BIOSCIENCES FEDERATION

Enthusing the next generation

A report on the bioscience curriculum by a working group established by the Biosciences Federation.

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Recent years have seen a disturbing decline in numbers choosing to study physical sciences, and a move away from core bioscience disciplines. This report explores how more young people might be enthused by, and benefit from, their exposure to biology education. It recommends key changes to the biology curriculum and its delivery from primary school through to university.

The report is also available at **www.bsf.ac.uk/responses/enthusing**

Please e-mail your views and comments on the report to **info@bsf.ac.uk**

The Biosciences Federation was founded in 2002 in order to create a single authority within the life sciences that science and education decision-makers can consult for opinion and information to assist the formulation of public policy. It brings together the strengths of 38 organisations, including the Institute of Biology, with a cumulative membership of some 70,000 bioscientists. The Biosciences Federation is a registered charity (no. 1103894).

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Front cover: Secondary science students immobilise algae as part of a range of activities to measure factors which affect the rate of photosynthesis. Activities such as these clearly capture student interest and enthusiasm. Image courtesy of Dr D Eldridge, Science and Plants for Schools (SAPS), Cambridge CB2 2PH

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Contents

Summary	2
Conclusions	2
Recommendations	2
Introduction	4
Working group methodology	5
Bioscience Education: principles and challenges	6
Skills	7
Ages 3–11	7
Ages 11–16	8
Ages 16–19	8
Higher Education	9
Knowledge	10
Ages 3–11	11
Ages 11-16	11
Ages 16-19	12
Higher Education	12
Assessment	13
Ages 3-11	13
Ages 11-16	13
Ages 16-19	14
Higher Education	14
Teaching	15
Ages 3-11	15
Ages 11-16	15
Ages 16-19	16
Higher Education	16
Appendix 1	18
The consultation questionnaire	18
Appendix 2	19
Organisations or individuals who responded to the consultation questionnaire	19
Appendix 3	20
Organisations and individuals who commented on the original draft report	20

Summary

Conclusions

The UK is an acknowledged world leader in bioscience research and development. Advances in the biosciences offer major benefits to the health and wealth of society, but also throw up ethical and moral dilemmas for which citizens need to be well prepared. Education in the biosciences lies at the heart of the country's ability to maximise the potential of these advances. We need to maintain a flow of well-trained, high calibre young people into research and development or technical careers in order to build on Britain's current excellence. At the same time we must ensure that all school and college students have a reasonable level of scientific literacy so that they can make informed decisions as mature citizens on the acceptability of such things as embryonic stem cell cloning and genetically modified food.

While the study of the biosciences remains popular, there are several grounds for concern: much school biology is outdated, fails to enthuse students, or deals inadequately with the social and ethical implications of the subject. Much careers advice is poor, and consequently students do not appreciate the range of jobs for which a science education fits them. Many bioscience students are weak in chemistry, mathematics and physics, and are thus ill-equipped to cope with the cross-disciplinarity of modern bioscience; and some core bioscience disciplines (eg pharmacology, biochemistry and microbiology) are not recruiting as well at university as they used to. It would be unwise to assume that because overall bioscience numbers at university are being maintained – due chiefly to the popularity of courses such as psychology and sports science – there is no problem.

This report examines bioscience education as a whole from primary school to university, and is intended to demonstrate how improving the curriculum and its delivery can help address these important issues. We believe that action needs to be taken in the next five years with regard to the skills and knowledge that are learnt, and how these are taught and assessed.

Recommendations

1. **The curriculum for each age group must ensure appropriate learning progression, suit the full spread of individuals and be a suitable platform for the next stage of education.** The science curriculum is intended to ensure progression but too often there is unnecessary repetition of content between successive stages. Discontinuities between school and university and between school and the work place need to be addressed.

2. **Curricula must be kept up-to-date and concentrate on key principles and concepts rather than excessive detail.** Knowledge in the biosciences is expanding rapidly, thus making it essential to be selective in deciding course content. Students must be able to understand and apply key concepts and have the ICT skills to be able to find and use more detailed material as required. The excessive content of many secondary and post-16 courses restricts open-ended activities and extended practical work.

3. **Curricula must ensure that bioscience students develop appropriate scientific and generic skills as well as knowledge.** The ability to apply knowledge to new situations and to communicate in styles appropriate to different audiences is essential, as is the development of scientific literacy.

4. **Curricula need to take account of the personal, social and ethical implications of the subject.** This is essential for awareness and informed appraisal of ethical and moral questions that advances in the biosciences pose to society, and to stimulate interest by making study more relevant to everyday life.

5. **Practical work, including fieldwork and investigations, must be given greater prominence in the curriculum.** Practical work is crucial to the development of bioscience skills and should be a core activity. Genuine concerns about health and safety and respect for living organisms must not result in poorer learning experiences.

6. **Assessment at all ages must reward students who can demonstrate that they have learnt intended skills and knowledge and can apply them in new situations.** Current national arrangements for summative assessment of students aged 7–19 can distort the curriculum and stifle learning, and should be rethought. Assessment too frequently measures the ability to regurgitate facts rather than apply knowledge or utilise scientific skills.

7. **Research is needed to discover why it is hard to achieve high A-level grades in biology, physics and chemistry, and how this may be overcome.** Any changes, though, should be introduced with great care to avoid giving the misleading impression that standards are being diluted.

8. **Students must receive informed and up to-date careers advice before making subject choices at ages 14, 16 and subsequently.** Science-related careers advice in most schools is often poor.

9. **Bioscience students aged 16-19 should be made aware of the advantages of also studying another science or mathematics.** They will need a good grounding in physical science and mathematics to cope with university bioscience courses and the cross-disciplinary nature of much bioscience research.

10. **Universities should not overspecialise in the early stages of undergraduate bioscience courses.** A broad first-year curriculum builds skills and a knowledge base in related fields and enables students to make a more informed decision on specialisation later.

11. **Undergraduate courses should take account of the rapid advances in the biosciences and industry's need for graduates with the knowledge and skills required in a competitive international market. Funding must be sufficient to provide appropriate teaching facilities and practical training.** Pharmaceutical and biotech companies and graduates themselves complain that bioscience graduates sometimes leave university with insufficient practical skills, which can often best be obtained through work-placements. Many bioscience departments are having to cut back on practical work.

12. **Teachers and lecturers need high quality continuing professional development to help them develop their teaching skills and update their knowledge, and time in their work schedules to engage fully with this development. Technicians, too, need appropriate continuing professional development.** The need to keep up with rapidly moving bioscience and to present the subject to students in stimulating new ways is highly challenging. We reiterate the importance of high quality teaching and technical support for students' learning, attitudes and values.

