**Plants in the national curriculum audit**

(Compiled by Angela Hall[[1]](#footnote-1), August 2019)

**Introduction**

This curriculum audit identifies plant science topics in the national curriculum for England and general biology topics that could be taught in the context of plants. It has been compiled for Reading Botany 2019’s *Symposium: The Big Botany Challenge – promoting passion for plants in secondary schools* at the University of Readingon Friday, 8th November.

Columns for 'resources and assessment' and 'plant stories' in tables on p.4-18 are included for delegates to add examples of these relevant to curriculum topics. Some examples will be provided at the symposium.

National Curriculum content for Key Stages 3 and 4, and core (statutory) content for Biology A level is presented below. Only those topics which directly refer to plants or could be exemplified through plant topics are included.

One advanced level and one GCSE specification are also provided as examples to demonstrate the balance of plant science and non-plant science topics and those which could be taught using plant examples in the Appendices. A summary is provided of this audit in the Symposium booklet.

**Contents**

[SUMMARY OF AUDIT 2](#_Toc23593255)

[Table 1. KS3 Working Scientifically 4](#_Toc23593256)

[Table 2. KS3 Biology 5](#_Toc23593257)

[Table 3. KS3 Chemistry 7](#_Toc23593258)

[Table 4. KS3 Physics 8](#_Toc23593259)

[KEY STAGE 4 9](#_Toc23593260)

[Table 5. KS4 Working Scientifically 9](#_Toc23593261)

[Table 6. KS4 Biology 10](#_Toc23593262)

[Table 7. KS4 Chemistry 12](#_Toc23593263)

[Table 8. KS4 Physics 13](#_Toc23593264)

[KEY STAGE 5 15](#_Toc23593265)

[Table 9. KS5 Working Scientifically 15](#_Toc23593266)

[Table 10. KS5 Biology 15](#_Toc23593267)

[**APPENDIX 1. Example of KS4 external examination** 19](#_Toc23593268)

[**APPENDIX 2. Example of KS5 external examination** 42](#_Toc23593269)

# SUMMARY OF AUDIT

Plant topics at GSCE: using the example ofAQA Biology GCSE

Overview:

* 3 of the 10 required practical activities are plant based;
* 9 of the 102 statements in the specification are specifically plant topics;
* 52 of the 102 statements in the specification could be illustrated by both plants and other organisms;, and,
* 41 can only be illustrated by other organisms (not plants).

GCSE plant-based topics:

* Meristems and differentiation into specialised plant tissues
* Plant cloning and its role in conservation and horticulture
* Adaptations of roots and leaves for exchange
* Uptake of water by osmosis
* Structure and function of plant tissues
* Plant organ systems, including transpiration, transport, nutrition and active transport
* Viral, bacterial and fungal plant diseases and mineral deficiencies, and their effects on plants
* Development of digitalis and aspirin from plants
* Physical and chemical defence mechanisms
* Photosynthesis and the effect of light intensity on rate
* Starch and cellulose in plants
* Control and coordination through hormones – applications in horticulture
* Effect of light and gravity on seedlings
* Sexual and asexual reproduction
* Selective breeding
* Genetic engineering and GM crops
* Commercial uses of cloning
* Mendel and plant breeding
* Competition between species in a community
* Producers in food chains

Plant topics at A level Biology: using the example of Edexcel A Salters-Nuffield

Overview:

* 6 of the 18 core practicals are plant-based;
* 15 of the 120 statements in the specification are specifically plant topics;
* 59 of the 120 statements in the specification could be illustrated by both plants and other organisms; and,
* 44 can only be illustrated by other organisms (not plants).

A level plant-based topics:

* Mitosis root tip squash
* Ultrastructure of plant cells and function of organelles
* Biochemistry and properties of cellulose and starch in relation to their functions in plants
* Sclerenchyma, xylem and phloem structure and function in transport and support
* Plant nutrition
* Drug development using plant-based compounds
* Antimicrobial properties of plant-based chemicals
* Role of plant material in sustainable plastic alternatives
* The role of seed banks in conservation
* Photosynthesis
* Plant productivity and respiration
* Evidence of climate change from peat bogs and dendrochronology
* Reforestation and use of sustainable biofuels
* Plant responses including effect of IAA and phytochrome on transcription

# Table 1. KS3 Working Scientifically

| **Plant topics** | **KS3 Working Scientifically general topics** | **Resources and assessment** | **Plant stories** |
| --- | --- | --- | --- |
| **A. Scientific attitudes** |
|  | 1. *pay attention to objectivity and concern for accuracy, precision, repeatability and reproducibility;*
2. *understand that scientific methods and theories develop as earlier explanations are modified to take account of new evidence and ideas, together with the importance of publishing results and peer review; and,*
3. *evaluate risks.*
 |  |  |
| **B. Experimental skills and investigations** |
|  | 1. *ask questions and develop a line of enquiry based on observations of the real world, alongside prior knowledge and experience;*
2. *make predictions using scientific knowledge and understanding;*
3. *select, plan and carry out the most appropriate types of scientific enquiries to test predictions, including identifying independent, dependent and control variables;*
4. *use appropriate techniques, apparatus, and materials during fieldwork and laboratory work, paying attention to health and safety;*
5. *make and record observations and measurements using a range of methods for different investigations; and evaluate the reliability of methods and suggest possible improvements; and,*
6. *apply sampling techniques.*
 |  |  |
| **C. Analysis and evaluation** |
|  | 1. *apply mathematical concepts and calculate results;*
2. *present observations and data using appropriate methods, including tables and graphs;*
3. *interpret observations and data, including identifying patterns and using observations, measurements and data to draw conclusions;*
4. *present reasoned explanations, including explaining data in relation to predictions and hypotheses;*
5. *evaluate data, showing awareness of potential sources of random and systematic error; and,*
6. *identify further questions arising from their results.*
 |  |  |
| **D. Measurement** |
|  | 1. *understand and use SI units and IUPAC (International Union of Pure and Applied Chemistry) chemical nomenclature;*
2. *use and derive simple equations and carry out appropriate calculations; and,*
3. *undertake basic data analysis including simple statistical techniques.*
 |  |  |

# Table 2. KS3 Biology

| **Plant topics** | **KS3 Biology general topics** | **Resources and assessment** | **Plant stories** |
| --- | --- | --- | --- |
| **A. Structure and function of living organisms - cells and organisation** |
| The similarities and differences between plant and animal cells.The functions of the cell wall, cell membrane, cytoplasm, nucleus, vacuole, mitochondria and chloroplasts. | *Cells as the fundamental unit of living organisms, including how to observe, interpret and record cell structure using a light microscope.**The role of diffusion in the movement of materials in and between cells.**The**hierarchical organisation of multicellular organisms: from cells to the tissues to organs to systems to organisms.* |  |  |
| **B. Structure and function of living organisms - nutrition and digestion** |
| Plants making carbohydrates in their leaves by photosynthesis and gaining mineral nutrients and water from the soil via their roots. | *The content of a healthy human diet: carbohydrates, lipids (fats and oils), proteins, vitamins, minerals, dietary fibre and water, and why each is needed; and,**Calculations of energy requirements in a healthy daily diet.* |  |  |
| **C. Structure and function of living organisms - gas exchange systems** |
| The role of leaf stomata in gas exchange in plants. |  |  |  |
| **D. Structure and function of living organisms - reproduction** |
| Reproduction in plants, incl. flower structure, wind and insect pollination, fertilisation, seed and fruit formation and dispersal, including quantitative investigation of some dispersal mechanisms. |  |  |  |
| **E. Material cycles and energy - photosynthesis** |
| The reactants in, and products of, photosynthesis, and a word summary for photosynthesis.* The dependence of almost all life on Earth on the ability of photosynthetic organisms, such as plants & algae, to use sunlight in photosynthesis to build organic molecules that are an essential energy store & to maintain levels of oxygen and carbon dioxide in the atmosphere.
* The adaptations of leaves for photosynthesis.
 |  |  |  |
| **F: Material cycles and energy - cellular respiration** |
|  | *Aerobic & anaerobic respiration in living organisms, including the breakdown of organic molecules to enable all the other chemical processes necessary for life.**A word summary for aerobic respiration.* |  |  |
| **G. Interactions and interdependencies – relationships in an ecosystem** |
| * The interdependence of organisms in an ecosystem, including food webs and insect pollinated crops.
* The importance of plant reproduction through insect pollination in human food security.
 | *How organisms affect, & are affected by, their environment, including the accumulation of toxic materials.* |  |  |
| **H. Genetics and evolution - inheritance, chromosomes, DNA and genes** |
|  | *Heredity as the process by which genetic information is transmitted from one generation to the next.**A simple model of chromosomes, genes & DNA in heredity, incl. the part played by Watson, Crick, Wilkins & Franklin in the development of the DNA model.**Differences between species.**The variation between individuals within a species being continuous or discontinuous, to include measurement and graphical representation of variation.**The variation between species and between individuals of the same species meaning some organisms compete more successfully, which can drive natural selection.**Changes in the environment which may leave individuals within a species, and some entire species, less well adapted to compete successfully and reproduce, which in turn may lead to extinction.* |  |  |

# Table 3. KS3 Chemistry

| **Plant topics** | **KS3 Chemistry general topics** | **Resources and assessment** | **Plant stories** |
| --- | --- | --- | --- |
| **Materials**  |
| The importance of maintaining biodiversity and the use of gene banks to preserve hereditary material. | *Properties composites (qualitative).* |  |  |
| **Earth and atmosphere** |
|  | *Earth as a source of limited resources and the efficacy of recycling.* |  |  |

# Table 4. KS3 Physics

| **Plant topics** | **KS3 Physics general topics** | **Resources and assessment** | **Plant stories** |
| --- | --- | --- | --- |
| **Energy - calculation of fuel uses and costs in the domestic context** |
|  | *Comparing energy values of different foods (from labels) (kJ).**Fuels and energy resources.* |  |  |
| **Energy changes and transfers** |
|  | *Other processes that involve energy transfer: metabolism of food, burning fuels.* |  |  |
| **Light waves** |
|  | *Light transferring energy from source to absorber, leading to chemical and electrical effects.**Colours and the different frequencies of light [..] differential colour effects in absorption and diffuse reflection.* |  |  |

# KEY STAGE 4

# Table 5. KS4 Working Scientifically

| **Plant topics** | **KS4 Working Scientifically general topics** | **Resources and assessment** | **Plant ‘stories’** |
| --- | --- | --- | --- |
| **1. The development of scientific thinking** |
|  | 1. *the ways in which scientific methods and theories develop over time*
2. *using a variety of concepts and models to develop scientific explanations and understanding*
3. *appreciating the power and limitations of science and considering ethical issues which may arise*
4. *explaining everyday and technological applications of science; evaluating associated personal, social, economic and environmental implications; and making decisions based on the evaluation of evidence and arguments.*
5. *evaluating risks both in practical science and the wider societal context, including perception of risk.*
6. *recognising the importance of peer review of results and of communication of results to a range of audiences.*
 |  |  |
| **2. Experimental skills and strategies** |
|  | 1. *using scientific theories and explanations to develop hypotheses*
2. *planning experiments to make observations, test hypotheses or explore phenomena*
3. *applying a knowledge of a range of techniques, apparatus, and materials to select those appropriate both for fieldwork and for experiments*
4. *carrying out experiments appropriately, having due regard to the correct manipulation of apparatus, the accuracy of measurements and health and safety considerations*
5. *recognising when to apply a knowledge of sampling techniques to ensure any samples collected are representative*
6. *making and recording observations and measurements using a range of apparatus and methods*
7. *evaluating methods and suggesting possible improvements and further investigations.*
 |  |  |
| **3. Vocabulary, units, symbols and nomenclature** |
|  | 1. *developing their use of scientific vocabulary and nomenclature*
2. *recognising the importance of scientific quantities and understanding how they are determined*
3. *using SI units and IUPAC chemical nomenclature unless inappropriate*
4. *using prefixes and powers of ten for orders of magnitude (e.g. tera, giga, mega, kilo, centi, milli, micro and nano)*
5. *interconverting units*
6. *using an appropriate number of significant figures in calculations*
 |  |  |

# Table 6. KS4 Biology

| **Plant topics** | **KS4 Biology general topics** | **Resources and assessment** | **Plant ‘stories’** |
| --- | --- | --- | --- |
| **A. Cell biology** |
| Meristems in plants | 1. *cells as the basic structural unit of all organisms; adaptations of cells related to their functions; the main sub-cellular structures of eukaryotic and prokaryotic cells*
2. *enzymes*
3. *factors affecting the rate of enzymatic reactions*
4. *the importance of cellular respiration; the processes of aerobic and anaerobic respiration*
5. *carbohydrates, proteins, nucleic acids and lipids as key biological molecules*
 |  |  |
| **B. Transport systems** |
| The need for transport systems in multicellular organisms, including plants |  |  |  |
| **C. Health, disease and the development of medicines** |
| Bacteria, viruses and fungi as pathogens in animals and plantsReducing and preventing the spread of infectious diseases in animals and plants | *The process of discovery and development of new medicines.* |  |  |
| **D. Photosynthesis** |
| Photosynthesis as the key process for food production and therefore biomass for lifeThe process of photosynthesisFactors affecting the rate of photosynthesis |  |  |  |
| **E. Ecosystems** |
|  | 1. *levels of organisation within an ecosystem*
2. *some abiotic and biotic factors which affect communities; the importance of interactions between organisms in a community*
3. *how materials cycle through abiotic and biotic components of ecosystems*
4. *the role of microorganisms (decomposers) in the cycling of materials through an ecosystem*
5. *organisms are interdependent and are adapted to their environment*
6. *the importance of biodiversity*
7. *methods of identifying species and measuring distribution, frequency and abundance of species within a habitat*
8. *positive and negative human interactions with ecosystems*
 |  |  |
| **F. Evolution, inheritance and variation** |
| The importance of selective breeding of plants (and animals) in agriculture | 1. *the genome as the entire genetic material of an organism*
2. *how the genome, and its interaction with the environment, influence the development of the phenotype of an organism*
3. *the potential impact of genomics on medicine*
4. *most phenotypic features being the result of multiple, rather than single, genes*
5. *single gene inheritance and single gene crosses with dominant and recessive phenotypes*
6. *genetic variation in populations of a species*
7. *the process of natural selection leading to evolution*
8. *the evidence for evolution*
9. *developments in biology affecting classification*
10. *the uses of modern biotechnology including gene technology; some of the practical and ethical considerations of modern biotechnology*
 |  |  |

