# Developing a new biology course for 16-19 year-olds
# Desarrollando un nuevo curso de biología para estudiantes de 16-19 años

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**Abstract**

*Salters-Nuffield Advanced Biology (SNAB) is a new advanced level biology course for 16-19 year-olds. It is being launched in England and Wales from September 2005; from September 2002 it has been piloted with around 4000 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 have been written and the specification devised. The aim of the project is to provide an up-to-date course that enthuses students, is considered appropriate by teachers and other professionals in biology, and takes full advantage of modern developments in biology and in teaching.*

***Key words:*** biology, ICT, assessment, education.

**Resumen**

*El nuevo curso Salters-Nuffield de biología (SNAB) de nivel avanzado está diseñado para estudiantes de 16-19 años. El curso se lanzará en Inglaterra y Gales en septiembre de 2005; desde septiembre del 2002 se ha aplicado con alrededor de 4.000 estudiantes. En el artículo se discuten las razones para desarrollar un nuevo curso de biología avanzado, la filosofía del proyecto y cómo los materiales han sido escritos y diseñados. El objetivo del proyecto es proporcionar un curso moderno que entusiasme a los estudiantes, que sea apropiado para maestros y otros profesionales en la biología, y aprovechado para el desarrollo moderno en la biología y la enseñanza.*

***Palabras clave:*** biología, computadores, evaluación, enseñanza.

## HISTORICAL CONTEXT

In England and Wales, and a number of other countries with historical links to England, advanced level examinations are the examinations usually taken by those students who remain in full-time education after the age of 16 years. Since September 2000, advanced level examinations have fallen into two halves, each of one year. 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 two-thirds of them) who continue with the subject after the AS year 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 in England and Wales 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 were 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 were, nevertheless, and still are, 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 in the UK 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 (http://www.ncbe.reading.ac.uk/) and Science and Plants for Schools (http://www-saps.plantsci.cam.ac.uk/), but even here the results have been restricted to small sections of the various specifications (syllabuses).

As a result, the advanced level biology specifications introduced in England and Wales in September 2000 (a time when all advanced level specifications had to be revised) failed to reflect many of the tremendous advances presently being made in biology in all its diverse fields - molecular biology, cell biology, medical physiology, agriculture, genetics, biotechnology, conservation, behavior, the brain and evolution. Furthermore, existing advanced level biology textbooks and other resources simply reflect the current 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 (HALL *et al.*, 2003).

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 and engagement (HOLBROOK, 1999; Reiss, in press). Concurrently, there is a broad-based acceptance by industrialists and organizations 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 has been 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 (REISS, 2000; OSBORNE *et al.*, 2003). Specifications have traditionally been constructed from a scientist's viewpoint with the concepts being developed in a way that is seen to be sensible by a scientist. Typically this means that preeminence is given to scientific concepts (HART, 2002). But many students see things differently and want teachers to show them *why* the concepts are 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 genetic' and '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 asked to join the project database, with many also offering help. A website (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 included these areas of biology within the course to ensure that what we produced was timely, challenging and motivated 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 and Fellow of the Royal Society when asked "What do you perceive as the sort of cutting edge biology that should be in a course for advanced level students?":

> If I break it down into three. First of all, it has to include the reductionary science, the molecular and cell biology, which has advanced so much. But it also needs to include the second component which is the integrated biology so that it draws together the knowledge of cells and molecules in terms of functions of organisms and obviously, thirdly, it has to address the more global issues of an environmental nature.

In many ways the most interesting thing about this quote, and this was true of most of the answers to this question, was that despite being asked about "cutting edge biology", the answer given is a very balanced one, rather than one that draws on the particular specialism of the academic concerned (animal physiology, in this case).

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, lecturers and biology educators. 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 / lecturers has ensured that the features they view as important have been incorporated from the outset.

## PRODUCING THE COURSE

Throughout the course, biological principles are 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 for the pilot (subsequently modified to four topics at AS and four at A2 for the roll out version to start in September 2005), 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 (then) currently newsworthy 'crises' in biology, such as BSE (bovine spongiform encephalopathy), the MMR (measles, mumps, rubella) vaccine 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 for many time to come. Ten potential contexts 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 pilot 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 eight topics for the September 2005 course (thankfully approved by QCA much more speedily) are presented in Table 1. These summaries are as presented in the specification (available from the Awarding Body, Edexcel, at http://www.edexcel.org.uk/qualifications/QualificationAward.aspx?id=72373). We hope that we have struck a balance between providing fresh, up-to-date material and classics of biology – without producing a specification 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 3, 'The voice of the genome'. This topic actually contains much biology that will be familiar to teachers / lecturers of biology students in the 16-19 year age range, for example, cell ultrastructure, mitosis and meiosis, the differences between eukaryotes and prokaryotes, mammalian gametes and fertilisation, gene induction and gene-environment interactions. In addition, the topic also includes some new factual and ethical material, in particular, issues to do with stem cell research and the Human Genome Project.