Much of the evidence for this report was drawn from England, but representatives of HM Inspectorate of Education for Scotland and Northern Ireland confirmed that the recommendations apply equally well to these countries. This is particularly true for progression, the need for relevance to everyday life, scientific literacy, and continuing professional development for teachers.

The new 21st Century Science GCSE course (for 14–16 year-olds) and the Salters-Nuffield Advanced Biology course (for 16–19 year-olds) address a number of the issues noted above and are developments on which to build.

Introduction

The UK has long been at the forefront of the biosciences[1]. UK bioscience research and bioscience industry are ranked second only to the USA[2]. Biosciences affect all aspects of our daily lives – from choices in our diet, new diagnostic procedures in healthcare, new medicines beginning to emerge from improved knowledge of the human genome, to food production and our interaction with the environment and climate change. There is thus much to celebrate in the current strength, but it has to be recognised that it is built on past scientific and educational policy decisions.

If strength is to be maintained so that the biosciences can play a full part in improving national health and increasing national wealth as envisaged in the Treasury's 10-year plan for Science and Innovation[3], some notable challenges affecting the supply of trained bioscientists need to be addressed:

- The boundaries between disciplines are becoming blurred; insights from chemistry and physics, for instance, are increasingly important for bioscience research. The present decline in popularity of the chemical and physical sciences and mathematics thus threatens to hinder bioscience developments.

- Although the biosciences have not experienced the same course closures as the physical sciences, this masks undesirable variations in the strength of interest and engagement across different areas of the discipline. Subjects such as sports science, psychology and forensic science are increasingly popular in universities whilst core subjects such as biochemistry, pharmacology and microbiology are finding it harder to recruit students[4]. We do not accept the implication in the report by the Higher Education Funding Council for England's advisory group on Strategically Important and Vulnerable Subjects that, because the overall number of bioscience students in universities has not declined, there is no potential problem[5].

- Developments in the biosciences have tremendous potential to improve quality of life, but they also raise social, ethical and moral issues that are of public concern. There needs to be much improved engagement with the public on developments such as the use of human stem cells, therapeutic cloning, nanotechnology and the genetic modification of organisms.

These issues can be addressed by making bioscience education more exciting and relevant, and able to equip young people better for their future lives whether as responsible adult citizens or the next generation of researchers. This is the focus of the present report from a working group set up by the Biosciences Federation in September 2004. The working group aimed to create an overall framework for future detailed consideration of the curricula, including methods of learning and teaching.

[1]Biology is the study of living organisms. It has a number of sub-divisions such as biochemistry and ecology, and extends to biomedical areas such as pharmacology. The sub-divisions are collectively termed the biosciences. In primary and secondary education the study of plants, animals and other organisms is referred to as biology; individual bioscience disciplines may be studied in further and higher education.

[2]Bioscience Innovation and Growth Team (2003) *Improving National Health, Increasing National Wealth,* 14; HM Treasury, DTI & DfES (2005) *The ten-year Science and Innovation Investment Framework Annual Report 2005,* HMSO, London.

[3]HM Treasury, DTI & DfES (2004) *Science and Innovation Investment Framework 2004–2014,* HMSO, London.

[4]Association of the British Pharmaceutical Industry (2005) *Sustaining the Skills Pipeline in the Pharmaceutical and Biopharmaceutical Industries.* Available at www.abpi.org.uk/category.asp?category=1

[5]HEFCE advisory group final report (2005) *Strategically Important and Vulnerable Subjects,* 4. Available at www.hefce.ac.uk (Last accessed 30 July 2005). See also House of Commons Science and Technology Committee *Strategic Science Provision in English Universities: Government Response to the Committee's Eighth Report of Session 2004–05.* Second Special Report of Session 2005–06. Available at http://www.publications.parliament.uk/pa/cm200506/cmselect/cmsctech/428/428.pdf (Last accessed 2 August 2005).

Working group methodology

Members of the working group were selected to include a wide range of knowledge and expertise in teaching, learning, research and other careers. The Biosciences Federation invited the working group to produce a report recommending how larger numbers of young people might be enthused by bioscience and choose to continue with its study, for their own and society's benefit and in order to maintain the current excellence of UK bioscience.

After agreeing the focus of its brief, the working group compiled a consultation questionnaire (Appendix 1) seeking views on the essential skills and knowledge that bioscience students should acquire at different levels of their education and training, how successful current curricula and teaching are in helping to instil those skills and knowledge, and how assessment and teaching could be improved. We agreed that we were concerned not only with the intended curriculum, as laid down in curricula and specifications, but with the curriculum as taught and learnt. The consultation paper was sent to 36 stakeholder groupings, including those engaged in teaching (all levels); curriculum, assessment and standards bodies; the Department for Education and Skills; education charities; field study organisations; parent associations; learned societies and subject bodies; research councils; employer organisations; and the scientific and educational media.

Responses were received from 24 organisations or individuals (Appendix 2). On the basis of the views submitted, separate discussions with individuals having particular knowledge or experience, and the findings of other recent surveys, the working group produced an initial draft report. This was returned to the organisations that responded to the consultation, and to other selected stakeholder groupings, with an invitation to comment critically (Appendix 3). The final report was drafted to incorporate the feedback from this second consultation.

The findings of the consultation are presented in terms of the essential principles of a sound bioscience education and what is needed to achieve this. We have emphasised the skills, knowledge, modes of assessment and teaching appropriate at different stages to ensure continuity and progression. The working group appreciates that many of the arguments will apply equally well to the teaching and learning of chemistry and physics.

Bioscience Education: principles and challenges

The seminal report *Beyond 2000*[6, 7] highlighted the need to look again at the science curriculum and the way it is taught. Although the report focussed mainly on the compulsory period of schooling (5–16), its principal messages relate to all phases of education and influenced the thinking of the present working group. Other developments in approaches to teaching, learning and assessment (e.g. work on formative assessment, alternative learning styles and critical thinking) also illuminated our discussions, and we agreed that bioscience education should embrace the principles set out below.

1. *Bioscience education cannot be undertaken without due regard for the other disciplines of science.*

   Much of the knowledge and understanding of biological systems is derived from ideas and techniques drawn from other scientific disciplines.

2. *Bioscience education must meet the needs of different individuals and groups of students.*

   Throughout their education, we must provide curricula for three broad and equally important groups of students: those whose main interest lies in further academic study with a view to a career in some aspect of research and development or teaching (although many will work outside science after graduating); those who wish to take a more vocational route working in a bioscience-related industry or context; and those who do not wish to become bioscientists but for whom their bioscience education contributes to a sense of culture and citizenship and provides some relevance to their lives.

3. *Bioscience education should be seen as a continuum from the early experiences of young children through to adulthood.*

   For many students, bioscience education is disjointed. While some progress to avoid this has been made in recent years, notably by the Qualifications and Curriculum Authority, greater efforts are required.