# Table 7. KS4 Chemistry

| **Plant topics** | **KS4 Chemistry general topics** | **Resources and assessment** | **Plant ‘stories’** |
| --- | --- | --- | --- |
| **Structure, bonding and the properties of matter** |
|  | Bulk properties of materials related to bonding and intermolecular forcesBonding of carbon leading to the vast array of natural and synthetic organic compounds that occur due to the ability of carbon to form families of similar compounds, chains and rings |  |  |
| **Chemical changes** |
|  | Balanced chemical equationsReduction and oxidation in terms of loss or gain of oxygen. |  |  |
| **Energy changes in chemistry** |
|  | Measurement of energy changes in chemical reactions (qualitative)Bond breaking, bond making, activation energy and reaction profiles (qualitative) |  |  |
| **Rate and extent of chemical change** |
|  | Factors that influence the rate of reaction: varying temperature or concentration…..Factors affecting reversible reactions |  |  |
| **Chemical analysis** |
|  | Separation techniques for mixtures of substances: [ ] chromatographyQuantitative interpretation of balanced equations |  |  |
| **Chemical and allied industries** |
|  | Life cycle assessment and recycling to assess environmental impacts associated with all the stages of a product’s lifeThe viability of recycling of certain materialsCarbon compounds, both as fuels and feedstock, and the competing demands for limited resources |  |  |
| **Earth and atmospheric science** |
|  | Potential effects of, and mitigation of, increased levels of carbon dioxide and methane on the Earth’s climate |  |  |
|  |  |  |  |

# Table 8. KS4 Physics

| **Plant topics** | **KS4 Physics general topics** | **Resources and assessment** | **Plant ‘stories’** |
| --- | --- | --- | --- |
| **Energy** |
|  | calculating energy efficiency for any energy transfersrenewable and non-renewable energy sources used on Earth, changes in how these are used |  |  |
| **Wave motion** |
|  | …. waves transferring energy; wavelengths and frequencies from radio to gamma-raysproduction and detection, ……. changes in atoms and nuclei |  |  |

# KEY STAGE 5

Biology AS and A level Core (statutory) content:

The A level knowledge and understanding combined must comprise approximately 60% of an A level specification. All of the content below is required for the A level. The AS knowledge and understanding in this core content must comprise approximately 60% of the AS specification, and is shown below in normal (nonbold) text. Biology specifications must ensure that there is an appropriate balance between plant biology, animal biology and microbiology and include an appreciation of the relevance of sustainability to all aspects of scientific developments.

# Table 9. KS5 Working Scientifically

| **Plant topics** | **KS5 Working Scientifically topics which can use plant contexts/ examples** | **Resources and assessment** | **Plant ‘stories’** |
| --- | --- | --- | --- |
| **Working Scientifically** |
|  | use theories, models and ideas to develop scientific explanations • use knowledge and understanding to pose scientific questions, define scientific problems, present scientific arguments and scientific ideas • use appropriate methodology, including information and communication technology (ICT), to answer scientific questions and solve scientific problems • carry out experimental and investigative activities, including appropriate risk management, in a range of contexts • analyse and interpret data to provide evidence, recognising correlations and causal relationships • evaluate methodology, evidence and data, and resolve conflicting evidence • know that scientific knowledge and understanding develops over time • communicate information and ideas in appropriate ways using appropriate terminology • consider applications and implications of science and evaluate their associated benefits and risks • consider ethical issues in the treatment of humans, other organisms and the environment • evaluate the role of the scientific community in validating new knowledge and ensuring integrity • evaluate the ways in which society uses science to inform decision making |  |  |

# Table 10. KS5 Biology

| **Plant topics** | **KS5 Biology topics which can use plant contexts/ examples** | **Resources and assessment** | **Plant ‘stories’** |
| --- | --- | --- | --- |
| **Interdependence** |
|  | Living organisms, including plants, animals and microorganisms, interact with each other and with the non-living world. The living world can be studied at population, organism, cell and molecular levels. There are fundamental similarities as well as differences between plants, animals and microorganisms. |  |  |
| **Biodiversity** |
|  | the variety of life, both past and present, is extensive, but the biochemical basis of life is similar for all living things • biodiversity refers to the variety and complexity of life and may be considered at different levels • biodiversity can be measured, for example within a habitat or at the genetic level • classification is a means of organising the variety of life based on relationships between organisms and is built around the concept of species • originally classification systems were based on observable features but more recent approaches draw on a wider range of evidence to clarify relationships between organisms • adaptations of organisms to their environments can be behavioural, physiological and anatomical • adaptation and selection are major factors in evolution and make a significant contribution to the diversity of living organisms |  |  |
| **Exchange and transport** |
|  | organisms need to exchange substances selectively with their environment and this takes place at exchange surfaces • factors such as size or metabolic rate affect the requirements of organisms and this gives rise to adaptations such as specialised exchange surfaces and mass transport systems • substances are exchanged by passive or active transport across exchange surfaces • the structure of the plasma membrane enables control of the passage of substances into and out of cells |  |  |
| **Cells** |
|  | the cell theory is a unifying concept in biology • prokaryotic and eukaryotic cells can be distinguished on the basis of their structure and ultrastructure • in complex multicellular organisms cells are organised into tissues, tissues into organs and organs into systems • during the cell cycle genetic information is copied and passed to daughter cells • daughter cells formed during mitosis have identical copies of genes while cells formed during meiosis are not genetically identical |  |  |
| **Biological molecules** |
|  | biological molecules are often polymers and are based on a small number of chemical elements • in living organisms nucleic acids (DNA and RNA), carbohydrates, proteins, lipids, inorganic ions and water all have important roles and functions related to their properties • the sequence of bases in the DNA molecule determines the structure of proteins, including enzymes • enzymes catalyse the reactions that determine structures and functions from cellular to whole-organism level • enzymes are proteins with a mechanism of action and other properties determined by their tertiary structure • enzymes catalyse a wide range of intracellular reactions as well as extracellular ones • ATP provides the immediate source of energy for biological processes |  |  |
| **Ecosystems** |
|  | **ecosystems range in size from the very large to the very small • biomass transfers through ecosystems and the efficiency of transfer through different trophic levels can be measured • microorganisms play a key role in recycling chemical elements • ecosystems are dynamic systems, usually moving from colonisation to climax communities in a process known as succession • the dynamic equilibrium of populations is affected by a range of factors • humans are part of the ecological balance and their activities affect it both directly and indirectly • effective management of the conflict between human needs and conservation help to maintain sustainability of resources** |  |  |
| **Control systems** |
|  | **homeostasis is the maintenance of a constant internal environment • negative feedback helps maintain an optimal internal state in the context of a dynamic equilibrium. Positive feedback also occurs • stimuli, both internal and external, are detected leading to responses • the genome is regulated by a number of factors • coordination may be chemical or electrical in nature** |  |  |
| **Genetics and evolution** |
|  | **transfer of genetic information from one generation to the next can ensure continuity of species or lead to variation within a species and possible formation of new species • reproductive isolation can lead to accumulation of different genetic information in populations potentially leading to formation of new species • sequencing projects have read the genomes of organisms ranging from microbes and plants to humans. This allows the sequences of the proteins that derive from the genetic code to be predicted • gene technologies allow study and alteration of gene function in order to better understand organism function and to design new industrial and medical processes** |  |  |
| **Energy for biological processes** |
| **• in photosynthesis energy is transferred to ATP in the light- dependent stage and the ATP is utilised during synthesis in the light-independent stage** | **in cellular respiration, glycolysis takes place in the cytoplasm and the remaining steps in the mitochondria • ATP synthesis is associated with the electron transfer chain in the membranes of mitochondria and chloroplasts**  |  |  |

# **APPENDIX 1. Example of KS4 external examination**

**AQA Biology GCSE**

To demonstrate the balance of content, the entire examination specification is shown.

The content is highlighted to show topics which:

1. are not connected with plants (red);
2. could be exemplified by plant examples (yellow); and,
3. comprise specific plant biology content (green).

**\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_**

**4.1 Cell biology - 4.1.1 Cell structure**

4.1.1.1 Eukaryotes and prokaryotes Plant and animal cells (eukaryotic cells) have a cell membrane, cytoplasm and genetic material enclosed in a nucleus. Bacterial cells (prokaryotic cells) are much smaller in comparison. They have cytoplasm and a cell membrane surrounded by a cell wall. The genetic material is not enclosed in a nucleus. It is a single DNA loop and there may be one or more small rings of DNA called plasmids. Students should be able to demonstrate an understanding of the scale and size of cells and be able to make order of magnitude calculations, including the use of standard form.

4.1.1.2 Animal and plant cells Students should be able to explain how the main sub-cellular structures, including the nucleus, cell membranes, mitochondria, chloroplasts in plant cells and plasmids in bacterial cells are related to their functions. Most animal cells have the following parts: • a nucleus • cytoplasm • a cell membrane • mitochondria • ribosomes. In addition to the parts found in animal cells, plant cells often have: • chloroplasts • a permanent vacuole filled with cell sap. Plant and algal cells also have a cell wall made of cellulose, which strengthens the cell.

Students should be able to use estimations and explain when they should be used to judge the relative size or area of sub-cellular structures.

Required practical activity 1: use a light microscope to observe, draw and label a selection of plant and animal cells. A magnification scale must be included.

4.1.1.3 Cell specialisation Students should be able to, when provided with appropriate information, explain how the structure of different types of cell relate to their function in a tissue, an organ or organ system, or the whole organism. Cells may be specialised to carry out a particular function: • sperm cells, nerve cells and muscle cells in animals • root hair cells, xylem and phloem cells in plants.

4.1.1.4 Cell differentiation

Students should be able to explain the importance of cell differentiation. As an organism develops, cells differentiate to form different types of cells. • Most types of animal cell differentiate at an early stage. • Many types of plant cells retain the ability to differentiate throughout life. In mature animals, cell division is mainly restricted to repair and replacement. As a cell differentiates it acquires different sub-cellular structures to enable it to carry out a certain function. It has become a specialised cell.

4.1.1.5 Microscopy Students should be able to: • understand how microscopy techniques have developed over time • explain how electron microscopy has increased understanding of sub-cellular structures. Limited to the differences in magnification and resolution. An electron microscope has much higher magnification and resolving power than a light microscope. This means that it can be used to study cells in much finer detail. This has enabled biologists to see and understand many more sub-cellular structures. Students should be able to carry out calculations involving magnification, real size and image size using the formula: magnification = size of image size of real object. Students should be able to express answers in standard form if appropriate.

4.1.1.6 Culturing microorganisms Bacteria multiply by simple cell division (binary fission) as often as once every 20 minutes if they have enough nutrients and a suitable temperature. Bacteria can be grown in a nutrient broth solution or as colonies on an agar gel plate. Uncontaminated cultures of microorganisms are required for investigating the action of disinfectants and antibiotics. Calculate the number of bacteria in a population after a certain time if given the mean division time. Calculate cross-sectional areas of colonies or clear areas around colonies using πr². Students should be able to describe how to prepare an uncontaminated culture using aseptic technique. They should be able to explain why: • Petri dishes and culture media must be sterilised before use • inoculating loops used to transfer microorganisms to the media must be sterilised by passing them through a flame • the lid of the Petri dish should be secured with adhesive tape and stored upside down • in school laboratories, cultures should generally be incubated at 25°C. Students should be able to calculate cross-sectional areas of colonies or clear areas around colonies using πr². Students should be able to calculate the number of bacteria in a population after a certain time if given the mean division time. (HT only) Students should be able to express the answer in standard form.

Required practical activity 2: investigate the effect of antiseptics or antibiotics on bacterial growth using agar plates and measuring zones of inhibition.

**4.1 Cell biology - 4.1.2 Cell division**

4.1.2.1 The nucleus of a cell contains chromosomes made of DNA molecules. Each chromosome carries a large number of genes. In body cells the chromosomes are normally found in pairs. Use models and analogies to develop explanations of how cells divide.

4.1.2.2 Mitosis and the cell cycle Cells divide in a series of stages called the cell cycle. Students should be able to describe the stages of the cell cycle, including mitosis. During the cell cycle the genetic material is doubled and then divided into two identical cells. Before a cell can divide it needs to grow and increase the number of sub-cellular structures such as ribosomes and mitochondria. The DNA replicates to form two copies of each chromosome. In mitosis one set of chromosomes is pulled to each end of the cell and the nucleus divides. Finally the cytoplasm and cell membranes divide to form two identical cells. Students need to understand the three overall stages of the cell cycle but do not need to know the different phases of the mitosis stage. Cell division by mitosis is important in the growth and development of multicellular organisms. Students should be able to recognise and describe situations in given contexts where mitosis is occurring.

4.1.2.3 Stem cells A stem cell is an undifferentiated cell of an organism which is capable of giving rise to many more cells of the same type, and from which certain other cells can arise from differentiation. Students should be able to describe the function of stem cells in embryos, in adult animals and in the meristems in plants. Stem cells from human embryos can be cloned and made to differentiate into most different types of human cells. Stem cells from adult bone marrow can form many types of cells including blood cells. Meristem tissue in plants can differentiate into any type of plant cell, throughout the life of the plant. Knowledge and understanding of stem cell techniques are not required. Treatment with stem cells may be able to help conditions such as diabetes and paralysis. In therapeutic cloning an embryo is produced with the same genes as the patient. Stem cells from the embryo are not rejected by the patient’s body so they may be used for medical treatment. The use of stem cells has potential risks such as transfer of viral infection, and some people have ethical or religious objections. Stem cells from meristems in plants can be used to produce clones of plants quickly and economically. • Rare species can be cloned to protect from extinction. • Crop plants with special features such as disease resistance can be cloned to produce large numbers of identical plants for farmers.

