into their project or struggle with concepts.

Troubleshooting

We now have two years experience of offering the analysis alternative to the traditional research project. Several issues have arisen in this time. The first is convincing colleagues of the value of such a module and this type of project, and that it is not a soft option for students. One colleague was very sceptical as to the appropriateness of the module. However, having supervised a student undertaking this sort of project (bioinformatics/molecular modelling), he is now a strong advocate of the Analyses in Biology module. Not only are these types of projects relatively cheap (no consumables, though there can be software requirements), they are less time consuming as the student needs much less 'hands-on' supervision and often the student can carry out some sort of analysis which the supervisor has been wanting to undertake.

Nevertheless, some colleagues remain reluctant to offer this type of project. Sometimes this is a case of lack of ideas or data for the student to work with, but more often it is that the supervisor has not thought through the possibility of such a project nor realised what this style of project could offer a student.

Some students are reluctant to opt for an analysis project, although the reasons for this are not immediately apparent. Perhaps it is perceived as having less importance than the traditional laboratory project, and we have not yet managed to convince them of the value. We hope that this issue will become less of a problem as more students (and supervisors) have successfully passed through the module.

Does it work?

We have run the Analyses in Biology module for only two years and in that time only a relatively small proportion of our students (7%) have taken the module instead of the traditional research project. With such small numbers of students it is difficult to obtain meaningful statistics; however, in their evaluation of the module this year it scored the same high score as the traditional research project. The students were very positive about their experience: "I really did enjoy my project, it was brilliant. I got to delve in to the subject" and "I enjoyed the project and liked the nature of the analysis". Students have also recognised the advantages of an analysis project "felt as if you were up and running right from the start rather than the slower learning curve of a lab-based project". As more of these projects are carried out both staff and students are becoming more comfortable with their style and learning outcomes. Colleagues are beginning to see the projects' value (scientifically equivalent to the laboratory or field-based research projects and time and financially less intensive) and that they have a useful place within our final year teaching.

Mentoring scientific minds through group research projects: maximising available resources while minimising workloads

Momna V Hejmadi

Background and rationale

Laboratory research projects should be designed to help train scientific minds by enabling students to understand the process of inquiry and scientific rigour. In practice however, they place huge demands on resources. In our department, student numbers have increased substantially without any increase in research lab space. Projects are expensive but the budgets are small, and they place huge demands on staff workloads. Most importantly, students may not necessarily enjoy or appreciate the process of scientific inquiry or develop the key skills needed for research or employment. These problems are common to many universities (Cowie, 2005a).

To tackle these issues, I successfully introduced changes to our final-year laboratory project for biochemists in 2005: Students carry out laboratory research projects in pairs or groups of three, and are assessed on the individual report and key research skills. The changes were designed to help students appreciate the process of scientific inquiry and develop transferable skills such as team-work, problem-solving, etc., with a minimal demand on resources. This 12-credit unit, involving 200 study hours, runs in Semester 2 (11 weeks) and is mandatory for all final year biochemists without placement experience and optional for those with placement experience (year 3/4).

How to do it

Instead of taking place in research labs these projects are carried out in the teaching labs, with students working together to plan and carry out their research. Additional assessment criteria encourage development of key skills, and staff workloads associated with student research projects are minimised. The specific changes are outlined below:

- 1) **Choice of Projects:** Students choose from research projects which are carefully selected to highlight key research skills while minimising demands on space and consumables. E.g. Bioinformatics projects involving identifying novel targets such a gene homologues, splice variants, differentially imprinted genes/ promoters etc in different but relevant tissues, assay development strategies etc. Initial training on bioinformatics, PCR, cloning etc. is given to the entire group. Students are also encouraged to help each other by sharing reagents, resources etc.
- 2) **Location:** Instead of using research labs, these projects take place in the spacious practical-teaching labs, thereby making the best use of the resources available. Bench space is set aside for project students and students are directed to manage their experimental time around scheduled practicals. The labs are fully equipped and technicians are on hand to supervise basic aspects of laboratory work (buffer / media preparation etc.). The research ethos is maintained as a result of these students collaborating with each other, other postgraduate students and regular meetings with the supervisor (similar to a regular research environment).
- 3) **Team work:** Each project is done by a pair of students (3 if needed). This helps develop their team work and communication skills, with the added benefit of students learning from each other. It also reduces the number of projects by at least half. Generally, students self-select their partners and project choices, but I have intervened occasionally where I thought this would benefit the students.
- 4) **Using dedicated postgraduate demonstrators:** Two PhD students help in the supervision of the projects. They are funded by the department for 4 years (instead of 3) with the undertaking they help in this project for 11 weeks every year. The benefit for the postgraduate students is that they gain experience in research supervision work and are involved in all aspects of project teaching, including assessments. These students are trained in aspects of research supervision by regular meetings with the unit convenor and by attending staff development workshops on research supervision.

- **5) Assessment:** Instead of conventional assessments based on a written report alone, I embedded additional key skills as part of the assessment (below). These were monitored contemporaneously through regular meetings with the supervisor. This was done to enable students to recognise and develop key skills that are invaluable for their future (either PhD or employment). These skills are presumed but not always rewarded in conventional assessments for research projects (usually written report / viva).

Assessment weighting (%)	Assessment criterion/ skills assessed	How assessed/ assessment task
50	Scientific report writing?	Final report
5	Experimental design	Experimental draft (before meetings)
5	Critical appraisal skills	Abstract of project and literature review (week 2)
5	Data analysis and interpretation	Reflection in lab records; discussion meetings with supervisor
25	Performance in the laboratory:	
10	effort	Observation and lab records
5	good laboratory practice	Observation and lab records
5	record keeping	Lab notebook
5	team work	Observation, lab records and progress
5	Development of problem solving skills	Discussion meetings with supervisor
5	Originality / flair for experimentation or initiative	Discussion meetings with supervisor; lab notebook

Advice on using this approach

Preparation: Carefully planning and choosing projects that optimise output is vital. For example, a broad project can be shared by a group of teams with each team adding their component e.g. assays, RT-PCR, Western Blots, etc. can be done by individual teams and contribute to the overall results. It also encourages teamwork.

Communication: It expedites things if everyone is informed of the details in advance, e.g. teaching technicians (for practical scheduling etc.), students (choice of projects given at least 2-weeks in advance), and postgraduate demonstrators (detailed briefing sessions).

Regular meetings: I found it very important to schedule regular meetings with student teams to go over problems, discuss results and ways forward. I always try and get them to think out answers to problems and ways forward. I usually meet students every week for ~30 min for each team (sometimes a whole day may be spent doing this).

Troubleshooting

This style of lab projects has run very well for the past 2 years. There have not been any major problems. However some issues that have arisen in the past include:

- Large numbers of students: I started off with 12 students in the first year and had 25 last year. The maximum capacity for doing research in the practical labs is ~40. This has enabled four colleagues to share this space with their project students using a similar model.
- Most of the students were very keen to spend more time in the lab to get good data, although not everyone will be so inclined (see student feedback). Ensuring that students have realistic expectations of how much they can achieve in terms of results within the available time is important.
- Some students, particularly those from overseas, have not always interacted well with the rest of the group. This could be due to the relatively large student cohort (~60 in the biochemistry degree) combined with language or cultural barriers. See below for how we plan to address this issue.

Does it work?

- Mentoring the research mind: Since the new strategy for projects was introduced (including assessment criteria), more than 50% of the students have gone on to do a PhD, either in the UK or the USA. Although lab projects may not be the only reason, the research environment and ethos created may certainly have contributed to their decision (see feedback below).
- Effective use of resources: Maximising use of the bench space and reagents available. Reducing workloads on staff.
- Postgraduate skills training: The responsibilities given to postgraduate demonstrators ranged

from lab supervision to marking written reports (moderated by me). This empowerment helped their own research training and enabled them to better appreciate their own research supervision.

Student feedback

The vast majority of students (~ 85%) who completed the module evaluation form indicated the project had been a useful learning experience for them. Example comments on the best things about the project were:

- "The insight into real research gained through actually taking part in a real research project …"
- "Being able to complete a project from beginning to end without simply following a protocol, learning new skills and implementing the science you have learnt over the years. This project involves a lot of hard work but is very rewarding and enjoyable and a great learning experience"
- "My project was interesting and enjoyable. It has given me the chance to develop techniques and skills I will need for my PhD"
- "Really enjoyed it …"

The major criticism about the project from the student point of view was the amount of time spent in the laboratory (they felt this was much higher in practice than indicated in the module handbook).