4. *Bioscience education must develop appropriate levels of skills, both scientific and generic, which enable students to develop their own understanding and expertise and make a positive contribution to the work of others.*

   The rate at which bioscience knowledge is expanding, coupled with the ease of access to much of this information, has changed the basis on which any future bioscience curriculum should be designed.

5. *Bioscience education must engage with the social and ethical implications that result from the advances in knowledge, understanding and technology.*

   Throughout history, bioscientific advances have resulted in moral controversy, but today the controversy is more intense and faster moving, and involves a much wider cross-section of the public, largely because of news media. Students need to leave formal education understanding how bioscientific advances affect their lives, and with an ability to interpret and evaluate evidence on controversial issues from different sources and communicate it to others. They can then participate knowledgeably in the wider debate within society.

6. *Bioscience education should provide students with an appreciation of the major ideas of science in addition to the key concepts that underpin the structure and function of living systems .*

   Students need to understand the relationships between different branches of the biosciences and links with other disciplines. Helping students appreciate the way scientific knowledge is produced and the major science concepts that underpin the understanding of more detailed and specialised topics are key elements in moving away from a rote-learning approach.

7. *Bioscience education depends on enthusiastic teachers who are up to date and able to engage their students in developing an appreciation of the discipline.*

   No curriculum on its own can stimulate students without the support and help of teachers and others who can 'bring the subject alive'. To maintain their own enthusiasm, knowledge and expertise, teachers at all levels need to keep up to date with developments through continuing professional development. This must relate not only to the science itself, but also to approaches to teaching and learning.

[6]Millar R and Osborne J (eds) (1998) *Beyond 2000: Science education for the future. A report with ten recommendations,* King's College London School of Education, London.

[7]Reiss MJ, Millar R and Osborne J (1999) *Beyond 2000: science/biology education for the future,* Journal of Biological Education **33**, 68–70.

Skills

A striking finding from the consultation was the emphasis, irrespective of the age range of the students concerned, placed by respondents on bioscience education developing skills as well as knowledge. Crucial to this is meaningful and stimulating practical work, including fieldwork. Both of these should be core entitlements. Active discovery in both the natural environment and laboratory experiences of plants and animals is essential for understanding living things and their relationships with each other and their habitats.

At all levels, skills must be developed in parallel with the corresponding theoretical knowledge. While many of these skills will apply also to physics and chemistry, an appreciation of the use of statistics, risk analysis and probability is particularly relevant to aspects of bioscience such as observational fieldwork on populations. The working group believes that it is possible to outline a continuum of scientific and generic skills that students should acquire as they progress through bioscience education.

Throughout primary and secondary education the current drive to enhance literacy and numeracy skills should not be relaxed. Universities commented on the need for improvement in these skills, as did the recent Wellcome Trust report on biology A-level[8]. Scientific literacy must also be progressively developed from the earliest days – students need to be capable of differentiating between myth, opinion and fact in media reports about science.

Ages 3–11

There was a broad consensus among respondents that early biology teaching should focus on developing the skills of enquiry and critical observation. The working group considers that the existing primary curriculum already emphasises the skills and approaches identified by respondents (Box 1), but that many teachers find some of these challenging to deliver. Biology provides some of the best opportunities for experiencing a range of types of investigation – sampling and pattern finding, identifying, classifying and exploration – that go beyond the confines of the 'fair test', but these are frequently under-used. Teachers need help in appreciating when and how to use them – many lack confidence in facilitating open-ended investigations. Engaging in scientific enquiries can also develop a broad range of valuable generic skills, as indicated in Box 1. Less emphasis should be placed on the fair test in printed resources and in assessment.

Our conclusions are reinforced by a recent detailed survey of teachers' experiences of primary science[9]. This recommended a review of curriculum content to provide greater opportunities for teachers to focus on topics likely to develop scientific skills and generate enthusiasm. Primary science should *"place a greater emphasis on children's thinking, questioning and investigative skills".*

Box 1 Essential skills to develop between ages 3 and 11

Scientific

Developing scientific literacy through:

- First-hand observation and exploration;
- Developing from random curiosity and looking to scientific questioning and observing;
- Early experience of different types of scientific enquiry;
- Using simple scientific equipment such as a hand lens or ruler in early stages, or a thermometer or digital microscope in later stages;
- Using opportunities to move from qualitative to quantitative data;
- Experiencing a range of types of recording;
- Interpreting data.

Generic

- Ability to respond to experiences with curiosity and wonder;
- Using a range of strategies for problem solving;
- Working independently or in a team to approach simple tasks;
- Thinking skills including general questioning skills;
- Learning to use information sources appropriately, including the internet; simple use of ICT to obtain evidence, create graphs and tables and present information;
- Developing communication skills – oral, written, pictorial/ diagrammatic, symbolic and mathematical.

[8]The Wellcome Trust (2004) *Life Study: Biology A level in the 21st Century,* The Wellcome Trust, London

[9]The Wellcome Trust (2005) *Primary Horizons: Starting Out in Science,* The Wellcome Trust, London.

Ages 11–16

The essential scientific skills for 11–16 year-olds should overlap with, and build on, those developed earlier and equip the student with the skills an adult needs to make judgements about science (Box 2). The generic skills acquired also develop from those listed earlier as the student gains experience and maturity. An over-emphasis on assessment through short structured questions and multiple-choice questions militates against the student developing scientific literacy.

Box 2 Essential skills to develop between ages 11 and 16

Scientific

Developing scientific literacy through:

- Asking questions and answering them using scientific methods;
- Choosing and using appropriate equipment and techniques;
- Accurate and critical qualitative and quantitative observation;
- Accurate and appropriate recording of observations;
- Succinct and accurate reporting of results;
- Collection, analysis and interpretation of data (including use of ICT and basic statistics);
- Comparing results with hypotheses;
- Synthesis of new ideas from observations, results and deductions;
- Appreciating the variability of biological experiments and that there can be alternative explanations for a single observation;
- Making judgements about the quality of scientific evidence;
- Making sense of, and forming opinions about, science issues in the media and everyday life.

Generic

- Working independently or as part of a team; building up teamwork skills;
- Problem solving;
- Critical thinking and questioning;
- Perseverance;
- Discursive skills;
- Presentation skills;
- Increasingly good command of ICT;
- Ability to express scientific ideas and explanations clearly in written form and produce an extended yet concise piece of writing.

Ages 16–19

16–19 year-old students need to consolidate the scientific and generic skills they have learned up to the end of compulsory education, and move to an enquiry-based independent form of learning that is less teacher-led (Box 3). Experimental techniques should be improved by fieldwork and experimentation on living or once-living organisms, or using biologically active molecules such as enzymes. Crucially, students should be able to apply their knowledge to new situations, including being able to form and defend rational opinions on ethical issues on the basis of the available information.