**4.1 Cell biology - 4.1.3 Transport in cells**

4.1.3.1 Diffusion Substances may move into and out of cells across the cell membranes via diffusion. Diffusion is the spreading out of the particles of any substance in solution, or particles of a gas, resulting in a net movement from an area of higher concentration to an area of lower concentration. Some of the substances transported in and out of cells by diffusion are oxygen and carbon dioxide in gas exchange, and of the waste product urea from cells into the blood plasma for excretion in the kidney. Students should be able to explain how different factors affect the rate of diffusion. Factors which affect the rate of diffusion are: • the difference in concentrations (concentration gradient) • the temperature • the surface area of the membrane. A single-celled organism has a relatively large surface area to volume ratio. This allows sufficient transport of molecules into and out of the cell to meet the needs of the organism. Recognise, draw and interpret diagrams that model diffusion. Use of isotonic drinks and high energy drinks in sport. Students should be able to calculate and compare surface area to volume ratios. Students should be able to explain the need for exchange surfaces and a transport system in multicellular organisms in terms of surface area to volume ratio. Students should be able to explain how the small intestine and lungs in mammals, gills in fish, and the roots and leaves in plants, are adapted for exchanging materials. In multicellular organisms, surfaces and organ systems are specialised for exchanging materials. This is to allow sufficient molecules to be transported into and out of cells for the organism’s needs. The effectiveness of an exchange surface is increased by: • having a large surface area • a membrane that is thin, to provide a short diffusion path • (in animals) having an efficient blood supply • (in animals, for gaseous exchange) being ventilated.

4.1.3.2 Osmosis Water may move across cell membranes via osmosis. Osmosis is the diffusion of water from a dilute solution to a concentrated solution through a partially permeable membrane. Recognise, draw and interpret diagrams that model osmosis. Students should be able to: • use simple compound measures of rate of water uptake • use percentages • calculate percentage gain and loss of mass of plant tissue. Students should be able to plot, draw and interpret appropriate graphs.

Required practical activity 3: investigate the effect of a range of concentrations of salt or sugar solutions on the mass of plant tissue.

4.1.3.3 Active transport Active transport moves substances from a more dilute solution to a more concentrated solution (against a concentration gradient). This requires energy from respiration. Active transport allows mineral ions to be absorbed into plant root hairs from very dilute solutions in the soil. Plants require ions for healthy growth. It also allows sugar molecules to be absorbed from lower concentrations in the gut into the blood which has a higher sugar concentration. Sugar molecules are used for cell respiration. Students should be able to: • describe how substances are transported into and out of cells by diffusion, osmosis and active transport • explain the differences between the three processes.

**4.2 Organisation**

4.2.1 Principles of organisation Cells are the basic building blocks of all living organisms. A tissue is a group of cells with a similar structure and function. Organs are aggregations of tissues performing specific functions. Organs are organised into organ systems, which work together to form organisms. Students should be able to develop an understanding of size and scale in relation to cells, tissues, organs and systems.

4.2.2 Animal tissues, organs and organ systems

4.2.2.1 The human digestive system This section assumes knowledge of the digestive system studied in Key Stage 3 science. The digestive system is an example of an organ system in which several organs work together to digest and absorb food. Students should be able to relate knowledge of enzymes to Metabolism. Students should be able to describe the nature of enzyme molecules and relate their activity to temperature and pH changes. Students should be able to carry out rate calculations for chemical reactions. Enzymes catalyse specific reactions in living organisms due to the shape of their active site.

Students should be able to use the ‘lock and key theory’ as a simplified model to explain enzyme action. Students should be able to recall the sites of production and the action of amylase, proteases and lipases. Students should be able to understand simple word equations but no chemical symbol equations are required. Digestive enzymes convert food into small soluble molecules that can be absorbed into the bloodstream. Carbohydrases break down carbohydrates to simple sugars. Amylase is a carbohydrase which breaks down starch. Proteases break down proteins to amino acids. Lipases break down lipids (fats) to glycerol and fatty acids. The products of digestion are used to build new carbohydrates, lipids and proteins. Some glucose is used in respiration. Bile is made in the liver and stored in the gall bladder. It is alkaline to neutralise hydrochloric acid from the stomach. It also emulsifies fat to form small droplets which increases the surface area. The alkaline conditions and large surface area increase the rate of fat breakdown by lipase.

Students should be able to use other models to explain enzyme action.

Required practical activity 4: use qualitative reagents to test for a range of carbohydrates, lipids and proteins. To include: Benedict’s test for sugars; iodine test for starch; and Biuret reagent for protein.

Required practical activity 5: investigate the effect of pH on the rate of reaction of amylase enzyme. Students should use a continuous sampling technique to determine the time taken to completely digest a starch solution at a range of pH values. Iodine reagent is to be used to test for starch every 30 seconds. Temperature must be controlled by use of a water bath or electric heater.

4.2.2.2 The heart and blood vessels Students should know the structure and functioning of the human heart and lungs, including how lungs are adapted for gaseous exchange. The heart is an organ that pumps blood around the body in a double circulatory system. The right ventricle pumps blood to the lungs where gas exchange takes place. The left ventricle pumps blood around the rest of the body. Knowledge of the blood vessels associated with the heart is limited to the aorta, vena cava, pulmonary artery, pulmonary vein and coronary arteries. Knowledge of the names of the heart valves is not required. Knowledge of the lungs is restricted to the trachea, bronchi, alveoli and the capillary network surrounding the alveoli. The natural resting heart rate is controlled by a group of cells located in the right atrium that act as a pacemaker. Artificial pacemakers are electrical devices used to correct irregularities in the heart rate. The body contains three different types of blood vessel: • arteries • veins • capillaries. Students should be able to explain how the structure of these vessels relates to their functions. Students should be able to use simple compound measures such as rate and carry out rate calculations for blood flow.

4.2.2.3 Blood is a tissue consisting of plasma, in which the red blood cells, white blood cells and platelets are suspended. Students should know the functions of each of these blood components. Observing and drawing blood cells seen under a microscope. Evaluate risks related to use of blood products. Students should be able to recognise different types of blood cells in a photograph or diagram, and explain how they are adapted to their functions.

4.2.2.4 Coronary heart disease: a non-communicable disease Students should be able to evaluate the advantages and disadvantages of treating cardiovascular diseases by drugs, mechanical devices or transplant. In coronary heart disease layers of fatty material build up inside the coronary arteries, narrowing them. This reduces the flow of blood through the coronary arteries, resulting in a lack of oxygen for the heart muscle. Stents are used to keep the coronary arteries open. Statins are widely used to reduce blood cholesterol levels which slows down the rate of fatty material deposit. In some people heart valves may become faulty, preventing the valve from opening fully, or the heart valve might develop a leak. Students should understand the consequences of faulty valves. Faulty heart valves can be replaced using biological or mechanical valves. In the case of heart failure a donor heart, or heart and lungs can be transplanted. Artificial hearts are occasionally used to keep patients alive whilst waiting for a heart transplant, or to allow the heart to rest as an aid to recovery. Evaluate methods of treatment bearing in mind the benefits and risks associated with the treatment.

4.2.2.5 Health issuesStudents should be able to describe the relationship between health and disease and the interactions between different types of disease. Health is the state of physical and mental well-being. Diseases, both communicable and non-communicable, are major causes of ill health. Other factors including diet, stress and life situations may have a profound effect on both physical and mental health. Different types of disease may interact. • Defects in the immune system mean that an individual is more likely to suffer from infectious diseases. • Viruses living in cells can be the trigger for cancers. • Immune reactions initially caused by a pathogen can trigger allergies such as skin rashes and asthma. • Severe physical ill health can lead to depression and other mental illness. Students should be able to translate disease incidence information between graphical and numerical forms, construct and interpret frequency tables and diagrams, bar charts and histograms, and use a scatter diagram to identify a correlation between two variables. Students should understand the principles of sampling as applied to scientific data, including epidemiological data.

4.2.2.6 The effect of lifestyle on some non-communicable diseasesStudents should be able to: • discuss the human and financial cost of these non-communicable diseases to an individual, a local community, a nation or globally • explain the effect of lifestyle factors including diet, alcohol and smoking on the incidence of non-communicable diseases at local, national and global levels. WS 1.4 Risk factors are linked to an increased rate of a disease. They can be: • aspects of a person’s lifestyle • substances in the person’s body or environment. A causal mechanism has been proven for some risk factors, but not in others. • The effects of diet, smoking and exercise on cardiovascular disease. • Obesity as a risk factor for Type 2 diabetes. • The effect of alcohol on the liver and brain function. • The effect of smoking on lung disease and lung cancer. • The effects of smoking and alcohol on unborn babies. • Carcinogens, including ionising radiation, as risk factors in cancer. Many diseases are caused by the interaction of a number of factors. Interpret data about risk factors for specified diseases. Students should be able to understand the principles of sampling as applied to scientific data in terms of risk factors. Students should be able to translate information between graphical and numerical forms; and extract and interpret information from charts, graphs and tables in terms of risk factors. Students should be able to use a scatter diagram to identify a correlation between two variables in terms of risk factors.

4.2.2.7 Cancer Students should be able to describe cancer as the result of changes in cells that lead to uncontrolled growth and division. Benign tumours are growths of abnormal cells which are contained in one area, usually within a membrane. They do not invade other parts of the body. Malignant tumour cells are cancers. They invade neighbouring tissues and spread to different parts of the body in the blood where they form secondary tumours. Scientists have identified lifestyle risk factors for various types of cancer. There are also genetic risk factors for some cancers.

4.2.3 Plant tissues, organs and systems

 4.2.3.1 Plant tissues Students should be able to explain how the structures of plant tissues are related to their functions. Plant tissues include: • epidermal tissues • palisade mesophyll • spongy mesophyll • xylem and phloem • meristem tissue found at the growing tips of shoots and roots. The leaf is a plant organ. Knowledge limited to epidermis, palisade and spongy mesophyll, xylem and phloem, and guard cells surrounding stomata.

4.2.3.2 Plant organ system Students should be able to explain how the structure of root hair cells, xylem and phloem are adapted to their functions. Students should be able to explain the effect of changing temperature, humidity, air movement and light intensity on the rate of transpiration. Measure the rate of transpiration by the uptake of water Investigate the distribution of stomata and guard cells. Process data from investigations involving stomata and transpiration rates to find arithmetic means, understand the principles of sampling and calculate surface areas and volumes. Students should be able to understand and use simple compound measures such as the rate of transpiration. Students should be able to: • translate information between graphical and numerical form • plot and draw appropriate graphs, selecting appropriate scales for axes • extract and interpret information from graphs, charts and tables The roots, stem and leaves form a plant organ system for transport of substances around the plant. Students should be able to describe the process of transpiration and translocation, including the structure and function of the stomata. Root hair cells are adapted for the efficient uptake of water by osmosis, and mineral ions by active transport. Xylem tissue transports water and mineral ions from the roots to the stems and leaves. It is composed of hollow tubes strengthened by lignin adapted for the transport of water in the transpiration stream. The role of stomata and guard cells are to control gas exchange and water loss. Phloem tissue transports dissolved sugars from the leaves to the rest of the plant for immediate use or storage. The movement of food molecules through phloem tissue is called translocation. Phloem is composed of tubes of elongated cells. Cell sap can move from one phloem cell to the next through pores in the end walls. Detailed structure of phloem tissue or the mechanism of transport is not required.

4.3 Infection and response

Pathogens are microorganisms such as viruses and bacteria that cause infectious diseases in animals and plants. They depend on their host to provide the conditions and nutrients that they need to grow and reproduce. They frequently produce toxins that damage tissues and make us feel ill. This section will explore how we can avoid diseases by reducing contact with them, as well as how the body uses barriers against pathogens. Once inside the body our immune system is triggered which is usually strong enough to destroy the pathogen and prevent disease. When at risk from unusual or dangerous diseases our body’s natural system can be enhanced by the use of vaccination. Since the 1940s a range of antibiotics have been developed which have proved successful against a number of lethal diseases caused by bacteria. Unfortunately many groups of bacteria have now become resistant to these antibiotics. The race is now on to develop a new set of antibiotics.

4.3.1 Communicable diseases

4.3.1.1 Communicable (infectious) diseases Students should be able to explain how diseases caused by viruses, bacteria, protists and fungi are spread in animals and plants. Students should be able to explain how the spread of diseases can be reduced or prevented. Pathogens are microorganisms that cause infectious disease. Pathogens may be viruses, bacteria, protists or fungi. They may infect plants or animals and can be spread by direct contact, by water or by air. Bacteria and viruses may reproduce rapidly inside the body. Bacteria may produce poisons (toxins) that damage tissues and make us feel ill. Viruses live and reproduce inside cells, causing cell damage.

4.3.1.2 Viral diseases Measles is a viral disease showing symptoms of fever and a red skin rash. Measles is a serious illness that can be fatal if complications arise. For this reason most young children are vaccinated against measles. The measles virus is spread by inhalation of droplets from sneezes and coughs. HIV initially causes a flu-like illness. Unless successfully controlled with antiretroviral drugs the virus attacks the body’s immune cells. Late stage HIV infection, or AIDS, occurs when the body’s immune system becomes so badly damaged it can no longer deal with other infections or cancers. HIV is spread by sexual contact or exchange of body fluids such as blood which occurs when drug users share needles. Tobacco mosaic virus (TMV) is a widespread plant pathogen affecting many species of plants including tomatoes. It gives a distinctive ‘mosaic’ pattern of discolouration on the leaves which affects the growth of the plant due to lack of photosynthesis.

