Designing and implementing a new advanced level biology course

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Abstract

Salters-Nuffield Advanced Biology is a new advanced level biology course currently being piloted from September 2002 in England with around 1200 students. This paper discusses the reasons for developing a new advanced biology course at this time, the philosophy of the project and how the materials are being written and the specification devised. The aim of the project is to provide an up-to-date course that interests students, is considered appropriate by teachers and other professionals in biology, and takes full advantage of modern developments in biology and in teaching.

Historical context

In England and Wales, and a number of overseas countries, the advanced level examinations are the examinations usually taken by those pupils who remain in full-time education after the age of 16 years. Since September 2000, they have fallen into two halves. At the end of the first year each student is awarded an AS grade; at the end of the second year, those students (typically around 75% of them) who continue with the subject are awarded their final A2 grades, half of which is made of up marks obtained during and at the end of the second year of study – the other half coming from the marks that contributed to the AS grade.

To a certain extent, advanced level biology appeared during the 1990s to be in a healthier state than either advanced level chemistry or physics (Reiss, 1998). The number of candidates grew fairly steadily throughout the 1990s and there appeared, though the data are anecdotal, to be fewer complaints from those running university biology courses about the knowledge of students coming to read undergraduate degrees in the subject.

There are, nevertheless, worrying concerns about advanced level biology, for there has been mounting (though, again, mostly anecdotal) evidence that much teaching in the subject results in little student involvement, lacks variety and is dull (Lock, 1998). Perhaps most importantly, we are now in the century that is likely to be dominated by biology, and yet there has, until the project reported here, been no major curriculum initiative in the subject since Nuffield Biology was launched some thirty years ago. Significant and valuable work has been done by a number of groups (notably the National Council for Biotechnology Education and Science and Plants for Schools) but even here the results have been restricted to small sections of the various specifications (syllabuses).

As a result, the new advanced level biology specifications introduced in September 2000 failed to reflect many of the tremendous advances presently being made in the discipline in all its diverse fields – molecular biology, cell biology, medical physiology, genetics, biotechnology, conservation, behaviour, the brain and evolution. Furthermore, the current textbooks and other resources simply reflect the existing specifications, presenting a somewhat narrow impression of what it is to be a biologist, whether industrial or academic, and making disappointingly little use of recent developments in Information and Communications Technology (ICT) for teaching and learning.

All this is at a time when there is increasing recognition that different teaching methods used in biology vary in their effectiveness (Killermann, 1996), that students learn science best by being mentally active and reflective (Woolnough *et al.,* 1999) and that there is no substitute for student and teacher enthusiasm (Holbrook, 1999). Concurrently, there is a broad-based acceptance by industrialists and organisations such as The Science, Technology and Mathematics Council that school biology/science curricula need to be reformed (Anon, 1999: Gadd, 1999).

Salters-Nuffield Advanced Biology

On the 1st September 2000, The University of York Science Curriculum Centre and The Nuffield Curriculum Projects Centre launched the Salters-Nuffield Advanced Biology (SNAB) Project. This is a major curriculum initiative to develop a new Biology AS&A2 course. Our intention is to produce a modern, relevant and exciting course that engages students, takes account of the many recent advances in biology and makes use of the most appropriate teaching approaches and technologies to enable student learning.

Much of school science has the reputation of being difficult, dull, out-of-touch with students' aspirations and irrelevant to society as a whole (Osborne *et al.,* 1998). Specifications have traditionally been constructed from a scientist's viewpoint with the concepts being developed in a pattern that is seen to be sensible by a scientist. But many students see things differently and want teachers to show them *why* the concept is important. One possibility is to make the context – or storyline – the driving force.

To a certain extent, the case study/storyline approach is already used by some authors and within some advanced level biology specifications, particularly within certain optional modules (e.g. Applications of Genetics, Food Technology). It has been argued that existing biology curricula provide an inadequate representation of what practising biologists do (Roberts & Gott, 1999). Salters-Nuffield Advanced Biology aims to produce a coherent course that will enthuse students and teachers/lecturers by portraying an up-to-date indication of what it is like to use contemporary biology in research, in industry and in everyday life.

The initiative quickly generated a great deal of interest among biology teachers, lecturers and educators. Some 400 people have asked to join the project database, with many also offering help. A web-site (www.advancedbiology.org) and e-mail contact list (contact ams12@york.ac.uk) have been established to ensure that everyone who wants is kept informed, and to allow us to draw on the wealth of expertise on offer.