Students should be equipped to use a range of styles as appropriate to communicate to different audiences, and given the opportunity to enhance skills in extended writing and numeracy in the context of the bioscience studied. The Wellcome Trust report[8] noted that undergraduates are often surprised by the harder analytical and mathematical demands of degree-level biosciences.

Box 3 Essential skills to develop between ages 16 and 19

Scientific

Developing scientific literacy through:

- Ability to carry out a piece of scientific research to evaluate a formulated hypothesis, using statistics as appropriate, including measurement and understanding of error;
- Refined experimental techniques;
- Ability to apply scientific understanding in new and changing situations, and to make connections between different areas of knowledge;
- Ability to form and defend opinions about social or ethical issues surrounding the biosciences.

Generic

- Enhanced ability to find, organise, evaluate and use factual information from a range of resources, not just on-line ones;
- Ability to write a report in a scientific style and in good English, in the student's own words;
- Developing more independent work practices, such as owning responsibility for personal study and reflecting on learning and achievements;
- Enhanced literacy, oral and numeracy skills, including the ability to communicate ideas to a range of audiences;
- Ability to recognise the growing capabilities brought about by advances in technology.

Higher Education

The biosciences are no longer simply 'biology' at this level, but a broad and diverse range of sub-disciplines. Some practical skills are particularly relevant to certain sub-disciplines – for example chemistry skills for biochemistry, whole animal experimentation for pharmacology and physiology, fieldwork for ecology, plant sciences and zoology, computation for bioinformatics – but many are common to all. The Quality Assurance Agency Benchmark statement for biosciences provides an excellent reference point[10].

Respondents agreed that the undergraduate years need to instil the practical and early research skills needed for a career in the biosciences, as well as the transferable skills, particularly critical reasoning, problem solving, team-working, analytical skills and ability to synthesise a viewpoint, that are valued in all forms of employment[11] (Box 4).

Box 4 Essential skills to develop at undergraduate level

Scientific

Developing scientific literacy through:

- High level laboratory and fieldwork skills that may be needed in a later career;
- Ability to use higher education level tools and equipment;
- Enhanced ability to apply bioscience knowledge to new situations, and to make connections between different areas of knowledge;
- Ability to turn bioscience knowledge into original and creative ideas for solving problems;
- Ability to use the scientific literature and data sources;
- Ability to construct reasoned arguments to support a position on the ethical and social impact of developments in the biosciences.

Generic

- High level literacy, numeracy, ICT, communication and team skills;
- Enhanced critical reasoning, analytical and synthesis skills;
- Ability to be self-critical, and to reflect on and plan learning, performance, achievements and career development.

[10] Quality Assurance Agency for Higher Education (2002) *Academic standards – Biosciences,* http://www.qaa.ac.uk/academicinfrastructure/benchmark/honours/default.asp (Last accessed 28 May 2005).

[11] Higgin N and Pettifer C (2004) *From Learning to Earning, 2nd edn,* Trotman, Richmond.

Knowledge

Each stage of the curriculum must also be suitable as a platform for the next. While progression is intended in the National Curriculum, there is often a delivery problem. The 'spiral curriculum' whereby topics are repeated at a slightly greater depth at each level can be a turn-off for school students if the activities are not varied and there is no real progression. Poor continuity in science education between primary and secondary schools in Scotland was acknowledged in a recent report from HM Inspectorate of Education[12]. The gap between schools and colleges or universities or the workplace also needs to be rectified.

To help improve continuity between the science taught at the primary and secondary phases of education, we have produced a framework of key ideas and themes which students should have covered by the time they reach 16 (Box 5)[13]. Clearly, not all topics would be encountered in the early years; some would be introduced at a later stage in a planned progression. The levels to be reached at different ages require careful thought. It is important that biological topics that need physical science or mathematics support, or are cross-disciplinary, are co-ordinated with the provision of the relevant knowledge in the associated discipline.

There is a strong message from the consultation that curriculum content must not be excessive, but allow time for stimulating activities, especially discussion, practical and field work and placing biosciences in the context of everyday life. The compulsory core must be kept as slim and as up-to-date as possible. This was also emphasised in a Scottish study of the school to university transition[14]. Similarly, the Northern Ireland Department of Education has endorsed proposals for a new Northern Ireland Curriculum for pupils aged 4 to 14[15]. The new curriculum will place greater emphasis on wide objectives such as employability, personal and social education and citizenship; the development of skills such as working with others and taking responsibility for own learning will play a central part.

Students of all ages need to be able to apply knowledge and not merely able to recall it for the purposes of assessment. Reducing the emphasis on factual learning, and illustrating the relevance of biology to the experiences of everyday life, should help to reduce the number of students turning away from science[16, 17].

Box 5 Ideas and themes with which students should be familiar by age 16

- Science proceeds by the generation of ideas that lead to hypotheses that can be objectively tested
- Scientific knowledge is initially provisional but can become more certain as it is tested over time
- Developments in scientific knowledge are crucial for advances in medicine, agriculture and other fields
- Technological developments may have risks associated with them and often give rise to social and ethical issues
- All living things obey the laws of chemistry and physics, such as those of conservation of energy and of matter
- All living organisms are made of cells. Cells can be aggregated into tissues, tissues into organs and organs into organ systems
- Inherited DNA plays a central role in the structure and functioning of organisms
- Almost all biologists believe that evolution, through natural selection, has given rise to the range of life we see today
- Similarities and differences between organisms allow them to be classified. Organisms can be assigned scientific names and this aids in cataloguing biodiversity
- Carbohydrates, fats, nucleic acids and proteins are large chemicals essential for life
- An understanding of human anatomy, physiology and biochemistry is essential if diseases are to be combated by doctors, and helps individuals to look after their own health
- Human and animal behaviour is generally adaptive
- Organisms co-exist in ecosystems and depend on one another for such things as energy, nutrients, pollination and habitats
- Plants capture energy from the sun in photosynthesis and form the basis of virtually all food webs
- Certain bacteria, fungi and other organisms break down and recycle waste products and dead organisms
- Humans have responsibilities towards living organisms and the environment
- Humans are increasingly responsible for pollution, climate change and species extinctions

[12]HM Inspectorate of Education (2005) *Improving achievement in science in primary and secondary schools,* HM Inspectorate of Education, Livingstone (Available at www.hmie.gov.uk/documents/publication/iais.pdf) (Last accessed 2 August 2005).

[13]For a recent study on what 'ideas-about-science' should be taught in school science see Osborne, J, Collins, S, Ratcliffe, M, Millar, R and Duschl, R (2003) *What "ideas-about-science" should be taught in school science? A Delphi study of the expert community*, Journal of Research in Science Teaching **40**, 692–720.