4.3.1.3 Bacterial diseases Salmonella food poisoning is spread by bacteria ingested in food, or on food prepared in unhygienic conditions. In the UK, poultry are vaccinated against Salmonella to control the spread. Fever, abdominal cramps, vomiting and diarrhoea are caused by the bacteria and the toxins they secrete. Gonorrhoea is a sexually transmitted disease (STD) with symptoms of a thick yellow or green discharge from the vagina or penis and pain on urinating. It is caused by a bacterium and was easily treated with the antibiotic penicillin until many resistant strains appeared. Gonorrhoea is spread by sexual contact. The spread can be controlled by treatment with antibiotics or the use of a barrier method of contraception such as a condom.

4.3.1.4 Fungal diseases Rose black spot is a fungal disease where purple or black spots develop on leaves, which often turn yellow and drop early. It affects the growth of the plant as photosynthesis is reduced. It is spread in the environment by water or wind. Rose black spot can be treated by using fungicides and/or removing and destroying the affected leaves.

4.3.1.5 Protist diseases The pathogens that cause malaria are protists. The malarial protist has a life cycle that includes the mosquito. Malaria causes recurrent episodes of fever and can be fatal. The spread of malaria is controlled by preventing the vectors, mosquitos, from breeding and by using mosquito nets to avoid being bitten.

4.3.1.6 Human defence systems Students should be able to describe the non-specific defence systems of the human body against pathogens, including the: • skin • nose • trachea and bronchi • stomach. Students should be able to explain the role of the immune system in the defence against disease. If a pathogen enters the body the immune system tries to destroy the pathogen. White blood cells help to defend against pathogens by: • phagocytosis • antibody production • antitoxin production.

4.3.1.7 Vaccination Students should be able to explain how vaccination will prevent illness in an individual, and how the spread of pathogens can be reduced by immunising a large proportion of the population. Vaccination involves introducing small quantities of dead or inactive forms of a pathogen into the body to stimulate the white blood cells to produce antibodies. If the same pathogen re-enters the body the white blood cells respond quickly to produce the correct antibodies, preventing infection. Students do not need to know details of vaccination schedules and side effects associated with specific vaccines.

4.3.1.8 Antibiotics and painkillers Students should be able to explain the use of antibiotics and other medicines in treating disease. Antibiotics, such as penicillin, are medicines that help to cure bacterial disease by killing infective bacteria inside the body. It is important that specific bacteria should be treated by specific antibiotics. The use of antibiotics has greatly reduced deaths from infectious bacterial diseases. However, the emergence of strains resistant to antibiotics is of great concern. There are links with this content to Culturing microorganisms (biology only). There are links with this content to Resistant bacteria. Antibiotics cannot kill viral pathogens. Painkillers and other medicines are used to treat the symptoms of disease but do not kill pathogens. It is difficult to develop drugs that kill viruses without also damaging the body’s tissues.

4.3.1.9 Discovery and development of drugs Students should be able to describe the process of discovery and development of potential new medicines, including preclinical and clinical testing. Traditionally drugs were extracted from plants and microorganisms. • The heart drug digitalis originates from foxgloves. • The painkiller aspirin originates from willow. • Penicillin was discovered by Alexander Fleming from the Penicillium mould. Most new drugs are synthesised by chemists in the pharmaceutical industry. However, the starting point may still be a chemical extracted from a plant. New medical drugs have to be tested and trialled before being used to check that they are safe and effective. New drugs are extensively tested for toxicity, efficacy and dose. Preclinical testing is done in a laboratory using cells, tissues and live animals. Clinical trials use healthy volunteers and patients. • Very low doses of the drug are given at the start of the clinical trial. • If the drug is found to be safe, further clinical trials are carried out to find the optimum dose for the drug. • In double blind trials, some patients are given a placebo.

4.3.2 Monoclonal antibodies (HT only)

4.3.2.1 Producing monoclonal antibodies Students should be able to describe how monoclonal antibodies are produced. Monoclonal antibodies are produced from a single clone of cells. The antibodies are specific to one binding site on one protein antigen and so are able to target a specific chemical or specific cells in the body. They are produced by stimulating mouse lymphocytes to make a particular antibody. The lymphocytes are combined with a particular kind of tumour cell to make a cell called a hybridoma cell. The hybridoma cell can both divide and make the antibody. Single hybridoma cells are cloned to produce many identical cells that all produce the same antibody. A large amount of the antibody can be collected and purified.

4.3.2.2 Uses of monoclonal antibodies Students should be able to describe some of the ways in which monoclonal antibodies can be used. Some examples include: • for diagnosis such as in pregnancy tests • in laboratories to measure the levels of hormones and other chemicals in blood, or to detect pathogens • in research to locate or identify specific molecules in a cell or tissue by binding to them with a fluorescent dye • to treat some diseases: for cancer the monoclonal antibody can be bound to a radioactive substance, a toxic drug or a chemical which stops cells growing and dividing. It delivers the substance to the cancer cells without harming other cells in the body. Students are not expected to recall any specific tests or treatments but given appropriate information they should be able to explain how they work. Appreciate the power of monoclonal antibodies and consider any ethical issues. Monoclonal antibodies create more side effects than expected. They are not yet as widely used as everyone hoped when they were first developed.

4.3.3 Plant disease (biology only)

 4.3.3.1 Detection and identification of plant diseases (HT only) Plant diseases can be detected by: • stunted growth • spots on leaves • areas of decay (rot) • growths • malformed stems or leaves • discolouration • the presence of pests. (HT only) Identification can be made by: • reference to a gardening manual or website • taking infected plants to a laboratory to identify the pathogen • using testing kits that contain monoclonal antibodies. The everyday application of scientific knowledge to detect and identify plant disease. Plants can be infected by a range of viral, bacterial and fungal pathogens as well as by insects. Knowledge of plant diseases is restricted to tobacco mosaic virus as a viral disease, black spot as a fungal disease and aphids as insects. Plants can be damaged by a range of ion deficiency conditions: • stunted growth caused by nitrate deficiency • chlorosis caused by magnesium deficiency. Knowledge of ions is limited to nitrate ions needed for protein synthesis and therefore growth, and magnesium ions needed to make chlorophyll.

4.3.3.2 Plant defence responses Students should be able to describe physical and chemical plant defence responses. Physical defence responses to resist invasion of microorganisms. • Cellulose cell walls. • Tough waxy cuticle on leaves. • Layers of dead cells around stems (bark on trees) which fall off. Chemical plant defence responses. • Antibacterial chemicals. • Poisons to deter herbivores. Mechanical adaptations. • Thorns and hairs deter animals. • Leaves which droop or curl when touched. • Mimicry to trick animals. There are links with this content to Adaptations.

4.4 Bioenergetics

In this section we will explore how plants harness the Sun’s energy in photosynthesis in order to make food. This process liberates oxygen which has built up over millions of years in the Earth’s atmosphere. Both animals and plants use this oxygen to oxidise food in a process called aerobic respiration which transfers the energy that the organism needs to perform its functions. Conversely, anaerobic respiration does not require oxygen to transfer energy. During vigorous exercise the human body is unable to supply the cells with sufficient oxygen and it switches to anaerobic respiration. This process will supply energy but also causes the build-up of lactic acid in muscles which causes fatigue.

4.4.1 Photosynthesis

4.4.1.1 Photosynthetic reaction Photosynthesis is represented by the equation: carbon dioxide +water light glucose +oxygen Students should recognise the chemical symbols: CO2, H2O, O2 and C6H12O6. Students should be able to describe photosynthesis as an endothermic reaction in which energy is transferred from the environment to the chloroplasts by light.

4.4.1.2 Rate of photosynthesis Students should be able to explain the effects of temperature, light intensity, carbon dioxide concentration, and the amount of chlorophyll on the rate of photosynthesis. Students should be able to: • measure and calculate rates of photosynthesis • extract and interpret graphs of photosynthesis rate involving one limiting factor • plot and draw appropriate graphs selecting appropriate scale for axes • translate information between graphical and numeric form. MS 3d Solve simple algebraic equations. (HT only) These factors interact and any one of them may be the factor that limits photosynthesis. (HT only) Students should be able to explain graphs of photosynthesis rate involving two or three factors and decide which is the limiting factor. (HT only) Students should understand and use inverse proportion – the inverse square law and light intensity in the context of photosynthesis. (HT only) Limiting factors are important in the economics of enhancing the conditions in greenhouses to gain the maximum rate of photosynthesis while still maintaining profit. (HT only) Use data to relate limiting factors to the cost effectiveness of adding heat, light or carbon dioxide to greenhouses.

Required practical activity 6: investigate the effect of light intensity on the rate of photosynthesis using an aquatic organism such as pondweed. AT skills covered by this practical activity.

4.4.1.3 Uses of glucose from photosynthesis The glucose produced in photosynthesis may be: • used for respiration • converted into insoluble starch for storage • used to produce fat or oil for storage • used to produce cellulose, which strengthens the cell wall • used to produce amino acids for protein synthesis. To produce proteins, plants also use nitrate ions that are absorbed from the soil.

4.4.2 Respiration

4.4.2.1 Aerobic and anaerobic respiration Students should be able to describe cellular respiration as an exothermic reaction which is continuously occurring in living cells. The energy transferred supplies all the energy needed for living processes. Respiration in cells can take place aerobically (using oxygen) or anaerobically (without oxygen), to transfer energy. Students should be able to compare the processes of aerobic and anaerobic respiration with regard to the need for oxygen, the differing products and the relative amounts of energy transferred. Organisms need energy for: • chemical reactions to build larger molecules • movement • keeping warm. Aerobic respiration is represented by the equation: glucose +oxygen carbon dioxide +water Students should recognise the chemical symbols: C6H12O6, O2, CO2 and H2O. Anaerobic respiration in muscles is represented by the equation: glucose lactic acid As the oxidation of glucose is incomplete in anaerobic respiration much less energy is transferred than in aerobic respiration. Anaerobic respiration in plant and yeast cells is represented by the equation: glucose ethanol + carbon dioxide Anaerobic respiration in yeast cells is called fermentation and has economic importance in the manufacture of bread and alcoholic drinks.

4.4.2.2 Response to exercise

During exercise the human body reacts to the increased demand for energy. The heart rate, breathing rate and breath volume increase during exercise to supply the muscles with more oxygenated blood. If insufficient oxygen is supplied anaerobic respiration takes place in muscles. The incomplete oxidation of glucose causes a build up of lactic acid and creates an oxygen debt. During long periods of vigorous activity muscles become fatigued and stop contracting efficiently. Investigations into the effect of exercise on the body. (HT only) Blood flowing through the muscles transports the lactic acid to the liver where it is converted back into glucose. Oxygen debt is the amount of extra oxygen the body needs after exercise to react with the accumulated lactic acid and remove it from the cells.

4.4.2.3 Metabolism Students should be able to explain the importance of sugars, amino acids, fatty acids and glycerol in the synthesis and breakdown of carbohydrates, proteins and lipids. Metabolism is the sum of all the reactions in a cell or the body. The energy transferred by respiration in cells is used by the organism for the continual enzyme controlled processes of metabolism that synthesise new molecules. Metabolism includes: • conversion of glucose to starch, glycogen and cellulose • the formation of lipid molecules from a molecule of glycerol and three molecules of fatty acids • the use of glucose and nitrate ions to form amino acids which in turn are used to synthesise proteins • respiration • breakdown of excess proteins to form urea for excretion.

4.5 Homeostasis and response Cells in the body can only survive within narrow physical and chemical limits. They require a constant temperature and pH as well as a constant supply of dissolved food and water. In order to do this the body requires control systems that constantly monitor and adjust the composition of the blood and tissues. These control systems include receptors which sense changes and effectors that bring about changes. In this section we will explore the structure and function of the nervous system and how it can bring about fast responses. We will also explore the hormonal system which usually brings about much slower changes. Hormonal coordination is particularly important in reproduction since it controls the menstrual cycle. An understanding of the role of hormones in reproduction has allowed scientists to develop not only contraceptive drugs but also drugs which can increase fertility.

4.5.1 Homeostasis Students should be able to explain that homeostasis is the regulation of the internal conditions of a cell or organism to maintain optimum conditions for function in response to internal and external changes. Homeostasis maintains optimal conditions for enzyme action and all cell functions. In the human body, these include control of: • blood glucose concentration • body temperature • water levels. These automatic control systems may involve nervous responses or chemical responses. All control systems include: • cells called receptors, which detect stimuli (changes in the environment) • coordination centres (such as the brain, spinal cord and pancreas) that receive and process information from receptors • effectors, muscles or glands, which bring about responses which restore optimum levels.

4.5.2 The human nervous system

 4.5.2.1 Structure and function Students should be able to explain how the structure of the nervous system is adapted to its functions. The nervous system enables humans to react to their surroundings and to coordinate their behaviour. Information from receptors passes along cells (neurones) as electrical impulses to the central nervous system (CNS). The CNS is the brain and spinal cord. The CNS coordinates the response of effectors which may be muscles contracting or glands secreting hormones. stimulus receptor coordinator effector response Students should be able to explain how the various structures in a reflex arc – including the sensory neurone, synapse, relay neurone and motor neurone – relate to their function. Students should understand why reflex actions are important. Reflex actions are automatic and rapid; they do not involve the conscious part of the brain. Students should be able to extract and interpret data from graphs, charts and tables, about the functioning of the nervous system. Students should be able to translate information about reaction times between numerical and graphical forms.

Required practical activity 7: plan and carry out an investigation into the effect of a factor on human reaction time.

4.5.2.2 The brain (biology only) The brain controls complex behaviour. It is made of billions of interconnected neurones and has different regions that carry out different functions. Students should be able to identify the cerebral cortex, cerebellum and medulla on a diagram of the brain, and describe their functions. (HT only) Students should be able to explain some of the difficulties of investigating brain function and treating brain damage and disease. (HT only) Neuroscientists have been able to map the regions of the brain to particular functions by studying patients with brain damage, electrically stimulating different parts of the brain and using MRI scanning techniques. The complexity and delicacy of the brain makes investigating and treating brain disorders very difficult. (HT only) Evaluate the benefits and risks of procedures carried out on the brain and nervous system.