Consultation

A wide-ranging consultation process was undertaken to determine the overall content and form of the course (Hall *et al.*, 2001). This included meetings with expert biologists, teachers, educators and students. The one-to-one discussions with academic and other specialist biologists allowed us to identify key areas of biology that are expected to make a significant contribution to the future of the subject and to society in general. We are including these areas of biology within the course to ensure that what we produce is timely, challenging and motivates students.

One feature of the consultation process that particularly encouraged us was the very considerable degree of agreement among people from the various categories we interviewed. In particular, there was strong agreement: (a) that the course should provide a broad-based introduction to biology with a good balance between the various sub-disciplines within biology (molecular biology, genetics, environmental biology, etc.); (b) that the course must develop the ability of students to think creatively and critically (cf. Lawson *et al.*, 2000); (c) that the course must not be overburdened by content. Here, for example, is one quote from a university professor of biology reflecting on his own teaching:

> When I was teaching, each successive year I took things out and every year the external assessors would come in and examine the students at the end and say they understood it better than last year. They seemed to know more. I think, probably, by the end of the time I was doing it, I was probably teaching less than half of what I had started and they were understanding it better. It meant that when they read something somewhere else they actually got the benefit of that instead of just having this huge batch of facts. There is a real benefit in the less you teach the more they retain of that. You have to just get the right balance – not so little they retain it all but there is only a tiny bit of it. Spouting facts at people does not switch on many at all.

In addition to many individual interviews, four consultation meetings were held in the first six months of the project; these were attended by over 100 teachers and lecturers/educationalists. The consultation meetings were valuable in shaping the ongoing development of the philosophy, structure and content of the course. The close liaison with a large number of practising advanced level biology teachers has ensured that the features they view as important were incorporated from the outset.

Producing the course

Throughout the course biological principles will be studied in the context of real life applications of biology, thus making the content more relevant to students. Having decided on the outline structure of the course, namely five topics at AS and four at A2, the contexts to be included were considered. This process was informed by the many discussions with biologists and advanced level biology teachers/lecturers. The contexts needed to be topical, of interest to the students, but also enduring. For this reason we were reluctant to have too much on recent or currently newsworthy 'crises' in biology, such as BSE (bovine spongiform encephalopathy) or foot-and-mouth disease, for fear that these might date quickly. On the other hand, contexts like global climate change, genetic engineering and cystic fibrosis are likely to be around at least until we have a second edition! Ten potential storylines were selected and presented at the Association for Science Education Annual Meeting in January 2001. The comments received were positive and helped us decide on the best order for the topics.

At this stage we embarked simultaneously on two major parts of the project: writing the materials to be used by the students and designing the specification to be examined. No specification can be taught at advanced level in England and Wales unless approved by the QCA (Qualifications and Curriculum Authority). Approval for the specification came, after protracted negotiation with QCA, in June 2002, allowing the pilot to start on time in September 2002 in about 45 centres, with some 1200 students initially taking the course. Summaries of the nine topics are presented in Table 1. These summaries are as presented in the pilot specification (available from the Awarding Body, Edexcel, at www.edexcel.org.uk/qualifications/QualificationAward.aspx?id=72372). We hope that we have struck a balance between providing fresh, up-to-date material and abandoning for no reason classics of biology, so that the specification is not overburdened with excessive content.

To give a more detailed indication of the content of a typical topic, Table 2 lists the learning objectives for Topic 4, 'Climate change'. This topic actually contains much biology that will be familiar to teachers/lecturers of advanced biology, for example: analysing and interpreting graphical and other data, global warming, the effect of increased CO_2 levels and increased temperatures on the rate of photosynthesis, experiments to see how temperature affects such biological processes as the growth of plants or the speed of hatching of poikilothermic eggs (those of brine shrimps), and the carbon cycle. In addition the topic also includes some new factual material, for example: the elucidation of past ecological records using pollen analysis and dendrochronology, remote sensing by satellites of sea surface temperatures, and the use of models to predict future climate changes.

Perhaps more importantly than the inclusion of new material, we have attempted throughout the course to make it as likely as possible that students engage with the issues, examine them critically and are able to develop their own opinions, substantiated by evidence. For instance, Topic 4 begins not – as one might have expected – with data on recent climate change , but with the extinction of the dinosaurs. The intention is not so much to teach students specifically about the extinction of the dinosaurs but to use that as a context allowing us to introduce the issue of what constitutes a valid scientific hypothesis and why. This should help students appreciate that there can be alternative explanations for scientific observations. In other words, we don't in this topic insist that current climate change is anthropogenic. We first examine the evidence that the climate really is changing; we then examine the evidence that this change is driven by human actions rather than being natural. For much the same reason we end Topic 4 with an analysis of the way in which different websites present data on climate change to illustrate the point that scientific conclusions about controversial issues can sometimes depend on who is reaching the conclusions.