Peer Response

I gave a talk to colleagues in the department on how I run the project and four colleagues have since used it for the projects they run. The external examiner commented "these carefully designed 'teaching' research projects can be more informative to a student than a poorly-planned or speculative 'real' research project. They also provide a more level playing field for the assessment of the abilities of these students."

Further developments

- Realistic expectations: Need to better manage student expectations by clarifying time limitations will result in limited data.
- 'Bonding' exercise: I was inspired by Elizabeth Dunne's (University of Exeter) teamwork activities presented at a Higher Education Academy meeting (Assessment: Students supporting students – London, 21 March 2007). I will be adapting some of her methods for this unit next semester in order to get the students (especially overseas students) to integrate better as a group.

Accompanying materials

The accompanying web site to this guide (www.bioscience.heacademy.ac.uk/resources/TeachingGuides/) contains a downloadable version of this case study and the following additional material:

- project handbook

Designing challenging 'dry' bioformatics projects: exploiting public databases of genetic and post-genomic plant science data

Carol Wagstaff

Background and rationale

Like many institutions we have experienced the pressure of many final year students wishing to do projects coupled with extremely limited financial resources that are not sufficient to support a laboratory based project without additional funding from existing research grants. Finding 'dry' projects that still provide a challenge to the student that goes beyond a literature review or dissertation is not easy, but the requirements are that the student can find out something novel, follow scientific method and have the scope to achieve the maximum grade if the project goes well. I have recently started to offer projects that make use of the wealth of post-genomic information and free databases that now exist, together with sequence information for many organisms, to design projects where information from one species can be used to inform a programme of research on another species.

Food Biosciences is small compared to most Biological Sciences departments (about 55 students per year of undergraduate study and the same on MSc programmes) and about 20 staff offer approximately three project titles each. At present, I am the only member of staff offering bioinformatics projects, although some of my colleagues do offer alternative dry projects in the form of conducting food choice surveys or accessing results from large-scale diet and health studies. We have no restrictions on project choice, other than to limit the number of students per staff member to around four. Both 'wet' and 'dry' projects carry the same amount of credit (40 out of 120 credits) in the final year and run over two terms. This is the second year of offering informatics projects in my present job, but I also ran them in my previous position when I was a post-doc in a Biological Sciences department. I would say that they were more popular amongst the Biologists than those studying Food Science or Nutrition, probably because the former have a better background in genetics and plant science and are more aware of the growth of bioinformatics within their discipline.

How to do it

Informatics projects involve 3 elements:

- 1) A biological problem;
- 2) Molecular genetics; and
- 3) Database interrogation.

The project can start at many different points depending on the prior knowledge of the student. Some will have a good understanding of the biological problem being investigated e.g. antioxidants in plants, but not of molecular genetics or database interrogation, whereas others will have knowledge and experience of different elements. Essentially the informatics project brings together components of all three areas by the end of the study.

I would always advise starting with the biological principles behind the project, explaining to the student the real-world relevance of the investigation. For example, my students are all studying some aspect of food biosciences and are wary of a project that looks too much like pure plant science. Once they appreciate that considerable breeding efforts go into our plant-based food crops and that plants donot make antioxidants (or any other secondary product) for our benefit, they begin to see the relevance. I generally have to do a lot of explaining about what Arabidopsis is and why it is so useful, but a student of plant sciences would have less need of this, and perhaps more need of an introduction to which plant products are of dietary significance to humans. Thankfully, with food issues having such a high profile in the media there is a high level of general awareness of dietary goods and evils amongst students.

These projects require a fairly heavy input of time from the supervisor at the beginning of the project in order to familiarise the student with the relevant databases, but once the student is equipped with the relevant tools the project requires much less effort to supervise. The important thing is that students feel confident to go and try things for themselves.

The student will collect a variety of data in the form of gene/protein sequences, descriptions of gene/protein function and expression values. The projects are written in the form of a research paper — our department has just taken the decision to use Biosciences Horizons (biohorizons.oxfordjournals.org/) as the guiding format

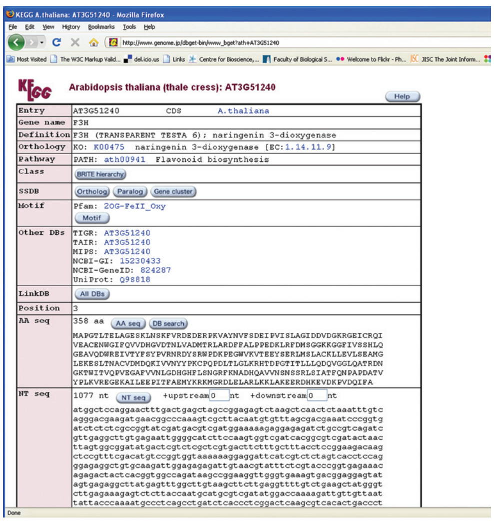
– and these projects are therefore assessed against the same criteria as laboratory based studies.

The following case study illustrates the resources I directed students to for a particular project: 'Using Arabidopsis to identify targets for future research to manipulate the flavonoid content of lettuce.'

a) Direct the student towards some reading designed to familiarise them with the different types of flavonoids, under what situations (e.g. stress) the plant produces them, and the importance of different flavonoid groups in the diet. Hopefully with a bit of guidance they will then decide to focus on one major pathway — for example anthocyanin biosynthesis.

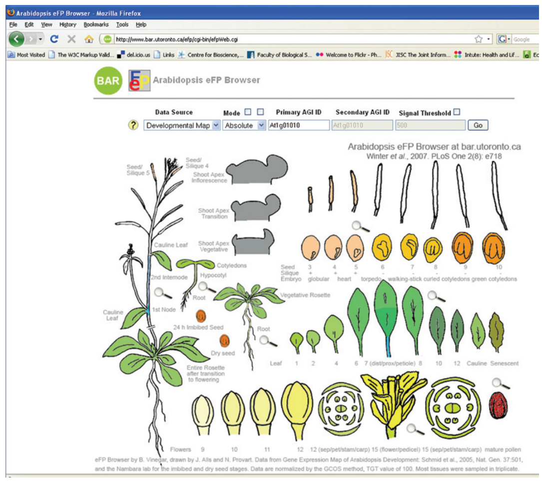
b) Show the student how to use the Kegg metabolic pathway maps for Arabidopsis www.genome.jp/kegg/pathway.html. The flavonoid biosynthesis pathway can be selected from the list of secondary metabolites and the reference pathway changed to the organism Arabidopsis thaliana. You should now be at www.genome.jp/kegg/pathway/ath/ath00941.html. On this page, the rounded boxes link to other pages from the same metabolic map (in this case specific flavonoid groups such as anthocyanins, phenylpropanoids). It can be useful to follow such links if you are looking for genes that regulate large chunks of the pathway. Each square box represents a gene that is thought to regulate that step of the reaction. If it is shaded green the information comes from Arabidopsis. If you select a square box by clicking on it you will be taken to the details of that gene, including AGI code, and genomic and cDNA sequence. Save the information in a separate document.

For example, www.genome.jp/dbget-bin/www_bget?ath+AT3G51240 encodes a gene involved in the synthesis of a number of important flavonoids, including anthocyanins. (See screenshot below.)



c) Ask the student to copy the amino acid sequence (ringed in red) from this page and paste it into the lettuce database blast facility at http://cgpdb.ucdavis.edu/database/sms/query.html using fasta format. Check the lettuce EST database and tblastn search boxes before running the blast. A number of sequences are produced with significant alignments. This is a good opportunity to explain to the student what to look for when assessing alignments — good % match over a short region or lower % over the whole sequence. Take care because the lettuce ESTs are not all full length. The lettuce genome is not fully sequenced so the student needs to check they have a homologue (or several) to their gene of interest in the lettuce database before proceeding with the more onerous tasks below.

d) The project can now go in several different directions. At this juncture I usually show the student some software for interrogating expression datasets such as Genevestigator https://www.genevestigator.ethz.ch/gv/index.jsp using their virtual northern tool. This tool can be used to select genes of interest and find out in which tissues they are expressed, at what stage of development and in response to which stress stimuli — all by taking publicly available array data.