At least as importantly as 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, in Topic 4 we use the evidence concerning global climate change as a way of 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 this topic we don't assume or insist that current climate change is caused by humans. 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 eight 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 teams either contained an academic biologist or made links with such a person. In the case of the climate change element of Topic 4, the team leader was Dr David Slingsby, a then 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 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 2001, Cathy Rowell from September 2002). Once each team handed over their materials, the central SNAB team edited them, often writing additional materials, particularly activities, too. The materials were then edited by Sarah Codrington of the Nuffield Curriculum Centre and sent to two or three academics for reviewing. Comments from these reviewers were incorporated before the materials went to Heinemann, the publishers of the course materials, for picture research and publication.

## THE ELECTRONIC COMPONENT OF THE COURSE

The text for the topics is appearing in conventional student textbooks - the first of four textbooks for the pilot being Hall *et al.* (2002a). At the time of writing, the AS student textbook is in press: Hall *et al.* (2005). 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. Each CD-ROM (and the associated area of the website) contains pdf files that relate to what we call 'activities'. Activities include practical work; so, for example, in Topic 3 we have a number of suggested items of practical work, some novel, some well established. Two of the items of practical work in Topic 3 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 review test for students to complete before starting the AS topics; 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, in protein synthesis, in the transport of materials across membranes and in photosynthesis); there are tutorials about key biochemical 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 are end-of-topic tests and so on.

The CD-ROM and website have 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. 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, zoo or pharmaceutical company 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, whether in the course or not.

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 distribute an examination paper for the Practical Work Review to centres that then give the paper to students on a specified date. A week or so later, students are given a one hour supervised period in which to complete the paper. In order to complete the paper for the Practical Work Review, students will need to refer to their portfolio of completed core (and other) 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 3000 words of an experimental investigation they have devised and carried out. This investigation is expected to take the equivalent of two weeks of normal lesson and homework time – of course, this might be spread over much longer than two weeks. The investigation 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.

Figure 1
Students at Ringwood School, a comprehensive school for 11-18 year-olds, studying the SNAB pilot course (November 2002). The students are just getting up to undertake an investigation on how enzyme concentration might affect the rate of a reaction, an investigation for which they had planned the procedure.

## WHERE NOW?

The project is now drawing towards the close of its pilot phase (Figure 1). In September 2005 the project goes (inter)national and becomes financially more self-supporting as income is received from examination fees and the sale of course materials. QCA have looked at the progress of the pilot and we 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 have been encouraged to submit feedback electronically on an on-going basis, and many have done so, while a sample of the centres (eleven in all) completed detailed questionnaires on each topic. In addition, members of the central SNAB team visited a number of pilot centres to gather informal data on how things were going.

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## BIBLIOGRAPHY

Anon, Sykes advises universities to turn clock back, *Chemistry & Education*, 18, 687, 1999.

Gadd, K., Hotspots in post 16 science, *Past Sixteen Science Issues*, 29, 17-18, 1999.

Hall, A.; Reiss, M. & Scott, A., Developing a new advanced level biology specification, *Science Teacher Education*, **31**, 14-16, 2001.

Hall, A.; Reiss, M. & Scott, A. (Eds.), *Salters-Nuffield Advanced Biology AS Student Book 1, Pilot edition*, Oxford: Heinemann, 2002a.

Hall, A.; Reiss, M. & Scott, A. (Eds.), *Salters-Nuffield Advanced Biology AS Student, Teacher and Technician Resource, CD-ROM 1, Pilot edition*, Oxford: Heinemann, 2002b.

Hall, A., Reiss, M.J., Rowell C. & Scott, C., Designing and implementing a new advanced level biology course, *Journal of Biological Education*, **37**, 161-167, 2003.

Hall, A., Reiss, M. Rowell, C. & Scott, A. (Eds.), *Salters-Nuffield Advanced Biology AS Student Book,* Oxford: Heinemann, 2005.

Hart, C., Framing curriculum discursively: theoretical perspectives on the experience of VCE Physics, *International Journal of Science Education*, **24**, 1055-1077, 2002.

Holbrook, J., World conference on science: science for the twenty-first century *A New Commitment* 26 June - 1 July 1999, Budapest, Hungary, *Science Education International*, **10** (3), 5-7, 1999.

Killermann, W., Biology education in Germany: research into the effectiveness of different teaching methods, *International Journal of Science Education*, **18**, 333-346, 1996.

Lawson, A.E.; Clark, B.; Cramer-Meldrum, E.; Falconer, K.A.; Sequist, J.M. & Kwon, Y.-J., Development of scientific reasoning in college biology: do two levels of general hypothesis-testing skills exist?, *Journal of Research in Science Teaching*, **37**, 81-101, 2000.