4.5.2.3 The eye (biology only) Students should be able to relate the structures of the eye to their functions. This includes: • accommodation to focus on near or distant objects • adaptation to dim light. The eye is a sense organ containing receptors sensitive to light intensity and colour.

Students should be able to identify the following structures on a diagram of the eye and explain how their structure is related to their function: • retina • optic nerve • sclera • cornea • iris • ciliary muscles • suspensory ligaments. Accommodation is the process of changing the shape of the lens to focus on near or distant objects. To focus on a near object: • the ciliary muscles contract • the suspensory ligaments loosen • the lens is then thicker and refracts light rays strongly. To focus on a distant object: • the ciliary muscles relax • the suspensory ligaments are pulled tight • the lens is then pulled thin and only slightly refracts light rays. Two common defects of the eyes are myopia (short sightedness) and hyperopia (long sightedness) in which rays of light do not focus on the retina. • Generally these defects are treated with spectacle lenses which refract the light rays so that they do focus on the retina. • New technologies now include hard and soft contact lenses, laser surgery to change the shape of the cornea and a replacement lens in the eye.

Students should be able to interpret ray diagrams, showing these two common defects of the eye and demonstrate how spectacle lenses correct them.

4.5.2.4 Control of body temperature (biology only Body temperature is monitored and controlled by the thermoregulatory centre in the brain. The thermoregulatory centre contains receptors sensitive to the temperature of the blood. The skin contains temperature receptors and sends nervous impulses to the thermoregulatory centre. If the body temperature is too high, blood vessels dilate (vasodilation) and sweat is produced from the sweat glands. Both these mechanisms cause a transfer of energy from the skin to the environment. If the body temperature is too low, blood vessels constrict (vasoconstriction), sweating stops and skeletal muscles contract (shiver). (HT only) Students should be able to explain how these mechanisms lower or raise body temperature in a given context.

4.5.3 Hormonal coordination in humans

4.5.3.1 Human endocrine system Students should be able to describe the principles of hormonal coordination and control by the human endocrine system. The endocrine system is composed of glands which secrete chemicals called hormones directly into the bloodstream. The blood carries the hormone to a target organ where it produces an effect. Compared to the nervous system the effects are slower but act for longer. The pituitary gland in the brain is a ‘master gland’ which secretes several hormones into the blood in response to body conditions. These hormones in turn act on other glands to stimulate other hormones to be released to bring about effects. Students should be able to identify the position of the following on a diagram of the human body: • pituitary gland • pancreas • thyroid • adrenal gland • ovary • testes.

4.5.3.2 Control of blood glucose concentration Blood glucose concentration is monitored and controlled by the pancreas. If the blood glucose concentration is too high, the pancreas produces the hormone insulin that causes glucose to move from the blood into the cells. In liver and muscle cells excess glucose is converted to glycogen for storage. Students should be able to explain how insulin controls blood glucose (sugar) levels in the body. Type 1 diabetes is a disorder in which the pancreas fails to produce sufficient insulin. It is characterised by uncontrolled high blood glucose levels and is normally treated with insulin injections. In Type 2 diabetes the body cells no longer respond to insulin produced by the pancreas. A carbohydrate controlled diet and an exercise regime are common treatments. Obesity is a risk factor for Type 2 diabetes. Students should be able to compare Type 1 and Type 2 diabetes and explain how they can be treated. Evaluate information around the relationship between obesity and diabetes, and make recommendations taking into account social and ethical issues. Students should be able to extract information and interpret data from graphs that show the effect of insulin in blood glucose levels in both people with diabetes and people without diabetes. MS 2c (HT only) If the blood glucose concentration is too low, the pancreas produces the hormone glucagon that causes glycogen to be converted into glucose and released into the blood. (HT only) Students should be able to explain how glucagon interacts with insulin in a negative feedback cycle to control blood glucose (sugar) levels in the body.

4.5.3.3 Maintaining water and nitrogen balance in the body (biology only) Students should be able to explain the effect on cells of osmotic changes in body fluids. Water leaves the body via the lungs during exhalation. Water, ions and urea are lost from the skin in sweat. There is no control over water, ion or urea loss by the lungs or skin. Excess water, ions and urea are removed via the kidneys in the urine. If body cells lose or gain too much water by osmosis they do not function efficiently. (HT only) The digestion of proteins from the diet results in excess amino acids which need to be excreted safely. In the liver these amino acids are deaminated to form ammonia. Ammonia is toxic and so it is immediately converted to urea for safe excretion. Students should be able to describe the function of kidneys in maintaining the water balance of the body. The kidneys produce urine by filtration of the blood and selective reabsorption of useful substances such as glucose, some ions and water. Knowledge of other parts of the urinary system, the structure of the kidney and the structure of a nephron is not required. Students should be able to translate tables and bar charts of glucose, ions and urea before and after filtration. MS 4a (HT only) Students should be able to describe the effect of ADH on the permeability of the kidney tubules. (HT only) The water level in the body is controlled by the hormone ADH which acts on the kidney tubules. ADH is released by the pituitary gland when the blood is too concentrated and it causes more water to be reabsorbed back into the blood from the kidney tubules. This is controlled by negative feedback. People who suffer from kidney failure may be treated by organ transplant or by using kidney dialysis. Students should know the basic principles of dialysis.

4.5.3.4 Hormones in human reproduction Students should be able to describe the roles of hormones in human reproduction, including the menstrual cycle. During puberty reproductive hormones cause secondary sex characteristics to develop. Oestrogen is the main female reproductive hormone produced in the ovary. At puberty eggs begin to mature and one is released approximately every 28 days. This is called ovulation. Testosterone is the main male reproductive hormone produced by the testes and it stimulates sperm production. Several hormones are involved in the menstrual cycle of a woman. • Follicle stimulating hormone (FSH) causes maturation of an egg in the ovary. • Luteinising hormone (LH) stimulates the release of the egg. • Oestrogen and progesterone are involved in maintaining the uterus lining. (HT only) Students should be able to explain the interactions of FSH, oestrogen, LH and progesterone, in the control of the menstrual cycle. (HT only) Students should be able to extract and interpret data from graphs showing hormone levels during the menstrual cycle.

4.5.3.5 Contraception Students should be able to evaluate the different hormonal and nonhormonal methods of contraception. Fertility can be controlled by a variety of hormonal and non-hormonal methods of contraception. These include: • oral contraceptives that contain hormones to inhibit FSH production so that no eggs mature • injection, implant or skin patch of slow release progesterone to inhibit the maturation and release of eggs for a number of months or years • barrier methods such as condoms and diaphragms which prevent the sperm reaching an egg • intrauterine devices which prevent the implantation of an embryo or release a hormone • spermicidal agents which kill or disable sperm • abstaining from intercourse when an egg may be in the oviduct • surgical methods of male and female sterilisation.

4.5.3.6 The use of hormones to treat infertility (HT only) Students should be able to explain the use of hormones in modern reproductive technologies to treat infertility. This includes giving FSH and LH in a ‘fertility drug’ to a woman. She may then become pregnant in the normal way. In Vitro Fertilisation (IVF) treatment. • IVF involves giving a mother FSH and LH to stimulate the maturation of several eggs. • The eggs are collected from the mother and fertilised by sperm from the father in the laboratory. • The fertilised eggs develop into embryos. • At the stage when they are tiny balls of cells, one or two embryos are inserted into the mother’s uterus (womb). WS 1.1 Developments of microscopy techniques have enabled IVF treatments to develop. WS 1.3 Understand social and ethical issues associated with IVF treatments. Although fertility treatment gives a woman the chance to have a baby of her own: • it is very emotionally and physically stressful • the success rates are not high • it can lead to multiple births which are a risk to both the babies and the mother. WS 1.4 Evaluate from the perspective of patients and doctors the methods of treating infertility.

4.5.3.7 Negative feedback (HT only) Students should be able to explain the roles of thyroxine and adrenaline in the body. Adrenaline is produced by the adrenal glands in times of fear or stress. It increases the heart rate and boosts the delivery of oxygen and glucose to the brain and muscles, preparing the body for ‘flight or fight’. Thyroxine from the thyroid gland stimulates the basal metabolic rate. It plays an important role in growth and development. Thyroxine levels are controlled by negative feedback

4.5.4 Plant hormones (biology only)

4.5.4.1 Control and coordination Plants produce hormones to coordinate and control growth and responses to light (phototropism) and gravity (gravitropism or geotropism). Unequal distributions of auxin cause unequal growth rates in plant roots and shoots. (HT only) Gibberellins are important in initiating seed germination. (HT only) Ethene controls cell division and ripening of fruits. (HT only) The mechanisms of how gibberellins and ethene work are not required.

Required practical activity 8: investigate the effect of light or gravity on the growth of newly germinated seedlings. Record results as both length measurements and as careful, labelled biological drawings to show the effects.

4.5.4.2 Use of plant hormones (HT only) Students should be able to describe the effects of some plant hormones and the different ways people use them to control plant growth. Plant growth hormones are used in agriculture and horticulture. Auxins are used: • as weed killers • as rooting powders • for promoting growth in tissue culture. Ethene is used in the food industry to control ripening of fruit during storage and transport. Gibberellins can be used to: • end seed dormancy • promote flowering • increase fruit size.

4.6 Inheritance, variation and evolution

 In this section we will discover how the number of chromosomes are halved during meiosis and then combined with new genes from the sexual partner to produce unique offspring. Gene mutations occur continuously and on rare occasions can affect the functioning of the animal or plant. These mutations may be damaging and lead to a number of genetic disorders or death. Very rarely a new mutation can be beneficial and consequently, lead to increased fitness in the individual. Variation generated by mutations and sexual reproduction is the basis for natural selection; this is how species evolve. An understanding of these processes has allowed scientists to intervene through selective breeding to produce livestock with favoured characteristics. Once new varieties of plants or animals have been produced it is possible to clone individuals to produce larger numbers of identical individuals all carrying the favourable characteristic. Scientists have now discovered how to take genes from one species and introduce them in to the genome of another by a process called genetic engineering. In spite of the huge potential benefits that this technology can offer, genetic modification still remains highly controversial.

4.6.1 Reproduction

4.6.1.1 Sexual and asexual reproduction Students should understand that meiosis leads to non-identical cells being formed while mitosis leads to identical cells being formed. Sexual reproduction involves the joining (fusion) of male and female gametes: • sperm and egg cells in animals • pollen and egg cells in flowering plants. In sexual reproduction there is mixing of genetic information which leads to variety in the offspring. The formation of gametes involves meiosis. Asexual reproduction involves only one parent and no fusion of gametes. There is no mixing of genetic information. This leads to genetically identical offspring (clones). Only mitosis is involved.

4.6.1.2 Meiosis Students should be able to explain how meiosis halves the number of chromosomes in gametes and fertilisation restores the full number of chromosomes. Cells in reproductive organs divide by meiosis to form gametes. When a cell divides to form gametes: • copies of the genetic information are made • the cell divides twice to form four gametes, each with a single set of chromosomes • all gametes are genetically different from each other. Gametes join at fertilisation to restore the normal number of chromosomes. The new cell divides by mitosis. The number of cells increases. As the embryo develops cells differentiate. Knowledge of the stages of meiosis is not required. Modelling behaviour of chromosomes during meiosis.

4.6.1.3 Advantages and disadvantages of sexual and asexual reproduction (biology only) Advantages of sexual reproduction: • produces variation in the offspring • if the environment changes variation gives a survival advantage by natural selection • natural selection can be speeded up by humans in selective breeding to increase food production. Advantages of asexual reproduction: • only one parent needed • more time and energy efficient as do not need to find a mate • faster than sexual reproduction • many identical offspring can be produced when conditions are favourable. Some organisms reproduce by both methods depending on the circumstances. • Malarial parasites reproduce asexually in the human host, but sexually in the mosquito. • Many fungi reproduce asexually by spores but also reproduce sexually to give variation. • Many plants produce seeds sexually, but also reproduce asexually by runners such as strawberry plants, or bulb division such as daffodils. Knowledge of reproduction in organisms is restricted to those mentioned. Students are expected to be able to explain the advantages and disadvantages of asexual and sexual reproduction for any organism if given appropriate information.

4.6.1.4 DNA and the genome Students should be able to describe the structure of DNA and define genome. The genetic material in the nucleus of a cell is composed of a chemical called DNA. DNA is a polymer made up of two strands forming a double helix. The DNA is contained in structures called chromosomes. A gene is a small section of DNA on a chromosome. Each gene codes for a particular sequence of amino acids, to make a specific protein. The genome of an organism is the entire genetic material of that organism. The whole human genome has now been studied and this will have great importance for medicine in the future. Students should be able to discuss the importance of understanding the human genome. This is limited to the: • search for genes linked to different types of disease • understanding and treatment of inherited disorders • use in tracing human migration patterns from the past.

4.6.1.5 DNA structure (biology only) Students should be able to describe DNA as a polymer made from four different nucleotides. Each nucleotide consists of a common sugar and phosphate group with one of four different bases attached to the sugar. DNA contains four bases, A, C, G and T. A sequence of three bases is the code for a particular amino acid. The order of bases controls the order in which amino acids are assembled to produce a particular protein. The long strands of DNA consist of alternating sugar and phosphate sections. Attached to each sugar is one of the four bases. The DNA polymer is made up of repeating nucleotide units.

(HT only) Students should be able to: • recall a simple description of protein synthesis • explain simply how the structure of DNA affects the protein made • describe how genetic variants may influence phenotype: a) in coding DNA by altering the activity of a protein: and b) in non-coding DNA by altering how genes are expressed. (HT only) In the complementary strands a C is always linked to a G on the opposite strand and a T to an A. (HT only) Students are not expected to know or understand the structure of mRNA, tRNA, or the detailed structure of amino acids or proteins. (HT only) Students should be able to explain how a change in DNA structure may result in a change in the protein synthesised by a gene. (HT only) Proteins are synthesised on ribosomes, according to a template. Carrier molecules bring specific amino acids to add to the growing protein chain in the correct order. (HT only) When the protein chain is complete it folds up to form a unique shape. This unique shape enables the proteins to do their job as enzymes, hormones or forming structures in the body such as collagen. (HT only) Mutations occur continuously. Most do not alter the protein, or only alter it slightly so that its appearance or function is not changed. (HT only) A few mutations code for an altered protein with a different shape. An enzyme may no longer fit the substrate binding site or a structural protein may lose its strength. (HT only) Not all parts of DNA code for proteins. Non-coding parts of DNA can switch genes on and off, so variations in these areas of DNA may affect how genes are expressed.