Another really nice tool for visualising the spatial expression patterns of genes can be found at www.bar.utoronto.ca/ using the eFP browser tool (see screenshot above), although others on this site are worth a look too.

All the tools mentioned here of course use Arabidopsis so you will need to go back to your original gene IDs — but at this point the students are furnished with the knowledge of which ones show up in lettuce and are worth pursuing. This is particularly important when dealing with gene families and the tools mentioned above come into their own to really answer some questions. For example, the gene identified in part b above encodes a naringenin 3-dioxygenase. This is a family of several related genes and by interrogating a tool like Genevestigator the student can work out which one is most highly expressed in the desired tissue (leaves) and at what stage of development. The closest homologue to this gene can then be identified from the lettuce database and if the work were moving into the lab this would be the best sequence for any subsequent molecular work to modify flavonoid biosynthesis in lettuce.

e) Some students like to take a more biochemical approach and enjoy finding tools to analyse the predicted protein sequences and the corresponding nucleotide sequences to search for binding sites and recognition motifs using tools such as Prosite, www.expasy.org/prosite/. They could potentially move onto examining folding patterns and identifying docking sites on the mature protein if sufficient staff expertise is available.

f) There are lots of other tools and the students will probably surprise you by finding some of their own! www.arabidopsis.org, www.bar.utoronto.ca/ and www.expasy.org, each host a number of resources, and are good places to start.

Advice on using this approach

a) Be careful the student doesn't lose sight of the aim of the project and collect data without thinking what it means. It is very easy to be overwhelmed by pretty images and gene lists with this project and a bit of direction as to what to focus on is usually helpful.

b) You have to insist that the student is organised and writes as good a lab book for this project as they would for a 'wet' project. Otherwise they will end up with pages of unidentified sequence and very little clarity on what anything means. I encourage them to write down their thought processes as well as a straightforward record of what they have done.

Troubleshooting

It can be frustrating if databases or servers go down. It certainly helps if the student has their own laptop and a fast internet connection rather than being reliant on the average university resource. Some weak students can give into the temptation to stay at home and 'play' with databases without actually achieving anything and in these cases the supervisor will need to impose a more rigid structure of activities.

Does it work?

The strengths are that the student can rapidly develop a sense of independence and ownership of their project. Many like the flexibility of working practice it offers and bioinformatics projects can be helpful for students trying to juggle work and family pressures with study. However, it can be quite easy to lose focus and some students can feel as though they are drowning in data. I ran two very similar projects (on aspects of leaf development) at my previous institution with students with very different marks in their second year. To my surprise the 'first class' student did less well than the one who had a 2ii average carried forwards, and the latter really blossomed academically during this project, discovering an ability to synthesis large amounts of information and use the data to understand what was happening at the biological detail in far more detail. This person was able to produce a theory of leaf development and shape determination that challenged the boundaries of what was already known.

Further developments

Recently, new tools have become available to make simple phylogenetic trees using the TreeView function of BLAST as NCBI. This facility allows the development of projects that ask when certain genes evolved and therefore when certain biochemical pathways were in place. Inferences can be made from this to the way plants functioned at the time.

Commercial projects for final year Bioscience students

Mary F. Tatner and Anne Tierney

Background and rationale

Many students who graduate in the life sciences do not follow a laboratory based career, either through choice or lack of opportunity, and the classical laboratory research based final year honours project may not be the best preparation for them for their future employment. It could also be argued that with increasing budgetary/space/supervisory constraints on 'wet' projects, many departments would benefit not only themselves, but their students, by providing other types of Honours projects.

There have been some initiatives to offer so called 'dry' projects, usually involving some data acquisition, data handling or questionnaire studies which suit some students and degree disciplines very well. Another alternative pioneered at the University of Glasgow in the last two years has been the provision of 'commercial projects'. These are available to all final year students from the 20 different Honours degrees in Biosciences, offered by the Faculty of Biological and Life Sciences. They carry the same credit and assessment weighting as the traditional wet/dry projects and are completed in the same timescale, being worth approximately 12% of the final degree mark and taking 2 days a week over a 10 week period.

How to do it

Commercial projects are those in which students undertake a piece of work which is suggested by, and done for, a local bioscience company. They usually involve some form of market research for a new product, or a new market for an existing product, research on potential competitors, or the impact of new regulations on manufacture/marketing. For example, one project researched the market for two new herbal medicines; another resulted in the formation of a database on companies involved in biological defence; and another student prepared a dossier for the registration of an existing product under new EU regulations.

Each student has a company sponsor who guides the research, and provides a detailed plan of what is required by the company. They usually meet the student at the beginning and end of the project, and maintain contact in between by phone/Email. The student does most of the work in the University but can visit the company as and when required. In addition, the student has an academic supervisor who is responsible for all the assessment of the project and for validating the underlying science. The project report is written in two parts:

- A standard Honours project report, in the usual format of Introduction, Methods, Results, Discussion, Conclusion and Bibliography (which is assessed by the academic staff supervisor)
- An accompanying technical document which becomes the property of the company sponsor.

The student undergoes a viva by academic staff and the company mentor is asked to provide a written report on the performance of the student which is reflected in the final mark awarded.

Advice on using this approach

i) Ensure the projects on offer represent the appropriate range of biological disciplines

The commercial project scheme has benefitted enormously from the support of a full time Work Learning Officer (employed as part of the SHEFC funded Aiming University Learning @ Work programme, www.gla.ac.uk/services/careers/academicstaff/aulw/), who has greatly expanded the number and range of companies willing to take part in the scheme, such that the projects on offer are attractive to students. This has been achieved by attending networking events, liaising with Government Enterprise initiatives and directly contacting local companies.

ii) Prepare students appropriately with an introduction to business.

It would be unrealistic to send bioscience students with no training in business techniques out to companies and expect them to do a good job for them. Hence all students who opt for a commercial project take a 2 week intensive Level 4 course, called Business and Biosciences, prior to their project. The course runs for 5 days a week, for 2 weeks, from 9-5 and is held in week 0 and 1 of Term 1.

The course provides the students with the necessary knowledge and business skills to undertake a piece of useful work for a company. The course covers business planning, finance, marketing, presentation and culminates in the students (in teams) preparing and presenting a business plan (Dragon's Den style) to a panel of would-be investors (the academic staff involved in the course and the company sponsors). This is the first meeting of the company sponsors with their project student. The course is very interactive, with a mix of theory and practice and is taught by a mixture of University staff involved in the Enterprise schemes, and from the Department of Business, plus outside experts — a local businessman and other experts in the field of marketing. Scottish Enterprise offices in Glasgow city centre act as host for 2 days and the course also involves a visit to a bioscience company.

Although the course is a requirement for commercial project students, it is also open to all other Level 4 students as one of their option choices, and has proved popular. When asked why they chose it, students typically respond along the lines of "sounded interesting and relevant to what they hoped to do after graduation" to "wanting something different on their CV". The student feedback on the course has been most gratifying. From initial panic at being "outside their comfort zone", and being really pushed with tight deadlines such that they worked together all day and arranged evening sessions as well, they all reported a great sense of achievement and said that the experience had really boosted their confidence.

External company sponsors who attended the final presentations were also most impressed, and the students really valued their involvement and their opinion. The students preparing for their commercial projects said that the experience gave them a real feel for how business is conducted in a commercial setting.

Troubleshooting

As highlighted earlier, the recruitment of bioscience companies willing to take part in the scheme was very time consuming and was the major hurdle in the beginning. It is doubtful whether the academics involved could have found the time to do this. However, once a database of potential companies was established, the further workload was much reduced. The scheme has a high profile via the University website, and hopefully word will spread amongst the bioscience companies in the area and more will be encouraged to become involved.

The recruitment of the students proved difficult at first, as each degree programme matched students to projects in slightly different ways and at different times in the session, so that a coordinated response was not always achieved. The students are most persuaded to try this type of project by peer recommendation, and we have organised for past students to talk to prospective fourth year students about their experience. This is very useful as the students so far have been positively evangelical about the course/projects. This was exemplified at their willingness to become involved in research undertaken as part of the AUL@Work Programme.