[14]Coggins J, Finlayson M and Roach R (2005) *Science Education for the Future,* A report to the Scottish Executive Education Department.

[15]www.ccea.org.uk/ (Last accessed 2 August 2005).

[16]Osborne J and Collins S (2000) *Pupils' Views of the School Science Curriculum,* A report funded by the Wellcome Trust, King's College, London.

[17]House of Commons Science and Technology Committee (2002) *Science Education from 14–19,* HMSO, London.

Ages 3–11

Primary school practitioners in England and Wales consider the breadth of content and cognitive relevance of the science National Curriculum to be generally suitable for each age range. The existing curricula are consistent with the themes in Box 5, but it would need to be made clearer how they contribute to progression in knowledge up to age 16.

Many respondents pointed out that values and attitudes to science are vitally important. For example, the British Ecological Society stated:

The affective domain is as important (if not more so) as skills and knowledge – granted it is not easy to measure and even more difficult to measure reliably but this is not a reason for ignoring it.

The biosciences have immediate relevance to younger pupils who can be engaged in considering the care of their own bodies, attitudes to different types of living things and wider environmental issues. Children's natural curiosity and sense of awe and wonder, coupled with first-hand experiences, encourage the development of open and inquiring minds and positive attitudes to science and the natural world.

Ages 11-16

As part of the emphasis on using what is learned, the student should be enabled to:

- understand scientific methodologies;
- apply knowledge and skills across subjects;
- apply biology to everyday life;
- make judgements about the quality of scientific evidence;
- make sense of, and form opinions about, science issues in the media;
- discuss ethical issues arising from biological science.

We are concerned that students often receive a diet of short, disjointed modules that jump from topic to topic. Too often, there is a need to re-visit the same old factual material because not enough time has been given to developing and embedding understanding each time it is taught as there is always the rush to move to the 'end-of-topic test' and the next module. We hope that the forthcoming review in England and Wales of the key stage 3 science curriculum helps in the 11–14 age range.

In the 14–16 age range new specifications to be introduced in England, Wales and Northern Ireland from September 2006 will increase student choice. The new courses promote the view that all students need to be scientifically literate. The 21st Century Science course, which is currently being trialled, approaches this by introducing in an obligatory core unit key science concepts and explaining the way science and scientists work in society. The course provides for groups of students with different interests and needs by having an additional optional general unit, which prepares students for higher study, or an applied unit, which prepares students for science-related work.

Careers advice needs substantial improvement in most schools. Young people must have reliable information before making their subject choices at ages 14 and 16. Very few are presently aware of the range of careers that the study of biosciences can lead to. In a recent study of subject choices in secondary schools Cleaves[18] concluded:

… the lack of knowledge about science occupations and science work is a powerful factor militating against a post-16 science choice.

Bioscience graduates and more experienced bioscience professionals need to be encouraged to join schemes like Science and Engineering Ambassadors and Researchers in Residence to be trained and equipped to go into schools and convey some of the excitement of their work to students of all ages. Such Ambassadors can also help to stimulate informed debate about wider issues concerning the biosciences by bringing their experience of how classroom science relates to the real world, and can be valuable role models. Schools should welcome them and make space in the timetable for them.

Students also need to be helped to appreciate that modern biosciences require an underpinning knowledge of chemistry, mathematics and physics. Relatively few students opt for a combination of science and mathematics post-16 unless they wish to study medicine or veterinary science. They will subsequently struggle to cope with the physical science and mathematics content of university courses, and the cross-disciplinary nature of much current biological research.

[18] Cleaves A (2005) *The formation of science choices in secondary school,* International Journal of Science Education **27**, 471-486.

Ages 16-19

Most of the current post-16 biology specifications throughout the UK still have too much factual content and lack obvious relevance to everyday life. What is important is that students preparing for further study have a thorough grounding in core principles and know how to use ICT to access and evaluate material when it is required. A recent report[14] to the Scottish Executive Education Department commented:

There is a desire to see a school curriculum that is less factually based but which gives a good grounding in the basic principles of the sciences, studies a few subjects in more depth, deals with moral and ethical issues, and involves more practical work and extended problem solving exercises.

It is evident from the responses that there is some tension between the desire for post-16 biology courses to be more aligned to current research interests, which would introduce a larger chemical biology component, and the desire to retain the 'traditional' elements that are popular with students and command a high uptake level for the course. The new Salters-Nuffield Advanced Biology course makes an admirable attempt to combine academic rigour with high student motivation by teaching the subject through contemporary biological contexts[19]. Eight topics are covered in the course, each of which starts with a context (a storyline) that is related to the modern world and the application of biology. Biological principles are introduced when required to aid understanding, so that the theory always has an obvious relevance.

Whatever post-16 course is taken, students need to be enthused by an understanding of recent advances, their possibilities for the health and wealth of society and the societal issues that they may raise. The question is the depth to which such topics should be covered. There needs to be much more dialogue between A-level biology teachers, curriculum developers, university bioscience tutors and researchers on this and other curriculum matters, to ensure that there is sensible progression from school and college to university science. Post-16 biology teachers may need additional help to teach enthusiastically about recent advances. One university respondent who recently organised updating workshops for teachers commented that *"Several teachers conceded they were rather 'scared' of teaching the critical molecular area of biology".*

It is essential for 16–19 students to receive sound advice about university courses and careers. In order to generate teaching income, many universities are creating new undergraduate 'science' courses such as sports science and forensic science that are popular but may offer less breadth and depth of learning. There is often little regard to the requirements of the potential employers of these graduates, who generally prefer recruits with solid degrees in mainstream bioscience subjects. Many graduates of the new courses will come to be disappointed with their career prospects.

[19]www.advancedbiology.org (Last accessed 28 May 2005).

We suggest in Box 6 the areas of biological knowledge with which students should be familiar by the end of A-level biology.

Box 6 Areas of biological knowledge with which A-level biology students should become familiar

- The nature of biology
- The chemicals of life
- Cell biology
- Biotechnology
- Energy transfer and nutrition
- Food production
- Homeostasis and control as exemplified by the various physiological systems within animals and plants
- Infection and defence against disease
- The nervous system and behaviour
- Reproduction, growth and development
- Heredity and genetics
- Ecology and the environment
- Biodiversity and taxonomy
- Natural selection, artificial selection and evolution

Higher Education

It is difficult to define a biosciences undergraduate curriculum, particularly for the later years of a course, since each sub-discipline will have separate requirements. It is also important that HE departments build on their own academic and research strengths and 'customise' programmes within a common framework. Nevertheless, there are some shared, general principles. Undergraduate bioscientists should experience courses that:

- expose them to, and allow them to develop, the core knowledge base of their discipline and gain sufficient knowledge in related fields as appropriate (e.g. chemistry, physics, earth sciences);
- provide a good understanding of biological systems across the board – from molecule to cell and from organism to community, and an appreciation of interdisciplinary or multidisciplinary approaches;
- create in them an awareness of the wider societal issues of their subject and in particular the ethical issues surrounding it;
- provide practical experience and an insight into research approaches, with opportunities for work experience where appropriate.