4.6.1.6 Genetic inheritance Students should be able to explain the terms: • gamete • chromosome • gene • allele • dominant • recessive • homozygous • heterozygous • genotype • phenotype. Some characteristics are controlled by a single gene, such as: fur colour in mice; and red-green colour blindness in humans. Each gene may have different forms called alleles. The alleles present, or genotype, operate at a molecular level to develop characteristics that can be expressed as a phenotype. A dominant allele is always expressed, even if only one copy is present. A recessive allele is only expressed if two copies are present (therefore no dominant allele present). If the two alleles present are the same the organism is homozygous for that trait, but if the alleles are different they are heterozygous. Most characteristics are a result of multiple genes interacting, rather than a single gene. Students should be able to understand the concept of probability in predicting the results of a single gene cross, but recall that most phenotype features are the result of multiple genes rather than single gene inheritance. Students should be able to use direct proportion and simple ratios to express the outcome of a genetic cross. Students should be able to complete a Punnett square diagram and extract and interpret information from genetic crosses and family trees. (HT only) Students should be able to construct a genetic cross by Punnett square diagram and use it to make predictions using the theory of probability.

4.6.1.7 Inherited disorders Some disorders are inherited. These disorders are caused by the inheritance of certain alleles. • Polydactyly (having extra fingers or toes) is caused by a dominant allele. • Cystic fibrosis (a disorder of cell membranes) is caused by a recessive allele. Students should make informed judgements about the economic, social and ethical issues concerning embryo screening, given appropriate information. Appreciate that embryo screening and gene therapy may alleviate suffering but consider the ethical issues which arise.

4.6.1.8 Sex determination Ordinary human body cells contain 23 pairs of chromosomes. 22 pairs control characteristics only, but one of the pairs carries the genes that determine sex. • In females the sex chromosomes are the same (XX). • In males the chromosomes are different (XY). Students should be able to carry out a genetic cross to show sex inheritance. Students should understand and use direct proportion and simple ratios in genetic crosses.

4.6.2 Variation and evolution

4.6.2.1 Variation Students should be able to describe simply how the genome and its interaction with the environment influence the development of the phenotype of an organism. Differences in the characteristics of individuals in a population is called variation and may be due to differences in: • the genes they have inherited (genetic causes) • the conditions in which they have developed (environmental causes) • a combination of genes and the environment. Students should be able to: • state that there is usually extensive genetic variation within a population of a species • recall that all variants arise from mutations and that: most have no effect on the phenotype; some influence phenotype; very few determine phenotype. Mutations occur continuously. Very rarely a mutation will lead to a new phenotype. If the new phenotype is suited to an environmental change it can lead to a relatively rapid change in the species.

4.6.2.2 Evolution Students should be able to describe evolution as a change in the inherited characteristics of a population over time through a process of natural selection which may result in the formation of a new species. The theory of evolution by natural selection states that all species of living things have evolved from simple life forms that first developed more than three billion years ago. Students should be able to explain how evolution occurs through natural selection of variants that give rise to phenotypes best suited to their environment. If two populations of one species become so different in phenotype that they can no longer interbreed to produce fertile offspring they have formed two new species.

4.6.2.3 Selective breeding Students should be able to explain the impact of selective breeding of food plants and domesticated animals. Selective breeding (artificial selection) is the process by which humans breed plants and animals for particular genetic characteristics. Humans have been doing this for thousands of years since they first bred food crops from wild plants and domesticated animals. Selective breeding involves choosing parents with the desired characteristic from a mixed population. They are bred together. From the offspring those with the desired characteristic are bred together. This continues over many generations until all the offspring show the desired characteristic. The characteristic can be chosen for usefulness or appearance: • Disease resistance in food crops. • Animals which produce more meat or milk. • Domestic dogs with a gentle nature. • Large or unusual flowers. Selective breeding can lead to ‘inbreeding’ where some breeds are particularly prone to disease or inherited defects.

4.6.2.4 Genetic engineering Students should be able to describe genetic engineering as a process which involves modifying the genome of an organism by introducing a gene from another organism to give a desired characteristic. Plant crops have been genetically engineered to be resistant to diseases or to produce bigger better fruits. Bacterial cells have been genetically engineered to produce useful substances such as human insulin to treat diabetes. Students should be able to explain the potential benefits and risks of genetic engineering in agriculture and in medicine and that some people have objections. In genetic engineering, genes from the chromosomes of humans and other organisms can be ‘cut out’ and transferred to cells of other organisms. Crops that have had their genes modified in this way are called genetically modified (GM) crops. GM crops include ones that are resistant to insect attack or to herbicides. GM crops generally show increased yields. Concerns about GM crops include the effect on populations of wild flowers and insects. Some people feel the effects of eating GM crops on human health have not been fully explored. Modern medical research is exploring the possibility of genetic modification to overcome some inherited disorders. (HT only) Students should be able to describe the main steps in the process of genetic engineering. (HT only) In genetic engineering: • enzymes are used to isolate the required gene; this gene is inserted into a vector, usually a bacterial plasmid or a virus • the vector is used to insert the gene into the required cells • genes are transferred to the cells of animals, plants or microorganisms at an early stage in their development so that they develop with desired characteristics.

4.6.2.5 Cloning (biology only) Tissue culture: using small groups of cells from part of a plant to grow identical new plants. This is important for preserving rare plant species or commercially in nurseries. Cuttings: an older, but simple, method used by gardeners to produce many identical new plants from a parent plant. Embryo transplants: splitting apart cells from a developing animal embryo before they become specialised, then transplanting the identical embryos into host mothers. Adult cell cloning: • The nucleus is removed from an unfertilised egg cell. • The nucleus from an adult body cell, such as a skin cell, is inserted into the egg cell. • An electric shock stimulates the egg cell to divide to form an embryo. • These embryo cells contain the same genetic information as the adult skin cell. • When the embryo has developed into a ball of cells, it is inserted into the womb of an adult female to continue its development.

4.6.3 The development of understanding of genetics and evolution

4.6.3.1 Theory of evolution (biology only) Charles Darwin, as a result of observations on a round the world expedition, backed by years of experimentation and discussion and linked to developing knowledge of geology and fossils, proposed the theory of evolution by natural selection. • Individual organisms within a particular species show a wide range of variation for a characteristic. • Individuals with characteristics most suited to the environment are more likely to survive to breed successfully. • The characteristics that have enabled these individuals to survive are then passed on to the next generation. Darwin published his ideas in On the Origin of Species (1859). There was much controversy surrounding these revolutionary new ideas. The theory of evolution by natural selection was only gradually accepted because: • the theory challenged the idea that God made all the animals and plants that live on Earth • there was insufficient evidence at the time the theory was published to convince many scientists • the mechanism of inheritance and variation was not known until 50 years after the theory was published. Other theories, including that of Jean-Baptiste Lamarck, are based mainly on the idea that changes that occur in an organism during its lifetime can be inherited. We now know that in the vast majority of cases this type of inheritance cannot occur. A study of creationism is not required.

4.6.3.2 Speciation (biology only) Students should be able to: • describe the work of Darwin and Wallace in the development of the theory of evolution by natural selection • explain the impact of these ideas on biology. Alfred Russel Wallace independently proposed the theory of evolution by natural selection. He published joint writings with Darwin in 1858 which prompted Darwin to publish On the Origin of Species (1859) the following year. Wallace worked worldwide gathering evidence for evolutionary theory. He is best known for his work on warning colouration in animals and his theory of speciation. Alfred Wallace did much pioneering work on speciation but more evidence over time has led to our current understanding of the theory of speciation. Students should be able to describe the steps which give rise to new species. There are links with this content to Evolution. The theory of speciation has developed over time.

4.6.3.3 The understanding of genetics (biology only) Students should be able to: • describe the development of our understanding of genetics including the work of Mendel • understand why the importance of Mendel’s discovery was not recognised until after his death. In the mid-19th century Gregor Mendel carried out breeding experiments on plants. One of his observations was that the inheritance of each characteristic is determined by ‘units’ that are passed on to descendants unchanged. In the late 19th century behaviour of chromosomes during cell division was observed. Our current understanding of genetics has developed over time. In the early 20th century it was observed that chromosomes and Mendel’s ‘units’ behaved in similar ways. This led to the idea that the ‘units’, now called genes, were located on chromosomes. In the mid-20th century the structure of DNA was determined and the mechanism of gene function worked out. This scientific work by many scientists led to the gene theory being developed.

4.6.3.4 Evidence for evolution Students should be able to describe the evidence for evolution including fossils and antibiotic resistance in bacteria. The theory of evolution by natural selection is now widely accepted. Evidence for Darwin’s theory is now available as it has been shown that characteristics are passed on to offspring in genes. There is further evidence in the fossil record and the knowledge of how resistance to antibiotics evolves in bacteria. Data is now available to support the theory of evolution.

4.6.3.5 Fossils Fossils are the ‘remains’ of organisms from millions of years ago, which are found in rocks. Fossils may be formed: • from parts of organisms that have not decayed because one or more of the conditions needed for decay are absent • when parts of the organism are replaced by minerals as they decay • as preserved traces of organisms, such as footprints, burrows and rootlet traces. Extract and interpret information from charts, graphs and tables. Many early forms of life were soft-bodied, which means that they have left few traces behind. What traces there were have been mainly destroyed by geological activity. This is why scientists cannot be certain about how life began on Earth. Appreciate why the fossil record is incomplete. We can learn from fossils how much or how little different organisms have changed as life developed on Earth. Understand how scientific methods and theories develop over time. Students should be able to extract and interpret information from charts, graphs and tables such as evolutionary trees.

4.6.3.6 Extinction Extinctions occur when there are no remaining individuals of a species still alive. Students should be able to describe factors which may contribute to the extinction of a species.

4.6.3.7 Resistant bacteria Bacteria can evolve rapidly because they reproduce at a fast rate. Mutations of bacterial pathogens produce new strains. Some strains might be resistant to antibiotics, and so are not killed. They survive and reproduce, so the population of the resistant strain rises. The resistant strain will then spread because people are not immune to it and there is no effective treatment. MRSA is resistant to antibiotics. To reduce the rate of development of antibiotic resistant strains: • doctors should not prescribe antibiotics inappropriately, such as treating non-serious or viral infections • patients should complete their course of antibiotics so all bacteria are killed and none survive to mutate and form resistant strains • the agricultural use of antibiotics should be restricted. The development of new antibiotics is costly and slow. It is unlikely to keep up with the emergence of new resistant strains.

4.6.4 Classification of living organisms Traditionally living things have been classified into groups depending on their structure and characteristics in a system developed by Carl Linnaeus. Linnaeus classified living things into kingdom, phylum, class, order, family, genus and species. Organisms are named by the binomial system of genus and species. Students should be able to use information given to show understanding of the Linnaean system. Students should be able to describe the impact of developments in biology on classification systems. As evidence of internal structures became more developed due to improvements in microscopes, and the understanding of biochemical processes progressed, new models of classification were proposed. Due to evidence available from chemical analysis there is now a ‘three domain system’ developed by Carl Woese. In this system organisms are divided into: • archaea (primitive bacteria usually living in extreme environments) • bacteria (true bacteria) • eukaryota (which includes protists, fungi, plants and animals). Understand how scientific methods and theories develop over time. Evolutionary trees are a method used by scientists to show how they believe organisms are related. They use current classification data for living organisms and fossil data for extinct organisms.

4.7 Ecology The Sun is a source of energy that passes through ecosystems. Materials including carbon and water are continually recycled by the living world, being released through respiration of animals, plants and decomposing microorganisms and taken up by plants in photosynthesis. All species live in ecosystems composed of complex communities of animals and plants dependent on each other and that are adapted to particular conditions, both abiotic and biotic. These ecosystems provide essential services that support human life and continued development. In order to continue to benefit from these services humans need to engage with the environment in a sustainable way. In this section we will explore how humans are threatening biodiversity as well as the natural systems that support it. We will also consider some actions we need to take to ensure our future health, prosperity and well-being.

4.7.1 Adaptations, interdependence and competition

4.7.1.1 Students should be able to describe: • different levels of organisation in an ecosystem from individual organisms to the whole ecosystem • the importance of interdependence and competition in a community. Students should be able to, when provided with appropriate information: • suggest the factors for which organisms are competing in a given habitat • suggest how organisms are adapted to the conditions in which they live. An ecosystem is the interaction of a community of living organisms (biotic) with the non-living (abiotic) parts of their environment. To survive and reproduce, organisms require a supply of materials from their surroundings and from the other living organisms there. Plants in a community or habitat often compete with each other for light and space, and for water and mineral ions from the soil. Animals often compete with each other for food, mates and territory. Within a community each species depends on other species for food, shelter, pollination, seed dispersal etc. If one species is removed it can affect the whole community. This is called interdependence. A stable community is one where all the species and environmental factors are in balance so that population sizes remain fairly constant. Recording firsthand observations of organisms. Students should be able to extract and interpret information from charts, graphs and tables relating to the interaction of organisms within a community.

4.7.1.2 Abiotic factors Students should be able to explain how a change in an abiotic factor would affect a given community given appropriate data or context. Abiotic (non-living) factors which can affect a community are: • light intensity • temperature • moisture levels • soil pH and mineral content • wind intensity and direction • carbon dioxide levels for plants • oxygen levels for aquatic animals. Students should be able to extract and interpret information from charts, graphs and tables relating to the effect of abiotic factors on organisms within a community. Extract and interpret information from charts, graphs and tables.