Another possible drawback to the commercial projects is the requirement for the students to take the Business and Bioscience course as one of their four Level 4 options. Some degree programmes are more prescriptive as to which options the students can take, and some Level 4 Course heads would prefer their students to take 4 courses in their subject discipline. However, the students on the course so far have more or less made the decision to move out of 'pure science' and it could be argued that to give them this extra breadth to their degree course is the most appropriate choice for them.

Does it work?

The commercial project scheme and the Business and Bioscience course has benefitted because the students participating are to some extent self-selecting — very motivated, they have often taken part in student enterprise schemes previously, and they have actively chosen to use and apply their scientific background in a commercial setting. They see the course and the chance to work for a company as something which will definitely help them in their future careers. This year, one of the students undertaking a project has been offered employment by her sponsoring company, after just 6 weeks working for them.

The companies also benefit by having a piece of work done for them at no cost — a 'free pair of hands', with the added benefit of fostering links with their local University. Most of the companies involved are small, and the projects they offer are work which they need done but are often constrained from completing by lack of resources. So the association is mutually beneficial.

One company that had been involved in the commercial project scheme from the very beginning was Bioforce (UK) Ltd, a biotechnology company employing 88 people and producing and selling herbal medicines and related products to health food shops and other outlets throughout the UK. This is the company that is visited during the course and within the visit the students receive a session on Good Laboratory and Manufacturing Practice from company staff. The

Project Manager, Dr Mark Cole, in an interview about the scheme in the Spring 2007 edition of Nexxus News, gave a sponsoring company perspective:

We suggest a project, meet with the student for a preliminary briefing, and then the student works independently for about 12 weeks, with occasional phone or email contact. The student then produces a fully referenced report of about 10,000 words. Apart from the time spent interacting with the student, there is no cost to us involved. These reports are invaluable tools in deciding on product development — we don't have the resources for our own staff to do these in depth studies and the students' contributions represent a real added value to the company.

One of the students involved in the scheme, Kate Macfarlane (Hons Biochemistry 2001-2005) gave her reflections:

My first degree was Biochemistry but by the end of third year, I knew I didn't want a laboratory based career but still wanted to use my scientific knowledge. So I leaped at the chance to do a commercial project for Bioforce. My project involved researching the market potential in the UK for extracts from the Neem tree as potential insecticides. I produced a report which formed the basis of the company's dossier for registration of a neem pesticide in this country. I felt that I had made a major commercial contribution and that working on this project has given me the experience and confidence to plan my future career.

Commercial projects and an associated training course (as either part of the formal course structure or in addition) could easily be adapted to suit other universities' degree programmes. The fact they are both credit and assessment bearing means that students take them seriously, and they are not seen as an added extra but an integral part of their degree programme.

Further developments

We are constantly refining the 'Business and Bioscience' course to make it Enquiry Based Learning-led (and have a student doing the research on this as his commercial project for 2007-08; for details see www.bioscience.heacademy.ac.uk/ftp/events/scothe07/EBL.pdf). We have also expanded the range of outside experts involved. The number of projects on offer has increased and we are endeavouring to make them attractive to students from all bioscience disciplines. In the future, we need more education, of both staff and students, as to the benefits of commercial projects as part of the overall thrust to embed work related learning into the curriculum and enhance students' employability.

As the Universities Scotland (2003) Getting Ready for Work document states: "What graduates need is to be employable; what employers need are employable graduates … An understanding of the world of work and awareness of business (public as well as private) is desirable".

Final year research projects in communicating science

Dan Lloyd

Background and rationale

We offer a range of final year project types to undergraduate students in the department, who are studying for degrees in Biomedical Sciences, Biochemistry, Biology and Forensic Biology. While laboratory-based projects remain the most popular, we also offer projects involving non-laboratory based research training: literature-based dissertation projects, computing-based projects and business plan projects for those who wish to gain valuable transferable skills in addition to experience of cutting-edge scientific research. Recognising the need for effective communication of science and seeing an opportunity to embed science communication activities and public engagement into the undergraduate curriculum, we added 'science communication projects' to the portfolio in 2004 to provide students with a more challenging outlet for those with an interest, enthusiasm and aptitude for communicating science to non-scientific audiences (Lloyd, 2007; 2006). This has particular resonance today in a period of rapid scientific progress but declining interest in science among the general population. It is also congruent with a number of initiatives from Research Councils and charitable organisations to promote public engagement.

In addition to the generic learning outcomes for our final year projects concerning research skills, appraisal of literature, critical thinking, and making and defending scientific arguments, we have specific learning outcomes for each of the project types. Successful completion of a science communication project should lead to:

- An in-depth understanding of an advanced research topic;
- An ability to write in clear and lucid scientific style;
- An ability to simplify complex scientific information;
- An appreciation of how knowledge must be adapted to suit the audience; and
- The ability to make science interesting, accessible and fun.

The learning outcomes are met and assessed by the completion of three specific elements:

- 1) A dissertation, 6,000 words long, reviewing in-depth the scientific literature related to the project.
- 2) An oral presentation, in which this research, or aspects of it, are presented in a way that is interesting, accessible and inspiring to a non-scientist. This element of the project is delivered and assessed in local schools.
- 3) A communication piece, which can be a magazine article, interactive CD-ROM/ website, museum display or other piece that communicates the science in a different media.

How to do it

Preparation

Before embarking on such projects, the project coordinator needs to engage with colleagues to ensure science communication projects will be fully embedded within the department and not marginalised. Each student needs a supervisor, so there needs to be enough staff willing to supervise them. Introducing them at Kent wasn't a problem — colleagues recognised science communication was important and was lacking in other parts of the curriculum, and the final year research project offered an extended period to engage fully with this important element of scientific activity. From a purely practical point of view, communication projects are a lot less intensive in terms of supervision than laboratory-based projects, and also less costly for the department as a whole — a big selling point for time- and cash-pressed academic staff! Guidelines and mark schemes need to be written to inform both students and supervisors (see accompanying material). Quality assurance procedures may vary across universities, but at Kent it involved a minor change to the module specification and Faculty level approval for additional learning outcomes prior to running the projects for the first time.

Timeframe

Project selection and assignment takes place in the first 3 weeks of the autumn term. The communication projects usually concern a topical, controversial or poorly understood area of science, and past examples have included the use of stem cells in medical research, the use of performance enhancing drugs in sport, and the potential impact of biological weapons. The titles and abstracts can either be put forward by the project coordinator or, preferably, prepared by potential supervisors before circulation to students. The remainder of the term can be used for reviewing the literature, although the main body of the project takes place in the 12-week Spring term. The deadline for handing in the dissertation and the communication piece is the last day of the Spring term, while the talks take place in mid-March — we coincide our talks with National Science Week to generate added publicity in liaison with the University Media Office. This timeframe works well within our 12-12-6 week term structure but may need adapting in other departments.

Student support

We advise weekly meetings with supervisors during the spring term (which students are responsible for organising), and these are supplemented by two student workshops. We advise students to begin working thoroughly on the dissertation, which accounts for 40% of the project mark; aside from this being a high proportion of the project marks as a whole it is important that students achieve a depth of understanding on the subject and that this in-depth knowledge underpins the 'science communication' elements of the project. The workshops help students to develop strategies for communicating science by dissecting their own learning experiences, and they leave the workshops with a tangible outcome — a 'checklist' of good and bad practice — which they can apply to their own work projects in describing their scientific research to non-scientists. Within these workshops, the students can put these checklists into practice; they are given examples of challenging scientific concepts and work in groups to develop ways of explaining them to a non-specialist audience using a variety of media. The students leave the workshops fully aware that presenting entertaining and interesting material that does not cover any scientific concepts will not address the learning outcomes and will not lead to a good mark. They are also reminded of the danger that the presentation might unduly distract from the two other elements of assessment, and the need for rigid time management throughout the project.

In the week before the oral presentation assessments take place, we arrange peer review sessions in which students can present to fellow communication project students, as well as those undertaking other project types and students from other disciplines across the university. These sessions in particular are very much appreciated by the students as it gives confidence in presenting skills as well as support and guidance from a friendly and non-judgemental audience.