There is widespread agreement that in the early undergraduate year(s) bioscience courses should maintain a broad perspective and knowledge base, in part to compensate for students arriving with different levels and fields of knowledge. Some respondents go further, to suggest that a student's decision on specialisation should not be made until after the first year.

Assessment

A recent study by the Royal Society[20] on the assessment of science learning 14–19 concluded:

Assessment of science learning is a complex but crucial issue in improving our education system. The results of assessment allow: students to understand and manage their own development; teachers to respond to individual learners' needs; parents to make decisions about which school or college they want their children to attend; colleges, universities and employers to identify and recruit future scientists; regulatory authorities to support particular institutions; and policy-makers to monitor and direct the health and progress of the education system in general. Our current assessment regime in science does not satisfy all these stakeholders, and is holding back students' and teachers' performance and creativity.

If biology education is to move to the development of skills and the application of knowledge then there must be a corresponding change in assessment in this direction. Criteria for assessment need ongoing review to ensure that they are appropriate for intended learning outcomes. It will be important to retain a balance of external examination and continuous assessment.

In the UK's high-stakes targeted results environment, what is assessed and reported at the end of a course largely determines what is taught. Designers of biology curricula should therefore address assessment and pedagogy from the start. We need an accurate assessment method for each desired outcome. The working group recognises that methods for assessing skills are less well developed than those for knowledge, but it is essential that things that are valued are not neglected simply because they are difficult to assess. Skills are generally best assessed directly by the teacher, if necessary with some kind of external moderation, and different skills may need different assessment approaches.

If teachers are to play a larger role in the assessment process they will need focused high quality professional training.

Ages 3-11

The weighting given to scientific enquiry in the National Curriculum for science falls from 50% at age 7 through 40% at age 11 to 25% at age 14; content knowledge – and all too often factual recall – becomes increasingly dominant. The development of skills will continue to be patchy until there is full recognition of both the intrinsic worth of these skills and their function in the acquisition of real scientific knowledge and understanding. A recent Wellcome Trust report on primary science[9] specifically recommended that assessment should be reviewed to ensure children are tested on scientific understanding and skills rather than simply factual recall. It called for a study of the effects of national tests in science on opportunities for children to develop investigative, questioning and thinking skills.

The working group recommends the following future changes:

- To determine more precisely levels of early progress in biological understanding, and to match this with the expected teaching progression;
- To include a greater emphasis on forms of enquiry other than 'fair testing', and to find a way of assessing/valuing the more ephemeral skills of curiosity, innovation and problem-solving;
- To replace formal Standard Attainment Tests (SATs) at age 11 with ongoing teacher assessment and to develop more flexible ways of monitoring progress.

Ages 11-16

The principal challenges in the 11–16 age range are to devise practicable ways of determining the development of different skills, and to reward the application of skills and knowledge rather than only factual recall. Laboratory skills, for example, need to be assessed differently from generic skills such as working in a team. It may be possible to create integrated assignments in which teachers assess a number of skills individually, within the context of the single task. In reality, it may not be possible to assess all the desired skills, making prioritisation essential. Notwithstanding the above, it is important that the burden of assessment does not fall too heavily on individual teachers. Under the current targeted outcome regimen, teachers and students can lose an inordinate amount of time preparing for and carrying out assessments.

[20] Royal Society (2004) *Statement on the Assessment of Science Learning 14–19*, Royal Society, London.

Ages 16-19

It was stated consistently in the responses to our consultation that there is too much assessment at this level. One senior educationalist in the Scottish schools system said:

(In our review of the science teaching in Scotland[12]) reduction in summative and external assessment is a major driver since this, in particular, has constrained the amount of practical work done from age 14–18.

Another respondent suggested uncoupling AS from A2 so that those who are committed to A-level biology do not have to spend time on formal AS assessment. Modular courses may also present a significant problem in creating artificial barriers and failing to make effective links between related topics such as genetics, cell biology, ecology and evolution. Synoptic assessments must be retained.

In the Wellcome Trust study[8] 45% of A-level students thought there is an over-reliance on memory recall in assessment, while 67% of teachers thought that future development of biology A-level should attach greater importance to scientific skills and understanding. A Scottish study of the school-to-university transition[14] commented:

There needs to be a change away from the examination of mainly factual material to a type of assessment that will consolidate understanding and develop skills as well as measure achievement.

Respondents considered that teachers should play a larger role in evaluating the skills noted above, which are more difficult to quantify than factual recall.

The Wellcome Trust study[8] referred to A-level coursework as *"time consuming, but rather artificial exercises which do not reflect the true nature of science as a process of enquiry".* It recommended a review to encourage a broader range of practical investigations to support understanding through the development of investigative and practical skills. We endorse this.

One specific problem with the assessment of A-level biology that has persisted for well over a decade is its difficulty relative to other A-level subjects. Based on A-level grades for students compared with what they achieved in their GCSEs (General Certificate of Secondary Education), general studies is now the hardest A-level, biology the second hardest, physics the third hardest and chemistry the fourth[21]. A candidate of average ability taking sociology A-level is likely to score two grades higher than a candidate of the same ability taking A-level biology. Some students appreciating this fact are likely to be put off taking science at A-level. We are not calling for a 'dumbing-down' of post-16 biology but for an investigation of the reasons for apparently poorer performance in biology and recommendations on how this may be overcome.

[21]Hill P (2004) *Study calls for grading reform,* THES **3 September**, 2–3.

Higher Education

There is a concern that present undergraduate assessment and course structures may lead to short-term, superficial learning rather than deep, long-term understanding. Much is blamed on modular degree structures. These can lead to fragmentation of knowledge and a lack of integration. As with post-16 modular biology courses, it is important that synoptic assessments are maintained to encourage an holistic approach to the subject. Testing should aim to reveal the level of independent thought and the skills acquisition. A significant piece of independent work should be required in the final year of undergraduate courses; for those wishing to pursue a research career this should be laboratory- or field-based.

A study[22] for the Quality Assurance Agency in 1997 demonstrated that universities' assessments do not necessarily prioritise the attributes that they value most highly in graduates. Departments ranked the top five desired attributes as: critical reasoning, knowledge of subject's conceptual basis, investigative skills, intellectual analysis, and communication skills. They ranked the attributes actually assessed as: knowledge of subject's content and range, knowledge of subject's conceptual basis, critical reasoning, intellectual analysis, and laboratory skills. The findings probably reflect the relative ease and familiarity of departments with assessing certain attributes as against others, and the situation has probably not changed markedly in recent years.