4.7.1.3 Biotic factors Students should be able to explain how a change in a biotic factor might affect a given community given appropriate data or context. Biotic (living) factors which can affect a community are: • availability of food • new predators arriving • new pathogens • one species outcompeting another so the numbers are no longer sufficient to breed. Students should be able to extract and interpret information from charts, graphs and tables relating to the effect of biotic factors on organisms within a community.

4.7.1.4 Adaptations Students should be able to explain how organisms are adapted to live in their natural environment, given appropriate information. Organisms have features (adaptations) that enable them to survive in the conditions in which they normally live. These adaptations may be structural, behavioural or functional. Some organisms live in environments that are very extreme, such as at high temperature, pressure, or salt concentration. These organisms are called extremophiles. Bacteria living in deep sea vents are extremophiles.

4.7.2 Organisation of an ecosystem

4.7.2.1 Levels of organisation Students should understand that photosynthetic organisms are the producers of biomass for life on Earth. Feeding relationships within a community can be represented by food chains. All food chains begin with a producer which synthesises molecules. This is usually a green plant or alga which makes glucose by photosynthesis. A range of experimental methods using transects and quadrats are used by ecologists to determine the distribution and abundance of species in an ecosystem. In relation to abundance of organisms students should be able to: • understand the terms mean, mode and median • calculate arithmetic means • plot and draw appropriate graphs selecting appropriate scales for the axes. Producers are eaten by primary consumers, which in turn may be eaten by secondary consumers and then tertiary consumers. Consumers that kill and eat other animals are predators, and those eaten are prey. In a stable community the numbers of predators and prey rise and fall in cycles. Interpret graphs used to model predator-prey cycles. Students should be able to interpret graphs used to model these cycles.

Required practical activity 9: measure the population size of a common species in a habitat. Use sampling techniques to investigate the effect of a factor on the distribution of this species.

4.7.2.2 How materials are cycled Students should: • recall that many different materials cycle through the abiotic and biotic components of an ecosystem • explain the importance of the carbon and water cycles to living organisms. All materials in the living world are recycled to provide the building blocks for future organisms. The carbon cycle returns carbon from organisms to the atmosphere as carbon dioxide to be used by plants in photosynthesis. The water cycle provides fresh water for plants and animals on land before draining into the seas. Water is continuously evaporated and precipitated. Students are not expected to study the nitrogen cycle. Students should be able to explain the role of microorganisms in cycling materials through an ecosystem by returning carbon to the atmosphere as carbon dioxide and mineral ions to the soil. Interpret and explain the processes in diagrams of the carbon cycle, the water cycle.

4.7.2.3 Decomposition (biology only) Students should be able to explain how temperature, water and availability of oxygen affect the rate of decay of biological material. Students should be able to: • calculate rate changes in the decay of biological material • translate information between numerical and graphical form • plot and draw appropriate graphs selecting appropriate scales for the axes. Gardeners and farmers try to provide optimum conditions for rapid decay of waste biological material. The compost produced is used as a natural fertiliser for growing garden plants or crops. Anaerobic decay produces methane gas. Biogas generators can be used to produce methane gas as a fuel.

Required practical activity 10: investigate the effect of temperature on the rate of decay of fresh milk by measuring pH change.

4.7.2.4 Impact of environmental change (biology only) (HT only) Students should be able to evaluate the impact of environmental changes on the distribution of species in an ecosystem given appropriate information. Environmental changes affect the distribution of species in an ecosystem. These changes include: • temperature • availability of water • composition of atmospheric gases. The changes may be seasonal, geographic or caused by human interaction.

4.7.3 Biodiversity and the effect of human interaction on ecosystems

4.7.3.1 Biodiversity Biodiversity is the variety of all the different species of organisms on earth, or within an ecosystem. A great biodiversity ensures the stability of ecosystems by reducing the dependence of one species on another for food, shelter and the maintenance of the physical environment. The future of the human species on Earth relies on us maintaining a good level of biodiversity. Many human activities are reducing biodiversity and only recently have measures been taken to try to stop this reduction. Explain how waste, deforestation and global warming have an impact on biodiversity.

4.7.3.2 Waste management Rapid growth in the human population and an increase in the standard of living mean that increasingly more resources are used and more waste is produced. Unless waste and chemical materials are properly handled, more pollution will be caused. Pollution can occur: • in water, from sewage, fertiliser or toxic chemicals • in air, from smoke and acidic gases • on land, from landfill and from toxic chemicals. Pollution kills plants and animals which can reduce biodiversity.

4.7.3.3 Land use Humans reduce the amount of land available for other animals and plants by building, quarrying, farming and dumping waste. The destruction of peat bogs, and other areas of peat to produce garden compost, reduces the area of this habitat and thus the variety of different plant, animal and microorganism species that live there (biodiversity). The decay or burning of the peat releases carbon dioxide into the atmosphere. Understand the conflict between the need for cheap available compost to increase food production and the need to conserve peat bogs and peatlands as habitats for biodiversity and to reduce carbon dioxide emissions.

4.7.3.4 Deforestation Large-scale deforestation in tropical areas has occurred to: • provide land for cattle and rice fields • grow crops for biofuels. Evaluate the environmental implications of deforestation.

4.7.3.5 Global warming Students should be able to describe some of the biological consequences of global warming. Levels of carbon dioxide and methane in the atmosphere are increasing, and contribute to ‘global warming’.

4.7.3.6 Maintaining biodiversity Students should be able to describe both positive and negative human interactions in an ecosystem and explain their impact on biodiversity. Scientists and concerned citizens have put in place programmes to reduce the negative effects of humans on ecosystems and biodiversity. These include: • breeding programmes for endangered species • protection and regeneration of rare habitats • reintroduction of field margins and hedgerows in agricultural areas where farmers grow only one type of crop • reduction of deforestation and carbon dioxide emissions by some governments • recycling resources rather than dumping waste in landfill. Evaluate given information about methods that can be used to tackle problems caused by human impacts on the environment. Explain and evaluate the conflicting pressures on maintaining biodiversity given appropriate information.

4.7.4 Trophic levels in an ecosystem (biology only)

4.7.4.1 Trophic levels Students should be able to describe the differences between the trophic levels of organisms within an ecosystem. Trophic levels can be represented by numbers, starting at level 1 with plants and algae. Further trophic levels are numbered subsequently according to how far the organism is along the food chain. Level 1: Plants and algae make their own food and are called producers. Level 2: Herbivores eat plants/algae and are called primary consumers. Level 3: Carnivores that eat herbivores are called secondary consumers. Level 4: Carnivores that eat other carnivores are called tertiary consumers. Apex predators are carnivores with no predators. Decomposers break down dead plant and animal matter by secreting enzymes into the environment. Small soluble food molecules then diffuse into the microorganism.

4.7.4.2 Pyramids of biomass Pyramids of biomass can be constructed to represent the relative amount of biomass in each level of a food chain. Trophic level 1 is at the bottom of the pyramid.

Students should be able to construct accurate pyramids of biomass from appropriate data.

4.7.4.3 Transfer of biomass Students should be able to: • describe pyramids of biomass • explain how biomass is lost between the different trophic levels. Producers are mostly plants and algae which transfer about 1 % of the incident energy from light for photosynthesis. Only approximately 10 % of the biomass from each trophic level is transferred to the level above it. Losses of biomass are due to: • not all the ingested material is absorbed, some is egested as faeces • some absorbed material is lost as waste, such as carbon dioxide and water in respiration and water and urea in urine. Large amounts of glucose are used in respiration. Calculate the efficiency of biomass transfer between trophic levels. Students should be able to calculate the efficiency of biomass transfers between trophic levels by percentages or fractions of mass. Students should be able to explain how this affects the number of organisms at each trophic level.

4.7.5 Food production (biology only)

4.7.5.1 Factors affecting food security Students should be able to describe some of the biological factors affecting levels of food security. Food security is having enough food to feed a population. Biological factors which are threatening food security include: • the increasing birth rate has threatened food security in some countries • changing diets in developed countries means scarce food resources are transported around the world • new pests and pathogens that affect farming • environmental changes that affect food production, such as widespread famine occurring in some countries if rains fail • the cost of agricultural inputs • conflicts that have arisen in some parts of the world which affect the availability of water or food. Sustainable methods must be found to feed all people on Earth. Interpret population and food production statistics to evaluate food security.

4.7.5.2 Farming techniques The efficiency of food production can be improved by restricting energy transfer from food animals to the environment. This can be done by limiting their movement and by controlling the temperature of their surroundings. Some animals are fed high protein foods to increase growth.

4.7.5.3 Sustainable fisheries Fish stocks in the oceans are declining. It is important to maintain fish stocks at a level where breeding continues or certain species may disappear altogether in some areas. Control of net size and the introduction of fishing quotas play important roles in conservation of fish stocks at a sustainable level. Understand how application of different fishing techniques promotes recovery of fish stocks.

4.7.5.4 Role of biotechnology Students should be able to describe and explain some possible biotechnical and agricultural solutions, including genetic modification, to the demands of the growing human population. Modern biotechnology techniques enable large quantities of microorganisms to be cultured for food. The fungus Fusarium is useful for producing mycoprotein, a protein-rich food suitable for vegetarians. The fungus is grown on glucose syrup, in aerobic conditions, and the biomass is harvested and purified. A genetically modified bacterium produces human insulin. When harvested and purified this is used to treat people with diabetes. GM crops could provide more food or food with an improved nutritional value such as golden rice.

# **APPENDIX 2. Example of KS5 external examination**

**Edexcel Biology A level (Salters-Nuffield)**

To demonstrate the balance of content, the entire examination specification is shown.

The content is highlighted to show topics which:

1. are not connected with plants (red);
2. could be exemplified by plant examples (yellow); and,
3. comprise specific plant biology content (green).

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**Topic 1 Lifestyle, Health and Risk**

Students should:

1.1 Understand why many animals have a heart and circulation (mass transport to overcome limitations of diffusion in meeting the requirements of organisms).

1.2 Understand the importance of water as a solvent in transport, including its dipole nature.

1.3 Understand how the structures of blood vessels (capillaries, arteries and veins) relate to their functions.

1.4 i) Know the cardiac cycle (atrial systole, ventricular systole and cardiac diastole) and relate the structure and operation of the mammalian heart, including the major blood vessels, to its function. ii) Know how the relationship between heart structure and function can be investigated practically.

1.5 Understand the course of events that leads to atherosclerosis (endothelial dysfunction, inflammatory response, plaque formation, raised blood pressure).

1.6 Understand the blood-clotting process (thromboplastin release, conversion of prothrombin to thrombin and fibrinogen to fibrin) and its role in cardiovascular disease (CVD).

1.7 Know how factors such as genetics, diet, age, gender, high blood pressure, smoking and inactivity increase the risk of cardiovascular disease (CVD).

1.8 Be able to analyse and interpret quantitative data on illness and mortality rates to determine health risks, including distinguishing between correlation and causation and recognising conflicting evidence.

1.9 Be able to evaluate the design of studies used to determine health risk factors, including sample selection and sample size used to collect data that is both valid and reliable.

1.10 Understand why people’s perceptions of risks are often different from the actual risks, including underestimating and overestimating the risks due to diet and other lifestyle factors in the development of heart disease.

1.11 i) Be able to analyse data on energy budgets and diet. ii) Understand the consequences of energy imbalance, including weight loss, weight gain, and development of obesity.

1.12 i) Know the difference between monosaccharides, disaccharides and polysaccharides, including glycogen and starch (amylose and amylopectin). ii) Be able to relate the structures of monosaccharides, disaccharides and polysaccharides to their roles in providing and storing energy (β-glucose and cellulose are not required in this topic).

1.13 Know how monosaccharides join to form disaccharides (sucrose, lactose and maltose) and polysaccharides (glycogen and amylose) through condensation reactions forming glycosidic bonds, and how these can be split through hydrolysis reactions.

1.14 i) Know how a triglyceride is synthesised by the formation of ester bonds during condensation reactions between glycerol and three fatty acids. ii) Know the differences between saturated and unsaturated lipids.

1.15 i) Be able to analyse and interpret data on the possible significance for health of blood cholesterol levels and levels of high-density lipoproteins (HDLs) and low-density lipoproteins (LDLs). ii) Know the evidence for a causal relationship between blood cholesterol levels (total cholesterol and LDL cholesterol) and cardiovascular disease (CVD).

1.16 Understand how people use scientific knowledge about the effects of diet, including obesity indicators, body mass index and waist-to-hip ratio, exercise and smoking to reduce their risk of coronary heart disease.

CORE PRACTICAL 1: Investigate the effect of caffeine on heart rate in Daphnia.

1.17 Be able discuss the potential ethical issues regarding the use of invertebrates in research.

CORE PRACTICAL 2: Investigate the vitamin C content of food and drink.

1.18 Know the benefits and risks of treatments for cardiovascular disease (CVD) (antihypertensives, statins, anticoagulants and platelet inhibitors).

**Topic 2: Genes and Health**

Students should:

2.1 i) Know the properties of gas exchange surfaces in living organisms (large surface area to volume ratio, thickness of surface, difference in concentration). ii) Understand how the rate of diffusion is dependent on these properties and can be calculated using Fick’s Law of Diffusion. iii) Understand how the structure of the mammalian lung is adapted for rapid gaseous exchange.

2.2 i) Know the structure and properties of cell membranes. ii) Understand how models such as the fluid mosaic model of cell membranes are interpretations of data used to develop scientific explanations of the structure and properties of cell membranes.

CORE PRACTICAL 3: Investigate membrane structure, including the effect of alcohol concentration or temperature on membrane permeability.

2.3 Understand what is meant by osmosis in terms of the movement of free water molecules through a partially permeable membrane (consideration of water potential is not required).

2.4 i) Understand what is meant by passive transport (diffusion, facilitated diffusion), active transport (including the role of ATP as an immediate source of energy), endocytosis and exocytosis. ii) Understand the involvement of carrier and channel proteins in membrane transport.