Presentations

We hold our oral presentations approximately 9-10 weeks into the project term to coincide with National Science Week (typically mid-March). Presentations are delivered in local schools to classes of students ranging from 14-18 years old. Schools are a convenient outlet for the oral presentations as they can provide a ready-made audience relatively easily; furthermore, they represent an important audience for the University in terms of outreach. We have our own contacts in schools, but also work with the University Partnership Development Office responsible for promoting widening participation which has strong links with target schools. Thus the presentations are undertaken in a range of environments, from selective grammar schools to those who do not traditionally send students to university. Students speak for 15-20 minutes, with the aid of PowerPoint and any appropriate props, after which the audience asks questions. Typically two presentations are undertaken within a 1 hour lesson, and the teacher acts as a co-assessor of each speaker.

Advice on using this approach

In designing communication projects, we were aware that external examiners would be interested in ensuring parity with other project types. It is therefore important to have an element of the project that ensures students are assessed on their ability to undertake in-depth research. The dissertation addresses this need and is designed so that students have to engage with research literature in the same way as other project students. It also prevents the perception from students and staff that a communication project might be an easier option than, for instance, a laboratory project.

The initial approach to schools can be time consuming and the teachers themselves are driven by their own timetable and learning agenda. They sometimes need convincing of the value of setting aside valuable lesson time to allow our students to speak to present their work to the class. However, once they have participated they are usually very willing to host the presentations again as it provides clear added value to their own pupils' learning experience.

As a safeguard against the negative impact of uncommitted students being given a platform in the schools, we have had to develop an 'in house' assessment strategy for the presentations, undertaken by two members of academic staff. Students are monitored by supervisors during the project and a decision as to whether students give their presentations in house is taken a week prior to the school visits.

Troubleshooting

There is a danger the communication piece using a different form of media than the oral presentation, can become an afterthought and does not get the attention it warrants. This is often where students lose sight of the learning outcomes and the fact the piece must contain scientific information that is 'translated' to make it more engaging and understandable to non-scientists. We are working to try to resolve this issue by providing suitable advice and guidance, but may ultimately need to resort to having more rigid guidelines relating to the use of a single type of media (for example, a magazine article) rather than allowing students to have more free rein in their choice of media; we have received posters, CD-ROM material, websites and even T-shirts for this part of the assessment, with mixed success in terms of marks awarded to the students.

Does it work?

Minor problems aside, we think it works on a number of levels. On a purely departmental level, it is logistically very difficult to accommodate increasing student numbers in laboratory-based projects. The communication projects have relieved a great deal of pressure by providing an attractive alternative that offers an equal learning experience to students but which places less demands on departmental infrastructure.

For the students that participate, the projects provide an outlet for developing skills that are useful in a variety of professional settings and opens doors to a range of careers that would otherwise be difficult to gain access to. For this reason, it has attracted students with diverse experience; those who do not wish to work in a laboratory after graduation, those who have previously undertaken laboratory research during a sandwich year or vacation placement; and those who aim for careers that have less to do with science but a lot to do with communication. A number of students have indicated how formative the communication projects have been in developing exciting careers. Feedback from the students has been overwhelmingly positive, and they clearly gain a lot from presenting their work to an unknown and potentially intimidating audience.

The response from both school pupils and teachers is similarly positive. It allows the teachers to extend their pupils' knowledge and aspirations without spending a great deal of time researching new topics beyond the national curriculum. Exposure of pupils to university students is a particularly powerful element of the scheme, since the majority of students presenting are only a few years older than the school pupils. The fact they appear so well-informed and engaging is clearly inspiring to the pupils, and is particularly so in the schools with low progression rates to higher education. There is usually an opportunity after the presentations for the students to mix with the pupils and talk more informally about life at university, studying science, etc.

Further developments

We have extended the scheme so the students have other opportunities to present their talks. After end of year examinations some students present their talks again at a public showcase event, which has become a fixture of the university calendar. We work closely with the Partnership Development Office to identify opportunities for our students to represent the university, within schools and colleges, local community groups and adult education networks. These offer paid working opportunities to our students and additional experience for presenting to diverse audiences.

We have also obtained funding to pay students over the summer vacation to generate 'teacher resource packs'. These packs link the content of their projects to elements of the national curriculum and provide teachers with PowerPoint presentations, question sheets, practical exercises, lesson plans and reading material. The hope is that this will allow teachers to deliver inspiring, cutting edge scientific research in schools to illustrate core elements of the national curriculum, without having to undertake extensive preparation. The first Resource Pack has been prepared and we are hoping several students will participate each year.

We are setting up an MSc in 'Science, Communication and Society'.

Accompanying materials

The accompanying website to this guide (www.bioscience.heacademy.ac.uk/TeachingGuides/) contains the following additional material:

- Guidelines and mark scheme for communication projects.

Implementing the Undergraduate Ambassadors Scheme (UAS) as a final-year project option

Martin R. Broadley

Background and rationale

In 2005 The University of Nottingham's School of Biosciences decided to participate in the Undergraduate Ambassadors Scheme (UAS).

The UAS (www.uas.ac.uk) is a national scheme which provides a framework for awarding academic credits to undergraduates for engaging with schools. The primary aims of UAS are to provide:

- Undergraduates with key transferable skills;
- Undergraduates with subject-specific skills, gained from communication of their subject;
- Undergraduates with encouragement to consider teaching careers;
- School pupils; and
- School teachers with additional classroom support and access to University resources.

In terms of academic credits, university departments and tutors adapt the UAS to fit their requirements based on general guidelines and support documentation. Participating students complete an initial day of training in their university and are then placed in a local school, where they work closely with their teacher/mentor to provide teaching and practical assistance and conduct special projects. UAS students can work with any age group according to the wishes of the university department. Students are assessed on a portfolio of evidence including an end-of-module presentation and written report.

Early decisions

Initial meetings with UAS staff, former UAS students and colleagues left me feeling a mixture of excitement and panic! I was excited to hear of the rewarding experiences of pioneer UAS participants, but daunted by the challenge of designing a new curriculum route. I was also concerned student UAS workloads — and the academic and administrative support required — could easily become incommensurate with running the UAS as a 10-credit Year 2 module (the most popular structure at the time). I therefore developed UAS activities in two-stages, with the UAS-proper be offered to final year students as an alternative honours project. This was ambitious as our final-year projects are worth 40 credits (23.3% of the final degree mark). I also designed a new 10-credit Level 2 module, Communicating Biosciences, as a prerequisite for UAS.

How to do it

Stage 1: Communicating Biosciences module

This module introduces students to the concepts of the UAS but has no school placement. It is generic to the School of Biosciences and is open to all BSc students. The module has proved extremely popular: numbers have grown to 95 for 2008/09.

The learning outcomes map to 18 of the 43 specific skills in the Biosciences Benchmark statement (QAA, 2007b) and in general are to:

- Gain an understanding of conceptual issues in communicating biosciences;
- Gain confidence in communicating their subject;
- Develop technical, organisational, interpersonal, and reflective skills;
- Understand how the needs of individuals within a diversity of audiences can differ;
- Develop the skills to engage people with the biosciences;
- Acquire, interpret and critically analyse primary research material; and
- Critically assess their peers' ability to acquire, interpret and communicate complex ideas.

Module activities

Activities include lectures, tutorials and interactive workshops on topics such as:

- Advice and guidance on the importance of reflective learning skills and the maintenance of a reflective diary;

- Principles of written and verbal communication to informed and lay audiences; and
- Skills in word-processing and other IT skills.

Module assessment is 100% coursework, including production of newspaper articles, peer-marking, school lesson-plans which map to the National Curriculum, and a reflective learning journal.

The learning journal

This critical component of the module was developed by Dr Martin Luck and is based on weekly (anonymous) online submissions of reflective thoughts and activities, and a (non-anonymous) final journal submission. To maximise weekly submissions, final (non-anonymous) journal submission marks are multiplied by the proportion of weekly submissions. Nine of the 49 participants in 2007/08 progressed to UAS.

Stage 2: The Undergraduate Ambassadors Scheme — proper

Final-year UAS activities were first approved for our students in 2007/08 under the existing Biosciences honours project module codes. The justification was that we considered the UAS to be academically equivalent to laboratory or literature-based final year projects. The aim of all our 40-credit final year BSc (Hons) projects is to provide students with an opportunity to undertake a programme of original research in an aspect of biological science. Project results are presented in a project talk and dissertation.