Each of our nine topics has been written by a team of about five or six authors. Most or all of these in each team are practising teachers/lecturers of advanced level biology, whether at school or college. Each of our nine teams either contained an academic biologist or made links with such a person. In the case of Topic 4, the team leader was Dr David Slingsby, a school teacher with a PhD in ecology; the academic most involved in the topic was the renowned plant ecologist, Professor Philip Grime of the University of Sheffield.

Each team was given a precise brief (philosophy of the course, overall length required, number of figures permitted, time-table for submission of interim drafts, etc.) and attended a briefing weekend. In addition to producing the text to be included in the four student books that accompany the course, each team was also asked to devise and produce some 15 to 20 activities (discussed in more detail in the section below). Teams varied in the extent they were able to meet their briefs. During the briefing weekend each team began to work on what it considered to be a good storyline and range of activities for the students to undertake. Throughout the writing process the team interacted with and received feedback from the central SNAB team (Michael Reiss and Anne Scott from September 2000, Angela Hall from January 2000, Cathy Rowell from September 2002). Once each team hands over their materials, the central SNAB team edits them, often writing additional materials, particularly activities, too. The materials are then edited by Sarah Codrington of the Nuffield Curriculum Centre and sent to two or three academics for reviewing. Comments from these reviewers are incorporated before the materials go to Heinemann, the publishers of the course materials, for picture research and publication.

The electronic component of the course

The text for the nine topics is appearing in conventional student textbooks – the first of four textbooks for the pilot being Hall *et al.* (2002a). However, the evidence we collected in the first few months of the project (late 2000 and early 2001) not only showed that, as expected, every school and college has CD-ROM and internet access, but that this was true of the majority of the homes of the advanced level biology students too. Accordingly, the course has a strong electronic component, though we have ensured that it is still perfectly possible for students fully to undertake the course so long as their school or college can run a single CD-ROM – the first one of four for the pilot being Hall *et al.* (2002b).

The electronic component of the course exists at several levels. The bulk of each CD-ROM consists of pdf files that relate to what we call ‘activities’. Activities include practical work; so, for example, in Topic 4 we have a number of suggested items of practical work, some novel, some well established. Two of the items of practical work in Topic 4 are compulsory – and are indicated as such by being underlined in the specification (see Table 2). Each practical activity comes in up to three pdf files: one for the student (nearly always present), one for the teacher/lecturer (always present), and one for a technician (present if apparatus needed).

In addition to practical work, whether novel or well established, we have included a range of other activities. There is a multimedia introduction to each topic and a GCSE review test for students to complete before starting the topic; there are extracts from newspapers and other written sources that students are expected to interrogate; there are suggestions for discussions and debates that students might have; there are weblinks to appropriate websites that contain up-to-the-minute data; there are animations to show students what happens over time (for example in DNA replication and in the transport of materials across membranes); there are tutorials about key chemical and mathematical ideas in biology; there is extension material to supplement the student text; there is guidance on how to use ICT (for example on drawing graphs in Excel and using a flexicam); there is an end-of-topic test and so on.

The CD ROM has an optional custom-built learning environment. Teachers/lecturers can post to a ‘noticeboard’ in order to communicate with their classes, and can set work with the students’ homepages displaying assignment details and due dates.. The marks from the electronic end-of-topic tests feed automatically into the system’s mark book, which can also receive manually entered marks or other data. Finally, the CD ROM also sets up a teacher/lecturer web-based discussion group, and separate groups for students and technicians. We hope that the electronic component of the course will enable students to work more autonomously than is typically the case in advanced level biology courses. The course should also make it easier for a teacher/lecturer to cope with a wide range of student abilities and with students who miss chunks of work through illness or for other reasons.

Coursework assessment

We are very well aware that a new course needs to have a set of assessment mechanisms in place that fit tightly with the aims of the course. We invited the existing Awarding Bodies to submit tenders for the specification development and assessment of the course and, after interview, awarded the contract to Edexcel. We have worked with Edexcel to produce a set of assessment instruments that avoid many of the current pitfalls of advanced level science assessment. In particular, we have striven to produce a mechanism for assessing coursework that allows students to demonstrate what they know without they and their teachers/lecturers going through a sterile and apparently endless ritual in which practical work is routinised and repeated so as to allow as many students as possible to provide the evidence to enable their teachers/lecturers to complete a checklist showing that they can do all that the specification says they need to do.