Assessment of undergraduate performance should, of course, be formative as well as summative. Good feedback to students is vital for their intellectual development.

[22]Biochemical Society and the Institute of Biology (1997) *The Core Attributes of Biological Sciences Graduates: A report for the Quality Assurance Agency,* Institute of Biology, London.

Teaching

Responses relating to primary and secondary education expressed concern that teaching is influenced all too often by the high-stakes testing regimen, the convenience of arranging provision in a particular manner or the limited confidence of some teachers, rather than the best interests of the students. These militate against the student being enthused.

The huge importance of Standard Attainment Tests (SATs), GCSE and A-level results to schools and colleges leads to over-emphasis on 'teaching to the test'. Teachers at all levels, particularly primary and secondary, need high quality continuing professional development; at the primary level because primary teachers are rarely science specialists, and at secondary level to keep up to date with advances, and to brush up skills in using a variety of teaching approaches to enthuse students. This entitlement was also emphasised in the Scottish report on science teaching[12]. The working group welcomes the establishment of the National Network of Science Learning Centres as a provider of professional development. It is particularly important that primary science co-ordinators receive high quality support whatever changes are made to the curriculum or to management arrangements in schools.

It is often stated that health and safety regulations limit access of students to practical work with animals and plants, but it is nearly always the perception of the regulations rather than the reality that is responsible[23]. Teachers need more help with interpreting health and safety regulations and assessing risks. Greater emphasis on studying living organisms must be accompanied by the development of tried and tested examples that still inspire and are safe. High quality video or computer simulation is a useful adjunct to laboratory studies and fieldwork, but not a substitute. ICT on its own cannot develop the skills and attitudes to which fieldwork gives access. It is vitally important that adequate earmarked support, both financial and personnel, is available for practical activities.

Ages 3-11

Science teaching at foundation and primary level is considered by our respondents to have developed well in the last decade. The great majority of new foundation and primary teachers come with GCSE passes (grade C or above) in balanced science, and have undertaken appropriate further work during training. However, according to the General Teaching Council, 45% of primary teachers are aged over 45, which emphasises the importance of high quality continuing professional development throughout a teaching career.

Primary teachers, even those with little background of science studies, generally find teaching the 'content' side of biology easy enough; aspects of the physical sciences can be a problem. However, the working group does not believe that all primary teachers necessarily understand biology better than the physical sciences; this can lead to false confidence and hence misrepresentation of the biology itself. Science enquiry is addressed well in early learning goals and in the National Curriculum, but may not be acquired well by the majority of pupils. The issue appears to be one of teacher knowledge and pedagogy rather than the intended curriculum. This is reinforced by the findings of the Wellcome Trust study of primary science[9] which found that a high proportion of teachers feel they lack the confidence, expertise and training to teach current science curricula effectively. Good-quality continuing professional development was strongly recommended in order to improve teacher confidence.

Ages 11-16

It is within the 11-16 age range, in particular, that students can lose their interest in science[24, 25]. Osborne and Collins[16] emphasised the importance of a variety of teaching approaches and of flexibility for engaging students. With this principle in mind, the working group recommends that the teaching and learning approaches should include:

- Direct experience of living things;
- Practical work, including laboratory investigations and fieldwork, to encourage enquiry;
- Visits, to experience the application of bioscience in society and its importance in wealth creation;
- Discussion of ethical, social and cultural issues;
- Encouragement of extended writing, especially of students' own explanations and arguments;
- Extensive use of ICT to:
    - Create graphs, diagrams and animations of biological processes and the diversity of life;
    - Provide data capture and analysis;
    - Develop research skills.

[23]Tranter J (2004) *Biology: dull, lifeless and boring?* Journal of Biological Education **38**, 104–105

[24]Ramsden J (1998) *Mission impossible? Can anything be done about attitudes to science?* International Journal of Science Education **20**, 125–137.

[25]Haste H (2004) *Science In My Future: A study of values and beliefs in relation to science and technology amongst 11–21 year olds,* Nestlé Social Research Programme, London.

It is encouraging that a higher proportion of secondary biology teachers have a degree in their discipline than teachers of any other subject[26]. Having a strong background knowledge and understanding is likely to make them more capable of inspiring students about biology. But a biology teacher whose degree is in the molecular biosciences may, for example, lack confidence in teaching fieldwork. This emphasises the importance of systematic and career-long continuing professional development. Feedback from schools trialling the 21st Century Science course noted that teachers found planning and running open discussion sessions challenging and time-consuming, and weaker students found these activities difficult. Support may therefore also be needed for engaging with other disciplines to make social and ethical discussion as stimulating as possible; and for arranging external visits to experience the applications of biology in society.

Ages 16-19

Post-16 biology should be taught by specialist teachers with good degrees in the biosciences, who understand their field in depth and how their science fits into a bigger picture.

For too long, A-levels have been seen as the most prestigious route for 16-19 year-olds studying biology. It is imperative that vocational routes are as well resourced and staffed as academic routes.

16-19 year-olds should be taught to think independently and accept responsibility for their own learning. The approaches listed for the 11-16 age range remain relevant but the emphasis should change. For example, practical work, including fieldwork, should encourage independent hypothesis-making and testing, while ICT could be used to resource material for extended investigative projects. This would also provide the opportunity for extended writing. Discussion of social and ethical issues could be used to evaluate the ability to formulate and defend a well-thought-out position. Such discussion should also be extended to debating the biology itself, e.g. what are the opposing arguments as to how a particular biological process works? Every effort should be made to encourage students to think laterally and to make links between different modules in biology, and between biology and other sciences and mathematics.

[26]Smithers A and Tracey L (2003) *Teacher Qualifications*, Sutton Trust, London.

Teaching in a social context can motivate students. For example, aspects of the curriculum dealing with homeostasis and control, and the structure and function of cells, lend themselves to an explanation of how an understanding of biology can help to treat and cure disease, and this can be coupled with visits to pharmaceutical and biotech companies. Projects on the environment or on health can be good vehicles for illustrating the interactions of biology with other disciplines.

Higher Education

Modular courses should be structured so that students can synthesise information across the range of modules, which should build on a core. The size of the core may vary (e.g. broad for biology, narrower for biochemistry) but should allow students to put their own sub-discipline within the general context. Students need to be encouraged to consider their curriculum choices in terms of their future study and employment plans. Teaching (and learning) methods should be varied both to accommodate different types of students and their learning, and also to deliver different skills. Many courses may still be primarily lecture-based, but it is important to include other methods, e.g. tutorials, seminars, enquiry (problem)-based learning, practical work and e-learning (which must be well designed and not simply producing electronic textbooks or putting lecture notes on the web).