Research skills developed within UAS projects relate to communication and pedagogy rather than the technical skills required to solve a specific scientific problem per se. The focus of UAS projects includes:

- Consideration of learning and teaching strategies from the perspective of different participants (school pupils, university students, school teachers);
- Active participation in school-based activities;
- Critical reflection; and
- Quantitative analysis of the effectiveness of the research project.

UAS assessment

The mark allocation framework is identical to other final year project modules: Quality of UAS-based research activity (30%); Dissertation (30%); Dissertation (second marker; 30%); and Oral presentation (10%).

The quality of UAS-based research activity is judged by the Biosciences UAS Co-ordinator.

UAS students submit a dissertation (ca 10,000 words, excluding references and appendices) which is independently marked by two academics. The mark allocations for the dissertation in 2007/08 were: Abstract (5%), Literature Review (25%), School Placement Report (i.e. a description of teaching activities/lesson plans, quantitative analyses etc., 25%), Retrospective (25%), Written Expression (10%) and References (10%).

UAS activities

Literature Review

Students are advised that their UAS project is a rigorous academic exercise and their Literature Review should be as methodical and rigorous as for a laboratory or literature-based dissertation. Students meet regularly with their supervisor to discuss the structure and content of their Literature Review, which comprises ca 4,000 words excluding references and must include specific aims and objectives. Students are advised to introduce the UAS and to consider how its aims and objectives relate to learning and teaching theories in the pedagogical literature. Students are expected to identify appropriate literature (including education papers and books) and web-based information, and compile a cohesive overview including a critical appraisal of sources.

School Placement

UAS students must take ownership of their relationship with their host school at the earliest opportunity. Thus, placement terms are negotiated between the school and the UAS student, who is encouraged to record this interaction in their Retrospective. Prior to their placement, students are inducted by the Biosciences UAS Co-ordinator. This includes a briefing on their placement school and provision of Criminal Records Bureau (CRB) forms. Students submit their forms in early-October and contact their school within one week of obtaining CRB clearance. Students are expected to visit their designated school prior to the school October half term and this visit may include an observational session. During the school half-term holiday UAS students attend induction/training sessions organised by the WPU (generic training for student ambassadors) and the PGCE Science Team (introduction to science teaching and the National Curriculum). A School Placement Plan is developed following negotiation between UAS students and the school. Placements consist of a minimum of 10-12 sessions (each of 3-4 h duration excluding preparation time) in their school. These placements are ideally arranged into two discrete blocks before and after Christmas. A typical School Placement Plan might develop thus: (1) Observation, (2) Classroom Assistance, (3) Lesson Hotspots, (4) Lesson Plan and (5) Lesson Delivery. School Placements may also involve extra-curricular activities. The School Placement Report is a core part of the dissertation.

Retrospective

The Retrospective is a reflective document, of ca 3,000 words. It is an important element of the student's project work, providing a synthesis of the weekly Learning Journal entries, and including thoughts about activities and progress on the UAS. The Learning Journal is used to describe events, lectures, discussions, study tasks, ideas or feelings. Entries can be substantial or small, significant or trivial, and can be written immediately (i.e. at the time or shortly after the event) or over the longer-term (e.g. after looking back over a period of time). The Learning Journal is more than just a diary (i.e. a list of events, kept as a reminder or a record) or log-book (a detailed record of events, facts or data), although it may contain elements of both. The Retrospective should be used to prompt new ideas and allow the student to identify how their knowledge, skills and understanding have developed and how their views have changed. It should also include critical reflections on how the learning and teaching strategies discussed in the Literature Review related to participation in the school placement.

Advice on using this approach

Securing UAS school placements

A daunting aspect of implementing the UAS was to establish contacts with local schools. Staff in our WPU provided contact details of potential school partners. For 2007/08, three students expressed a preference for secondary placements, and one for primary. Placements were established in September 2007 for placements starting in October 2007. I was tremendously impressed by the willingness of local schools to become involved and was able to secure the support of four schools after visiting them to discuss the UAS scheme. I strongly recommend using a personal approach to recruiting partner schools. For the nine 2008/09 placements, I had visited and confirmed six schools by early-July 2008 and await meeting dates with two schools and a Further Education (FE) college as we have a student who has expressed this preference which we aim to accommodate.

Does it work?

My experience of implementing the UAS as described has been overwhelmingly positive. The UAS office provided excellent support during the early curriculum development. The support of our Learning and Teaching Committee was essential for guiding curriculum development to the satisfaction of the five Divisions within Biosciences. I also found the support of the WPU and PGCE teams invaluable. Engaging potential partner schools has proven less challenging than feared and forging new interactions with local teachers is fast becoming a highlight of my teaching activities. UAS partner schools complete post-placement forms, and the feedback has all been extremely positive. For example, one teacher mentor writes, "[the student] was very enthusiastic and keen to learn. He ran a lower school science club which the students loved! He worked with a difficult Year 11 class and the students in there respected him and liked him … I believe he has the potential to be an excellent teacher". From the students' perspectives, the experience has been extremely beneficial. One student writes, "[the UAS] has given me an immeasurable gain in terms of my understanding and learning … [the UAS is] a sound introduction to the teaching profession, while providing key skills that can be very attractive to other employers." Another writes, "The UAS project has been an inspiring learning curve. Over the 20 weeks of organising, attending and reflecting upon the school placement I have made steady and some surprising progress with my communication skills."

Troubleshooting

During the 2007/08 session, it became apparent the single biggest issue in running a 40-credit UAS scheme is that some academics are reluctant to accept it is academically equivalent to a final-year laboratory based project. This is not a new issue as academic opinion differs on many final-year projects with a strong focus on communication. However, this is a minority view. In my opinion the UAS is entirely appropriate as a final-year honours project and its academic equivalence is clear from the dissertations produced (for example, see accompanying website). To allay some of these concerns and to ensure students are being judged equally, future students will be asked to include a specific lesson plan which relates directly to their own degree subject within their Dissertation, irrespective of whether they were able to deliver this during their placement. The marking scheme will be adjusted accordingly.

Further developments

No specific problems have yet arisen. However, due to the increase in student numbers we will run UAS under a single module code in 2009/10, so we can:

- 1) Run a separate UAS undergraduate symposium to ensure consistency of marking and engage more colleagues.
- 2) Pursue formal accreditation of UAS for specific degree courses.
- 3) Appoint a new external examiner with specific responsibility for UAS and Communicating Biosciences.
- 4) Better advertise the UAS to prospective undergraduates.

Additional materials

The accompanying web site to this guide (www.bioscience.heacademy.ac.uk/TeachingGuides/) contains an extended version of this case study and the following additional material:

- UAS guidelines, 2007/08 (includes qualitative assessment criteria);
- An example UAS project dissertation (Rosie Honeyman-Smith, BSc Hons, Nutrition, 2007/08); and
- Module handout for Communicating Bioscience.

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A virtual laboratory for Bioscience e-learning projects

Carol Wakeford and Ian Miller

Background and rationale

This case study presents a six-step framework for a course to train and support final year students who opt for e-learning projects. Students plan, design and develop e-learning resources that support the undergraduate curriculum and contribute to the Faculty's overall e-learning strategy. The course aim is to provide students with a similar experience to their laboratory counterparts, and develop skills associated with the scientific method, such as analysis, evaluation and critical thinking.

In the Faculty of Life Sciences (FLS) at The University of Manchester, the majority of bioscience final year projects are conducted in a traditional laboratory setting where students work independently under the supervision of a member of staff. Increasingly, however, non-laboratory projects are a popular alternative. This provision is driven by demand from a significant minority of students who are attracted by the opportunity to work away from the laboratory, as well as by pressure on staff to supervise relatively large numbers of students with somewhat limited resources. The challenge is to ensure such projects are scientifically rigorous, and that laboratory and non-laboratory students have a similar experience of project work. We have around 30-40 students per year, from a wide range of disciplines from Anatomy to Molecular Biology, who undertake e-learning projects. They are supported in an 'active-learning' training course that develops project skills, and they design, construct and then evaluate e-learning resources, such as data-driven activities, or virtual experiments to support laboratory classes, for example. Students use a range of software and technologies to develop their projects, as well as a variety of learning designs to promote enquiry-driven learning. We hope this approach will enhance and demonstrate the project students' problem solving and critical thinking skills as well as those of their target audience.