Half the marks for coursework in the SNAB course at AS are awarded for a report (which must be word-processed) of a visit the student has made or of an issue they have studied. For example, students might go to a hospital, garden centre or supermarket and then produce a report of one particular aspect of the biology they saw in action. Alternatively, students can produce a report on almost any biological issue. The other half of the AS coursework marks are awarded on a Practical Work Review. This assesses the knowledge and experimental and investigative skills developed during the course. Edexcel will distribute an examination paper for the Practical Work Review to centres on a specified date, up to four weeks prior to the submission date. Students are then given a supervised period, of up to one hour, in which to complete the paper. They should be given the paper not more than seven days before this supervised time to prepare for their writing.

In order to complete the paper for the Practical Work Review students will need to refer to their portfolio of completed core practical write-ups. It is not essential for students to have completed all the core practicals, though non-completion will restrict their choice of write-ups to use in answering the questions in the Practical Work Review. The whole of the AS coursework is marked by Edexcel.

At A2, students submit a written report of up to 2000 words of an experimental investigation they have devised and carried out. Each student is required to carry out an extended practical project, taking the equivalent of two weeks of normal lesson and homework time – of course, this might be spread over much longer than two weeks. (One of the reasons why there are only four A2 topics compared to five at AS is to ensure that students have time to carry out a genuine practical project, modifying their ideas and refining their procedures as necessary.)

These investigations will draw on the skills developed during the AS. At A2, students will be assessed on their ability to plan and carry out experimental procedures, to interpret their experimental results, and to report on their work. The report must include the presentation and analysis of numerical data obtained by the student. It needs to be word processed and submitted on disc, by e-mail or by uploading to Edexcel's website. It will be marked by the teacher/lecturer; reports from selected students will be inspected by a Moderator appointed by Edexcel.

Where now?

The project is now in its pilot phase (Figure 1) and we have funding to run the project until September 2005. The intention is that at that point the project goes (inter)national and becomes financially self-supporting. QCA will be looking at the progress of the pilot and we have appointed Dr Jenny Lewis of the University of Leeds to conduct a formative, in depth evaluation in three centres to help us learn lessons from the pilot, enabling us to modify the materials and specification for the post-pilot version. Students, technicians and teachers/lecturers from all the centres are encouraged to submit feedback electronically on an on-going basis, and many are already doing so, while a sample of the centres (eleven in all) are completing detailed questionnaires on each topic. In addition, members of the central SNAB team are visiting a number of pilot centres to gather informal data on how things are going.

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Figure 1. Students at Esher College studying the SNAB pilot course (November 2002).

Students work through an interactive activity about measuring blood pressure. Small groups go off in turn to measure their blood pressure practically.

Topic 1 (AS) – Lifestyle, health and risk

This topic builds on the knowledge and understanding which students bring to the course on the functioning of the circulatory system and the importance of diet in maintaining the body. The role of diet and other lifestyle factors in maintaining good health is considered with particular reference to the heart and circulation and to cardiovascular disease. The structures and functions of some carbohydrates and lipids are also detailed within this context. The concept of risks to health is covered along with ways in which cardiovascular diseases may be diagnosed and treated.

Topic 2 (AS) – Genes and health

This topic considers the following biological principles: the properties of and transport of materials, across cell membranes and gas exchange surfaces, DNA structure and replication, protein synthesis and monohybrid inheritance through the context of the genetic disease cystic fibrosis (CF). The biological principles behind current treatment methods for CF are considered and the potential that gene therapy offers is examined. The topic also allows for discussion of the social and ethical issues surrounding the diagnosis and treatment of genetic conditions.

Topic 3 (AS) – The voice of the genome

This topic follows the story of the development of multicellular organisms from single cells to complex individuals. The contribution of the Human Genome Project to our understanding of human genes and gene action is stressed. Cell structure and ultrastructure, cell differentiation, tissue organisation, cell division, the control of development, the roles of stem cells, gene expression and the importance of fertilisation are all taught within this topic.

Topic 4 (AS) – Climate change

The topic begins by focusing on the observable effects that are being attributed to climate change. Students will appreciate the difference between climate change and global warming, will learn how these can be measured and modelled, and discuss whether climate changes can be attributed to global warming. This topic covers the ways in which species are adapted to survive in particular environmental conditions, the recycling of materials and the evidence that human activities have far reaching effects on the environment.