The Higher Education Academy Centre for Bioscience[27] has led a study that gauges the suitability and relevance of higher education teaching by consulting former students from four universities now in various kinds of employment. Graduates were generally satisfied with the provision of a good theory base and knowledge of the subject, and considered that they developed good presentation and communication skills. This is consistent with universities expending considerably more effort in recent years to ensure that students acquire transferable skills. But graduates felt that their courses failed to provide sufficient practical knowledge and expertise. This is important because practical work trains students in the design of experiments, familiarises them with complex equipment and improves their experimental techniques. It also allows students to decide if they have the aptitude and motivation for a career in research.

[27]Brown CA, Calvert JE, Chairman P, Newton C, Wiles K and Hughes IE (in press) *Skills and knowledge needs among recent bioscience graduates – how do our courses measure up?* Bioscience Education E-journal **6**, www.bioscience.heacademy.ac.uk/journal/vol6/index.htm

The finding regarding practical work is likely to be replicated across the higher education sector. A survey of Heads of Department in 2002 by the Biochemical Society[28] found a significant decline in the amount of practical training in degree courses, particularly in early years, since an earlier survey in 1996. The cost of practical provision is a major problem; it is accepted to be one of the reasons for universities closing physical sciences departments. Such closures have not yet taken place in the biosciences, but departments face the same cost pressures. It is essential for the higher education funding councils to increase the unit of resource for teaching science subjects in line with the real cost of providing these courses.

While employment rates for graduates in the biosciences are above the average for graduates in other subjects[29], the pharmaceutical industry has also complained vociferously that bioscience graduates too frequently lack practical skills, and in particular that there are insufficient graduates coming through with in vivo skills. Dr Malcolm Skingle (GlaxoSmithKline) commented:

In recent years pharmaceutical companies have been alarmed to note that biosciences graduates frequently lack practical skills that would formerly have been taken for granted, and this has encouraged companies to recruit more staff from abroad.

Government policies through the higher education funding councils have driven many university Vice-Chancellors to the view that they are now simply operating in a market place, rather than seeking to meet the national needs for trained science, engineering and technology graduates. Pressures on cost are encouraging universities to move away from the 'hard' sciences towards cheaper arts, humanities and business courses, and to seek alternatives to expensive practical classes in those science courses that they do run. The government aim in the 10-year Science and Innovation Investment Framework is for the UK to be the best environment in the world for science, engineering and technology. This will not happen if universities cannot provide graduates with the essential practical skills that they need.

[28]Biochemical Society (2002) *Feasibility Study on Course Recognition,* internal report.

[29]HESA first destination data http://www.hesa.ac.uk/ (Last accessed 12 May 2005).

Appendix 1

The consultation questionnaire

Core 3+ to 16 biology education

1. What essential skills should the great majority of 16 year-olds acquire as a result of studying biology from the age of 3+, whether or not they continue their study of biology beyond 16?

2. What essential knowledge should the great majority of 16 year-olds acquire as a result of studying biology from the age of 3+, whether or not they continue their study of biology beyond 16?

3. How successful do you feel present curricula and teaching are in helping 16 year-olds acquire these core skills and knowledge?

4. The emphasis of this review is on keeping content to a core minimum, but looking ahead, what areas of biology do you think should be incorporated into the school curriculum (age range 3+ to 16 years) that are currently under-represented?

5. How do you think the assessment of biology skills and knowledge could be improved across the 3+ to 16 years age range?

6. How do you think the teaching of biology could be improved across the 3+ to 16 years age range?

For those continuing biology post-16

7. What skills should 19-year-olds who intend to take their study of biology further acquire as a result of studying biology between 16 and 19?

8. What knowledge should 19-year-olds who intend to take their study of biology further acquire as a result of studying biology between 16 and 19?

9. How do you think the assessment of biology skills and knowledge could be improved across the 16 to 19 years age range?

10. How do you think the teaching of biology could be improved across the 16 to 19 years age range?

For those continuing biological sciences in higher education

11. What skills should undergraduates in the biological sciences acquire?

12. What knowledge should undergraduates in the biological sciences acquire?

13. How do you think the assessment of biological sciences skills and knowledge at undergraduate level could be improved?

14. How do you think the teaching of the biological sciences at undergraduate level could be improved?

Appendix 2

Organisations or individuals who responded to the consultation questionnaire

1. Association of the British Pharmaceutical Industry
2. Association for Science Education (ASE) Primary Committee
3. ASE 11-19 Committee
4. Biochemistry Department, University of Bristol
5. Biotechnology and Biological Sciences Research Council
6. British Ecological Society
7. British Lichen Society
8. British Pharmacological Society
9. British Society for Cell Biology
10. Dr Don Smith, University of Derby
11. Dr Mike Tribe
12. Dr Peter Dean, Cambio Ltd
13. Field Studies Council
14. GlaxoSmithKline R&D
15. Higher Education Academy Centre for Bioscience
16. Laboratory Animal Science Association
17. Medical Research Council
18. Natural Environment Research Council
19. Qualifications and Curriculum Authority
20. Royal Society of Chemistry
21. Science, Engineering and Manufacturing Technologies Alliance
22. Society for General Microbiology
23. Biosciences, University of Durham
24. Wellcome Trust

Appendix 3

Organisations and individuals who commented on the original draft report

1. Association of the British Pharmaceutical Industry
2. ASE Primary Committee
3. ASE 11-19 Committee
4. Association for the Study of Animal Behaviour
5. Biochemistry Department, University of Bristol
6. Biosciences Federation Education Committee
7. Biotechnology and Biological Sciences Research Council
8. British Association
9. British Lichen Society
10. British Society for Cell Biology
11. Council for the Curriculum, Examinations and Assessment (Northern Ireland)
12. Dr J Calvert, Newcastle University
13. Dr K O'Dell, Glasgow University
14. Dr P Gadsdon, Liverpool John Moores University
15. Field Studies Council
16. Genetics Society
17. Higher Education Academy Centre for Bioscience
18. Higher Education Funding Council for England
19. HM Inspectorate of Education (Scotland)
20. Medical Research Council
21. National Centre for Biotechnology Education
22. Natural Environment Research Council
23. National Network for Science, Technology, Engineering and Mathematics (SETNET)
24. Prof K J Flynn, Swansea University
25. Prof T Blundell, Biosciences Federation Council
26. Prof W Bickmore, Edinburgh University
27. Qualifications and Curriculum Authority
28. Royal Society Education Committee
29. Royal Society of Chemistry
30. Salters-Nuffield Advanced Biology Project
31. Science and Plants in Schools
32. Wellcome Trust