How to do it

Six-Step Course Framework

The six-step course framework has an enquiry-driven focus based on the 'language of inquiry' model (Justice *et al*., 2002) to promote self-directed learning, critical thinking and collaborative learning. Further, the framework aims to improve the student experience of the online learning environment by focusing on four key areas identified by Boud and Prosser (2002) as being essential for enhancing student learning:

- Learner engagement;
- The learning context;
- Challenging learners; and
- Provision of practise.

1. Course Environment

The compulsory course takes place within a computer cluster and uses blended delivery by e-learning staff comprising 15 face-to-face sessions over a twelve-week period spanning Semesters 1 and 2. In Semester 1 the focus is on learning project-related skills whilst the students write a scientific Literature Review, and Semester 2 comprises actual project work accompanied by workshops and presentations on statistics and report writing, for example. Additional workshops are held according to demand. The course is also accessible online within our VLE. Each session has an associated task, on which students report in online discussion forums.

2. Student Support

The project supervisor delivers academic advice and guidance on scientific content, and the e-learning team (Course Coordinator plus one or two learning technologists) are course tutors, lecturers and facilitators within the discussion groups.

3. Course Content

Course sessions cover a range of topics including the use of software, copyright issues and statistical analysis. We follow Strickland's (date unknown) ADDIE instructional design principles (Analysis, Design, Development, Implementation and Evaluation) to guide students through the process of product development. Planning the resource in the Design phase is crucial, and students must produce a storyboard and discuss their individual requirements with the e-learning team in 1-to-1 meetings, who will advise on the most appropriate software for the job.

4. Focus on Enquiry and Active Learning

- Students select their topic and target audience with discipline-based advice from their supervisor.
- They formulate a hypothesis to test. In its simplest form, this might be based on whether the resource improves learning; students might compare test scores of their target group before and after using the resource. Alternatively, students might investigate the efficacy of formative assessment by using control and test groups, or correlate performance with variables such as gender or A-level point score.
- Students are encouraged to use a problem-oriented approach, using scenario- or data-based formats. They use a variety of software packages including web authoring tools such as Wimba Create and Dreamweaver, as well as Flash, Macromedia Breeze and various assessment tools, plus audio and video technologies and editing software.

5. Communication and Collaboration

Central to the framework is the 'virtual laboratory' where groups of students (7-10 students) communicate, collaborate, and participate in peer review (Semester 2) in discussion forums to troubleshoot design and usability issues. The intention is that these project groups mimic the social interactions students might experience in the laboratory and form social networks for mutual support (Topping, 2005), as well as develop critical thinking and evaluation skills by peer review (Race, 2001).

6. Assessment

We aim to engage students in the course by constructive alignment of aims, online activities/course content, and assessment (Biggs, 2003). Online activities are relevant to the project endpoint, and assessment is linked to both the performance of students during their project, as well as to the final product and report.

Assessment of e-learning projects follows the same guidelines and procedures as other final year projects with the supervisor as principle marker. Scientific focus is maintained by production of a 10-credit literature review based on the bioscience underpinning the resource, which is submitted in advance of the project work. The project proper counts for a further 30 credits and equates to around 300 hours work (including training sessions). The mark has 3 components:

- 20% for project performance;
- 20% for the e-resource; and
- 60% for the project report.

Supervisors are able to search for and access individual student contributions to the organised tasks and discussions within the VLE and use this information as a qualitative measure of the project performance. They are also provided with compiled transcripts of their student's contributions.

Student projects

Students employ a variety of project designs:

- **Linear resources:** allow the user to progress through a linear sequence of information, punctuated by interactive and assessment activities. This is useful for problem-solving activities where prerequisite knowledge is needed to move to the next stage of the problem. A resource on 'Molecular Cloning' designed to complement a Second Level laboratory class, for example, contained sequential information (figures, animations and text) and activities (such as searching databases and manipulating information) to enable the user to clone the Human insulin gene into a vector.
- **Non-linear resources:** Some students use innovative software, Scenario Based Learning Interactive (SBLinteractive, 2007) to design multi-path problems, which may have one or more final solutions. The user explores different possible routes through the content. The SBLi interface allows the user to visit different locations, such as a virtual laboratory, or clinic, and perform actions associated with that location, which then enable the user to progress to another stage of the investigation. Progression to the correct endpoint is dependent on the user successfully completing various pre-requisite tasks/actions.
- **Integrated resources (within the VLE):** these enable groups of users to interact via discussion forums, a key feature of enquiry-based learning. Thus, it is possible to move away from simple online assessment activities, to a forum where student users can present views based on critical analysis of information, such as ethical or data-based evidence. The process of investigation becomes group-based and more open-ended. Enquiry-based formats for group work can also be created with designs such as WebQuest (2007).

Advice on using this approach

- Market the course and projects to staff and students in order to recruit individuals interested in e-learning, rather than those who simply want to escape the lab!
- Report writing guidelines need to be clear so students understand how to present their project work, and we also provide criteria for assessment of the e-resources.
- Students tend to be over-ambitious and/or want to reproduce their literature review on the web. Encourage them to focus on one aspect and develop a problem-oriented approach to their topic.
- Remind students to maintain regular contact with their supervisor; the course coordinator cannot be responsible for 30-40 projects!
- Resources are unlikely to compete with commercially available packages but have the advantage of being tailored so they can be incorporated directly into course units.

Troubleshooting

- Non-participation of some students in online discussions is almost inevitable; advice is to review discussions weekly to see who is not participating and post 'reminder' messages to 'scaffold' and focus the discussion (Salmon, 2000), and email 'quiet' students.
- Time management is a problem for many students; provide deadlines to help them complete work on time (e.g. for posting plans online, constructing a Homepage, evaluating their resource).

Does it work?

- Annual evaluation of the programme over the past three years has demonstrated consistently high student attendance at face-to-face sessions and participation in the online course, as well as high level of satisfaction with the programme overall.
- Over 80% of students liked being a member of a project group, and found that working in project groups was helpful or very helpful.
- Students found that belonging to project groups facilitated socialisation and promoted participation in online tasks, as well as acting as a forum for support. They used the discussions to ask technical questions, make general enquiries, and share ideas and resources. Peer review was helpful to most students by providing feedback on project content, and in evaluating design features.
- Students used a range of strategies and designs to fulfil similar goals in creating e-learning resources. They demonstrated a range of skills traditionally associated with the scientific method, such as formulation of hypotheses, planning and experimental design, collecting, analysing and evaluating data, and communicating scientific ideas and results. The distribution of marks and degree classifications was similar to those of laboratory-based students, demonstrating that overall quality of project work was maintained.
- Our virtual laboratory offers many other advantages to students over more conventional laboratory projects; materials can be accessed remotely and at a convenient time; students can work through them at an appropriate pace, and communicate asynchronously and remotely. This is particularly important with increasing diversity in students, who may have different academic backgrounds, language issues, or family or employment commitments.
- The cost per student is minimal since software resources may be shared and recycled. Further, the training course run by one or two members of staff means that individual project supervisors do not have additional workload; indeed, supervision of more than one e-learning project student is more time effective because the students support each other.

Additional materials

The accompanying website to this guide (www.bioscience.heacademy.ac.uk/TeachingGuides/) contains an extended version of this case study and the following additional material:

- Full details of the Course sessions, associated learning outcomes and tasks.
- Examples of Student Projects.

Examples of student projects can be viewed at: www.ls.manchester.ac.uk/undergraduate/courses/modules/elearning/elearningprojects/ (under construction).