Topic 5 (AS) – Plants; can't run, can't hide

This topic focuses on both traditional and novel uses of plants. It has sections on plant fibres and their uses, the use of plant extracts, genetic modification of plants and biodegradable starch packaging. General biological principles covered include the relationship of anatomy to functioning, the transport of water through plants, the role of starch and the controversy surrounding genetically modified plants.

Topic 6 (A2) – On the wild side

This topic begins with Darwin's arrival on the Galapagos Islands where he was faced with a high biodiversity and very limited means to understand its origins. The topic continues by looking at the changing role of zoos. Students will then study how organisms are adapted to their environments. This will lead to an understanding of succession and an appreciation that photosynthesis is the primary process which underpins the majority of ecosystems. Students will see that successful conservation requires an understanding of the interactions between wildlife and human populations as well as a scientific knowledge of both genetics and ecology. Understanding how organisms become adapted to their environment requires an appreciation of the theory of evolution. By the end of the topic students will be able to appreciate how scientific understanding can make us aware of our responsibilities as stewards of the environment.

Topic 7 (A2) – Infection, immunity and forensics

This topic investigates the evolutionary battles that are taking place between invading pathogens and their hosts. Bacteria and viruses use a variety of routes into their hosts. Hosts have evolved barriers and internal mechanisms to combat infections. These protections are not always successful and many people in the world still die from infectious diseases. Forensic pathologists use a wide variety of analytical techniques to determine the cause of death of organisms, including humans, and to establish the time which has elapsed since death occurred.

Topic 8 (A2) – Run for your life

This topic is centred on the physiological adaptations that enable humans, particularly sportspeople, and other animals to undertake strenuous exercise. It explores the links between an animal's physiology and its performance. The topic summarises the biochemical requirements for respiration and looks at the links between homeostasis, muscle physiology and performance. It ends by looking at how medical technology is enabling more people to participate in sport, and by raising the issue as to whether the use of performance-enhancing substances by athletes can be justified.

Topic 9 (A2) – Grey matter

The first two decades of the twenty first century may be the decades of the brain. The scene is set by considering the methods which are used to compare the contributions of nature and nurture to brain development and by examining the role of genetics and animal models in understanding brain structure. The topic then looks at the workings of the nervous system, including the role of neurotransmitters, and at how imbalances in brain chemicals may result in conditions such as Parkinson's disease. The topic also demonstrates how an understanding of brain structure and functioning is relevant to such issues as the response to stimuli, learning, the development of vision and our ability to think and feel. The topic requires students to discuss the ethics of using animals for medical research.

Table 1. Specification summaries of the nine topics in the pilot Salters-Nuffield Advanced Biology course.

Topic 4 – Climate change

Learning Outcomes

Students should be able to:

1. Appreciate that there can be alternative explanations for scientific observations (e.g. the possible causes for the mass extinction of dinosaurs).
2. Explain how pollen records and dendrochronology can be used to determine past ecological conditions .
3. Analyse and interpret data which show climate change over time (temperature records, analysis of pollen in peat bogs, dendrochronology).
4. <u>Discuss the possible relationship between CO_2 levels and global warming and how this can be investigated practically.</u>
5. Interpret data on the effect of CO_2 concentration on atmospheric temperature.
6. Explain the effect of increased CO_2 levels and increased temperatures on the rate of photosynthesis and relate this to enzyme activity.
7. Discuss how climate change (including rising temperature, changes in rainfall, flooding patterns, seasonal cycles) can affect plants and animals (including distribution of species, development and lifecycles).
8. Describe how global environmental change is detected (remote sensing by satellites of sea surface temperatures, distribution and abundance of phytoplankton, distribution of vegetation cover).
9. <u>Describe how to investigate the effects of temperature on the development of organisms (e.g. plant growth or brine shrimp hatch rates).</u>

10. Explain the significance of the carbon cycle in regulating atmospheric carbon dioxide levels.

11. Explain the use of biofuels and reafforestation can help to reduce the impact of human activity on atmospheric CO_2 .

12. Understand how models can be used to predict future climate changes and discuss their limitations.

13. Describe the sources of greenhouse gases (water vapour, chlorofluorocarbons (CFCs), N_2O, CO_2 CH_4) and how their levels may be controlled.

14. Demonstrate the way in which scientific conclusions about controversial issues can sometimes depend on who is reaching the conclusions, including their ethical and cultural perspectives.

Table 2. The learning objectives for Topic 4, ‘Climate change’. Core practicals – i.e. practicals that need to be undertaken by students – are underlined.