Lock, R., Advanced-level biology - is there a problem, *School Science Review*, **80** (290), 25-28, 1998.

Osborne, J.; Simon, S. & Collins, S., Attitudes towards science: a review of the literature and its implications, *International Journal of Science Education*, **25**, 1049-1079, 2003.

Reiss, M.J., The future of life science education, *School Science Review*, **79** (289), 19-24, 1998.

Reiss, M.J., *Understanding Science Lessons: Five Years of Science Teaching*, Open University Press, Buckingham, 2000.

Reiss, M.J., The importance of affect in science education. In: *The Affective Dimensions of Cognition: Studies from Education in the Sciences,* Alsop, S. (Ed.), Kluwer, Dordrecht, in press.

Roberts, R. & Gott, R., Procedural understanding: its place in the biology curriculum, *School Science Review*, **81** (294), 19-25, 1999.

Woolnough, B.E., McLaughlin, S. & Jackson, S., Learning by doing - two classroom studies of pupils' preferred ways of learning science, *School Science Review*, **81** (294), 27-34, 1999.

## Appendix

**Table 1**
**Specification summaries of the eight topics in the Salters-Nuffield Advanced Biology (SNAB) course.**

**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.

**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 potential that gene therapy offers as treatment for CF 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 organization, 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) - Plants and climate change**

The topic begins by focusing on how plants overcome the problems associated with being rooted in on spot and investigates how we have exploited their solutions. It has sections on both traditional and novel uses of plants, including 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. The effects of climate change on plants and animals are considered.

**Topic 5 (A2) - On the wild side**

This topic begins with crisis that faces biodiversity and looks at the role of classification in cataloguing the diversity of life. It then goes on to consider genetic diversity and ecological diversity. This provides students with an understanding of how ecosystems work. This builds an appreciation that photosynthesis is the primary process which underpins the majority of ecosystems and leads on to how organisms are adapted to their environments. The topic continues by looking at how the diversity of life has arisen through natural selection and evolution. Students then study how ecosystems and their biodiversity can be protected through *in situ* and *ex situ* conservation, in particular by looking at the changing role of zoos. 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. 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 6 (A2) - Infection, immunity and forensics**

This topic starts by looking at how 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. It then considers how bacteria and viruses use a variety of routes into their hosts and how 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. This topic also investigates the evolutionary battles that take place between invading pathogens and their hosts.

**Topic 7 (A2) - Run for your life**

This topic is centred on the physiological adaptations that enable humans, particularly sports people, and other animals to undertake strenuous exercise. It explores the links between an animal's physiology and its performance. The topic summarizes 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 8 (A2) - Grey matter**

The scene is set by considering how the working of the nervous system enables us to see. Brain imaging and the regions of the brain are considered. The topic also demonstrates how an understanding of brain structure and functioning is relevant to such issues as the response to stimuli, the development of vision and learning. 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 requires students to discuss the ethics of using animals for medical research. How imbalances in brain chemicals may result in conditions such as Parkinson's disease are investigated.

**Table 2**
**The learning objectives for Topic 3, 'The voice of the genome'. Core practicals – i.e. practicals that need to be undertaken by students for examination purposes – are underlined.**

**Topic 3 - The voice of the genome**

**Learning Outcomes**

Students should be able to:

1. Describe the ultrastructure of a typical eukaryotic cell (nucleus, ribosomes, rough and smooth endoplasmic reticulum, mitochondria, centrioles, lysosomes, nucleolus).
2. Explain the role of the rough endoplasmic reticulum (rER) and the Golgi apparatus in protein trafficking within cells.
3. Distinguish between the ultrastructures of eukaryotic and prokaryotic cells.
4. Explain the role of DNA replication and mitosis in the cell cycle.
5. Explain the significance of mitosis for growth and asexual reproduction.
6. Describe the stages of mitosis and how they can be observed practically.
7. Explain how mammalian gametes are specialized for their functions including the acrosome reaction.
8. Explain the importance of fertilisation in sexual reproduction.
9. Explain how meiosis results in the halving of chromosome numbers and the introduction of variation through random assortment (the stages of meiosis, crossing over chiasmata are not required).
10. Explain what is meant by stem cells, pluripotency and totipotency.
11. Discuss the moral, ethical and spiritual implications of stem cell research,
12. Explain how genes can be switched on and off by DNA transcription factors and how this gene switching gives rise to specialized cells.
13. *Describe how the expression of a gene can be demonstrated practically by induction of* b *galactosidase.*
14. Explain how certain characteristics may be affected by both genotype and the environment, including human height, skin colour, hair colour and cancers.
15. Explain that cancers arise from uncontrolled cell division (detailed knowledge of the checkpoint control in the cell cycle is not required) and describe genetic, environmental and lifestyle causes of cancer.
16. Discuss the principal outcomes of the Human Genome Project and the social, moral and ethical issues which arise from it.

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