Research for real - an intensive Honours research project

Mark Huxham

Background and rationale

In the School of Life Sciences at Napier, we have run a final year honours research project in all our biological science programmes for many years, for ~ 100 students per year. The following distinguishing features characterise our final year project provision:

- **Size** the module is worth 60 credits, contributing one third of the honours degree marks, and runs for the whole of semester 2 in the final year. Because the students have finished all other assessments (including any 'final exams', which are taken at the end of semester 1) they can thus focus entirely on their research, and have sufficient time to conduct a significant piece of work.
- **Choice** students are offered a wide variety of potential topics from which to choose, covering the whole range of the biological sciences. They are also encouraged to suggest their own research ideas and to discuss these with appropriate potential supervisors. All projects must involve the collection of original data (either primary or derived); they cannot consist only of literature reviews. But beyond that constraint the methods chosen are very varied and can include qualitative as well as quantitative approaches. Hence projects may range from interviewing creationists to isolating salmonella and from flamingo behaviour to nanotoxicology.
- **Authenticity** because the project is such an important part of their degree, and students commit significant time and effort, the resulting research is often of a high standard. This is demonstrated by the frequency with which student projects are published in peer-reviewed journals.

As far as possible, the project represents 'research for real'; carefully planned but opportunistic, full of false starts, frustrations and triumphs, driven by curiosity but controlled by ethical and health and safety guidelines, and constrained by money. As such we see it as a key vehicle for the development of all those 'research skills' that are also core employability skills: time management, independence, self-motivation and organisation, synthesis and analysis of diverse information, ethical sensibility and written communication.

More formally, the learning outcomes are to:

- Derive a project proposal, based on identification and review of relevant literature, consideration of experimental design and statistical analysis, and safety considerations.
- Develop a programme of independent research, using appropriate investigative techniques and research tools.
- Organise and analyse data derived from the research in order to test appropriate hypotheses.
- Synthesise results and present them in the context of previously published information, as part of a detailed scientific report, to appropriate standards of presentation.

How to do it

Early preparation

Because our students need to get started fast on a big piece of research, it is important they know the basics of literature review and retrieval and study design beforehand. Elements of these skills are developed in various modules throughout the programmes, but all students take a core 'dissertation and statistics' module at level 9 ('3rd year' of a 4 year Scottish degree), in which they produce a literature review on a topic of their choice, which ensures they all have these skills.

Choice of project topic

Students are encouraged to begin thinking about project topics at level 9, and can informally approach potential supervisors at any time to discuss ideas. Staff provide a list of potential projects at the start of semester 1, level 10 (4th year), and students choose a selection of potential topics and discuss these with the relevant supervisors (along with their own ideas if they have them). They are expected to confirm a project choice and supervisor by mid-semester.

Project plan

By the start of semester 2 level 10 (in February), students have completed all other assessments and focus entirely on their project work. They have two weeks to produce a fully referenced project plan. This includes details of the background of the proposed study, procedures to be used, experimental design, statistical methods to be employed, safety considerations, and a project time plan. The plan is marked by the supervisor (and is worth 10% of the total project marks). Detailed feedback is provided to the student within 2 weeks of submission, thus ensuring there has been scrutiny of the project design and methodology.

Where relevant (particularly when working with humans or human material) students also complete a form for rapid independent scrutiny by an ethics committee.

Project execution and supervision

Students have ~10 weeks in total for their projects. During this time they are expected to communicate regularly with their supervisors; weekly or fortnightly meetings are normal, although considerable flexibility applies depending on the nature of the project. For example, some students conduct fieldwork abroad, and may thus have additional supervision arrangements where they are working, whilst others are in daily contact with supervisors while working in their laboratories. All students are encouraged to submit drafts of their thesis chapters and receive detailed feedback on these. They also maintain a project record book, which includes self assessment of skills developed.

Although students are assessed individually on their projects, they may work with peers during data collection. This can help with health and safety issues and also ensures the generation of sufficient data for some projects. There is a nominal sum of £50 available from the School for each project student – this helps cover small costs such as photocopying and travel.

Project assessment

The total project mark is composed of:

10% — project proposal. Mark given by the supervisor.

10% — project performance. This mark is given by the supervisor on the basis of the student's performance during the execution of the project. It includes aspects such as sticking to agreed meeting times and deadlines, engaging positively with advice and criticism, showing sufficient commitment and initiative and maintaining the project book and skills record. It is included partly as a partial safeguard against those occasions when there is less data collected than expected because of problems beyond the control of the student (such as extreme weather events etc.).

80% — project report. The final report is 10-15,000 words (excluding references) and usually follows the format of a scientific paper. It is marked by the supervisor and a second marker, and reviewed by an external examiner. Some students (particularly borderline cases) have an oral examination based mostly around their reports.

Advice on using this approach

- **Start early**

  You need to begin explaining the project early in the programme — even from first year. Students look forward to doing it, but need time to consider their own topics and arrange logistics. Students are much more likely to suggest sensible topics of their own if they are briefed well in advance.

- **Celebrate diversity**

  Allowing students maximum choice in their topics (within basic constraints) inevitably leads to challenges — such as how to compare work on a microbial genome with interview surveys on attitudes to conservation. But students deserve and relish choice. Many will not go on to do 'standard' biological jobs or research, so where possible their experience of the research project should be relevant to their aspirations. A recent survey of Napier students found that the topic was by far the most important influence on students' choice of project (Alison Craig, pers. comm.).

- **Permit mistakes**

  Your assessment process should allow for genuine mistakes and false starts, giving credit for overcoming these. Whilst giving support and encouragement (and preventing dangerous and unethical practices) supervisors need to allow students freedom, and remember that the purpose of the project is student learning, not the production of research.

- **Make supervisors accessible**

  Students must be able to access their supervisors — so they should guarantee a minimum availability (during 'office hours' for example) and be as approachable as possible.

Troubleshooting

The following issues are raised every year and need careful consideration:

- a) What is 'original data'?
  Our project requires students to collect original data. This is usually interpreted as quantitative (and sometimes qualitative) data generated by standard observational or experimental approaches. But many marginal cases arise. For example, some students use data collected by other people (such as wildlife records from environmental charities) and analyse it; we think this can make a very demanding and useful project, but involves different skills from designing a study from scratch and generates 'derived' rather than primary data. Other students choose to create a resource (such as a web page), in which case they must also collect data such as evaluations of the resource.
- b) Costs and equity
  Projects can be expensive, but the costs vary widely depending on the topic and discipline. Whilst the £50 nominally available for each student may be more than sufficient for an excellent piece of work on the behaviour of crows, it may not cover one reagent in a biomedical project. Students working in more expensive areas rely on pooling resources and benefiting from supervisor's resources, but sometimes this leaves them with less choice than is available for other groups, such as animal biologists.
- c) Parity between supervisors
  The success of a project depends on good collaboration between students and supervisors. Because different supervisors take different approaches (and different projects imply different arrangements) some students may receive more support than others. For example, all supervisors are required to give feedback on drafts, but how detailed this is depends on the circumstances. Whilst diversity of approaches is inevitable (and good), there need to be ways of ensuring fairness between students.
- d) The assessment of 'performance'
  Our system involves a 10% 'performance' mark, awarded on the basis of student conduct during the project. Because this is a partly subjective judgement it is open to bias. Hence it needs to be supported wherever possible with evidence (such as attendance records at meetings, records of advice properly taken etc.).

Does it work?

Student evaluations suggest the project is usually the most valued part of the undergraduate experience. Recent graduates emphasised the importance of the freedom and responsibility involved in building confidence:

> "Undoubtedly the biggest skill gained from my project, was confidence. I had researched a subject, had produced a hypothesis, planned and carried out the piece of work, liaised with staff and fellow students and then produced a thesis. My very own work!!"

> "The fact that the whole project is your responsibility is very challenging, but also makes it an invaluable experience that I will never forget."

They also talked about the importance of having plenty of time to do good research:

> "The whole semester spent carrying out a full-time research project allowed me to apply all of the skills and knowledge I had gained during the rest of the degree program. The project felt like a natural culmination of the all of the teaching and learning we had been through".

> "The benefits of doing this over a whole semester are countless … it was vital that I had plenty time to let my experimental work take effect."

On average, student marks in the project are ~5% higher than in their other modules. We think this reflects the enthusiasm with which most students engage with their project.

Further developments

Project allocation

Currently students choose a topic then approach the relevant supervisor. But if the project is already allocated they lose out. We intend to develop a more sophisticated method of allocation, involving ranked choices adjudicated by a single member of staff, to ensure all students get a highly ranked project topic.

Accompanying materials

The accompanying web site to this guide (www.bioscience.heacademy.ac.uk/resources/TeachingGuides/) contains a downloadable version of this case study and the following additional material:

- The assessment scheme used in marking.

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