2.5 i) Know the basic structure of mononucleotides (deoxyribose or ribose linked to a phosphate and a base, including thymine, uracil, cytosine, adenine or guanine) and the structures of DNA and RNA (polynucleotides composed of mononucleotides linked through condensation reactions). ii) Know how complementary base pairing and the hydrogen bonding between two complementary strands are involved in the formation of the DNA double helix.

2.6 i) Understand the process of protein synthesis (transcription) including the role of RNA polymerase, translation, messenger RNA, transfer RNA, ribosomes and the role of start and stop codons. ii) Understand the roles of the DNA template (antisense) strand in transcription, codons on messenger RNA and anticodons on transfer RNA.

2.7 Understand the nature of the genetic code (triplet code, non-overlapping and degenerate).

2.8 Know that a gene is a sequence of bases on a DNA molecule that codes for a sequence of amino acids in a polypeptide chain.

2.9 i) Know the basic structure of an amino acid (structures of specific amino acids are not required). ii) Understand the formation of polypeptides and proteins (amino acid monomers linked by peptide bonds in condensation reactions). iii) Understand the significance of a protein’s primary structure in determining its three-dimensional structure and properties (globular and fibrous proteins and the types of bonds involved in its three-dimensional structure). iv) Know the molecular structure of a globular protein and a fibrous protein and understand how their structures relate to their functions (including haemoglobin and collagen).

2.10 i) Understand the mechanism of action and the specificity of enzymes in terms of their three-dimensional structure. ii) Understand that enzymes are biological catalysts that reduce activation energy. iii) Know that there are intracellular enzymes catalysing reactions inside cells and extracellular enzymes produced by cells catalysing reactions outside of cells.

CORE PRACTICAL 4: Investigate the effect of enzyme and substrate concentrations on the initial rates of reactions.

2.11 i) Understand the process of DNA replication, including the role of DNA polymerase. ii) Understand how Meselson and Stahl’s classic experiment provided new data that supported the accepted theory of replication of DNA and refuted competing theories.

2.12 i) Understand how errors in DNA replication can give rise to mutations. ii) Understand how cystic fibrosis results from one of a number of possible gene mutations.

2.13 i) Know the meaning of the terms: gene, allele, genotype, phenotype, recessive, dominant, incomplete dominance, homozygote and heterozygote. ii) Understand patterns of inheritance, including the interpretation of genetic pedigree diagrams, in the context of monohybrid inheritance.

2.14 Understand how the expression of a gene mutation in people with cystic fibrosis impairs the functioning of the gaseous exchange, digestive and reproductive systems.

2.15 i) Understand the uses of genetic screening, including the identification of carriers, pre-implantation genetic diagnosis (PGD) and prenatal testing, including amniocentesis and chorionic villus sampling. ii) Understand the implications of prenatal genetic screening.

2.16 Be able to identify and discuss the social and ethical issues related to genetic screening from a range of ethical viewpoints.

**Topic 3: Voice of the Genome**

Students should:

3.1 Know that all living organisms are made of cells, sharing some common features.

3.2 Know the ultrastructure of eukaryotic cells, including nucleus, nucleolus, ribosomes, rough and smooth endoplasmic reticulum, mitochondria, centrioles, lysosomes, and Golgi apparatus.

3.3 Understand the role of the rough endoplasmic reticulum (rER) and the Golgi apparatus in protein transport within cells, including their role in the formation of extracellular enzymes.

3.4 Know the ultrastructure of prokaryotic cells, including cell wall, capsule, plasmid, flagellum, pili, ribosomes, mesosomes and circular DNA.

3.5 Be able to recognise the organelles in 3.2 from electron microscope (EM) images.

3.6 Understand how mammalian gametes are specialised for their functions (including the acrosome in sperm and the zona pellucida in the egg).

3.7 Know the process of fertilisation in mammals, including the acrosome reaction, the cortical reaction and the fusion of nuclei.

3.8 i) Know that a locus (plural = loci) is the location of genes on a chromosome. ii) Understand the linkage of genes on a chromosome and sex linkage.

3.9 Understand the role of meiosis in ensuring genetic variation through the production of non-identical gametes as a consequence of independent assortment of chromosomes and crossing over of alleles between chromatids (details of the stages of meiosis are not required).

3.10 Understand the role of mitosis and the cell cycle in producing identical daughter cells for growth and asexual reproduction.

CORE PRACTICAL 5: Prepare and stain a root tip squash to observe the stages of mitosis.

3.11 i) Understand what is meant by the terms ‘stem cell, pluripotency and totipotency’. ii) Be able to discuss the way society uses scientific knowledge to make decisions about the use of stem cells in medical therapies.

3.12 Understand how cells become specialised through differential gene expression, producing active mRNA leading to synthesis of proteins, which in turn control cell processes or determine cell structure in animals and plants, including the lac operon.

3.13 Understand how the cells of multicellular organisms are organised into tissues, tissues into organs and organs into systems.

3.14 i) Understand how phenotype is the result of an interaction between genotype and the environment. ii) Know how epigenetic changes, including DNA methylation and histone modification, can modify the activation of certain genes. iii) Understand how epigenetic changes can be passed on following cell division.

3.15 Understand how some phenotypes are affected by multiple alleles for the same gene at many loci (polygenic inheritance) as well as the environment and how this can give rise to phenotypes that show continuous variation.

**Topic 4: Biodiversity and Natural Resources**

Students should:

4.1 Know that over time the variety of life has become extensive but is now being threatened by human activity.

4.2 i) Understand the terms biodiversity and endemism. ii) Know how biodiversity can be measured within a habitat using species richness and within a species using genetic diversity by calculating the heterozygosity index (H): H = number of heterozygotes / number of individuals in the population

 iii) Understand how biodiversity can be compared in different habitats using a formula to calculate an index of diversity (D): D = N (N-1) / Σn (n 1)

4.3 Understand the concept of niche and be able to discuss examples of adaptation of organisms to their environment (behavioural, physiological and anatomical).

4.4 Understand how natural selection can lead to adaptation and evolution.

4.5 i) Understand how the Hardy-Weinberg equation can be used to see whether a change in allele frequency is occurring in a population over time. ii) Understand that reproductive isolation can lead to accumulation of different genetic information in populations, potentially leading to the formation of new species.

4.6 i) Understand that classification is a means of organising the variety of life based on relationships between organisms using differences and similarities in phenotypes and in genotypes, and is built around the species concept. ii) Understand the process and importance of critical evaluation of new data by the scientific community, which leads to new taxonomic groupings, including the three domains of life based on molecular phylogeny, which are Bacteria, Archaea, Eukaryota.

4.7 Know the ultrastructure of plant cells (cell walls, chloroplasts, amyloplasts, vacuole, tonoplast, plasmodesmata, pits and middle lamella) and be able to compare it with animal cells.

4.8 Be able to recognise the organelles in 4.7 from electron microscope (EM) images.

4.9 Understand the structure and function of the polysaccharides starch and cellulose, including the role of hydrogen bonds between β-glucose molecules in the formation of cellulose microfibrils.

4.10 Understand how the arrangement of cellulose microfibrils and secondary thickening in plant cell walls contributes to the physical properties of xylem vessels and sclerenchyma fibres in plant fibres that can be exploited by humans.

CORE PRACTICAL 6: Identify sclerenchyma fibres, phloem sieve tubes and xylem vessels and their location within stems through a light microscope.

4.11 Know the similarities and differences between the structures, position in the stem and function of sclerenchyma fibres (support), xylem vessels (support and transport of water and mineral ions) and phloem (translocation of organic solutes).

4.12 Understand the importance of water and inorganic ions (nitrate, calcium ions and magnesium ions) to plants.

CORE PRACTICAL 7: Investigate plant mineral deficiencies.

CORE PRACTICAL 8: Determine the tensile strength of plant fibres.

4.13 Understand the development of drug testing from historic to contemporary protocols, including William Withering’s digitalis soup, double blind trials, placebo, three-phased testing.

4.14 Understand the conditions required for bacterial growth.

CORE PRACTICAL 9: Investigate the antimicrobial properties of plants, including aseptic techniques for the safe handling of bacteria.

4.15 Understand how the uses of plant fibres and starch may contribute to sustainability, including plant-based products to replace oil-based plastics.

4.16 Be able to evaluate the methods used by zoos and seed banks in the conservation of endangered species and their genetic diversity, including scientific research, captive breeding programmes, reintroduction programmes and education.

**Topic 5: On the Wild Side**

Students should:

5.1 Understand the terms ecosystem, community, population and habitat.

5.2 Understand that the numbers and distribution of organisms in a habitat are controlled by biotic and abiotic factors.

5.3 Understand how the concept of niche accounts for distribution and abundance of organisms in a habitat.

CORE PRACTICAL 10: Carry out a study on the ecology of a habitat, such as using quadrats and transects to determine distribution and abundance of organisms, and measuring abiotic factors appropriate to the habitat.

5.4 Understand the stages of succession from colonisation to a climax community.

5.5 Understand the overall reaction of photosynthesis as requiring energy from light to split apart the strong bonds in water molecules, storing the hydrogen in a fuel (glucose) by combining it with carbon dioxide and releasing oxygen into the atmosphere.

5.6 Understand how phosphorylation of ADP requires energy and that hydrolysis of ATP provides an immediate supply of energy for biological processes.

5.7 Understand the light-dependent reactions of photosynthesis including how light energy is trapped by exciting electrons in chlorophyll and the role of these electrons in generating ATP, reducing NADP in photophosphorylation and producing oxygen through photolysis of water.

5.8 i) Understand the light-independent reactions as reduction of carbon dioxide using the products of the light-dependent reactions (carbon fixation in the Calvin cycle, the role of GP, GALP, RuBP and RUBISCO). ii) Know that the products are simple sugars that are used by plants, animals and other organisms in respiration and the synthesis of new biological molecules (polysaccharides, amino acids, lipids and nucleic acids). CORE PRACTICAL 11: Investigate photosynthesis using isolated chloroplasts (the Hill reaction).

5.9 Understand the structure of chloroplasts in relation to their role in photosynthesis.

5.10 i) Be able to calculate net primary productivity. ii) Understand the relationship between gross primary productivity, net primary productivity and plant respiration.

5.11 Know how to calculate the efficiency of biomass and energy transfers between trophic levels.

5.12 Understand the different types of evidence for climate change and its causes (including records of carbon dioxide levels, temperature records, pollen in peat bogs and dendrochronology), recognising correlations and causal relationships.

5.13 Understand the causes of anthropogenic climate change, including the role of greenhouse gases (carbon dioxide and methane) in the greenhouse effect.

5.14 i) Understand that data can be extrapolated to make predictions and that these are used in models of future climate change. ii) Understand that models for climate change have limitations.

5.15 Understand the effects of climate change (changing rainfall patterns and changes in seasonal cycles) on plants and animals (distribution of species, development and life cycles).

5.16 Understand the effect of temperature on the rate of enzyme activity and its impact on plants, animals and microorganisms.

5.17 Understand how evolution (a change in the allele frequency) can come about through gene mutation and natural selection.

5.18 Understand the role of the scientific community (scientific journals, the peer review process, scientific conferences) in validating new evidence, including proteomics and genomics, that supports the accepted scientific theory of evolution.

5.19 Understand how isolation reduces gene flow between populations, leading to allopatric or sympatric speciation.

CORE PRACTICAL 12: Investigate the effect of temperature on the initial rate of an enzyme-catalysed reaction, to include Q10.

CORE PRACTICAL 13: Investigate the effects of temperature on the development of organisms (such as seedling growth rate, brine shrimp hatch rates).

5.20 Understand the way in which scientific conclusions about controversial issues, such as what actions should be taken to reduce climate change or the degree to which humans are affecting climate change, can sometimes depend on who is reaching the conclusions.

5.21 Understand how knowledge of the carbon cycle can be applied to methods to reduce atmospheric levels of carbon dioxide.

5.22 Understand how reforestation and the use of sustainable resources, including biofuels, are examples of the effective management of the conflict between human needs and conservation.

**Topic 6: Immunity, Infection and Forensics**

Students should:

6.1 Understand how to determine the time of death of a mammal by examining the extent of decomposition, stage of succession, forensic entomology, body temperature and degree of muscle contraction.

6.2 Know the role of micro-organisms in the decomposition of organic matter and the recycling of carbon.

6.3 Know how DNA profiling is used for identification and determining genetic relationships between organisms (plants and animals).

6.4 Know how DNA can be amplified using the polymerase chain reaction (PCR).

CORE PRACTICAL 14: Use gel electrophoresis to separate DNA fragments of different length.

6.5 Be able to compare the structure of bacteria and viruses.

6.6 Understand how Mycobacterium tuberculosis (TB) and Human Immunodeficiency Virus (HIV) infect human cells, causing a sequence of symptoms that may result in death.

6.7 Understand the non-specific responses of the body to infection, including inflammation, lysozyme action, interferon, and phagocytosis.

6.8 Understand the roles of antigens and antibodies in the body’s immune response including the involvement of plasma cells, macrophages and antigen-presenting cells.

6.9 Understand the differences between the roles of B cells (B memory and B effector cells) and T cells (T helper, T killer and T memory cells) in the body’s immune response.

6.10 Understand how one gene can give rise to more than one protein through posttranscriptional changes to messenger RNA (mRNA).

6.11 i) Know the major routes pathogens may take when entering the body. ii) Understand the role of barriers in protecting the body from infection, including skin, stomach acid, and gut and skin flora.

6.12 Understand how individuals may develop immunity (natural, artificial, active, passive).

6.13 Understand how the theory of an ‘evolutionary race’ between pathogens and their hosts is supported by the evasion mechanisms shown by pathogens.

6.14 Understand the difference between bacteriostatic and bactericidal antibiotics.

CORE PRACTICAL 15: Investigate the effect of different antibiotics on bacteria.

6.15 Know how an understanding of the contributory causes of hospital acquired infections have led to codes of practice regarding antibiotic prescription and hospital practice that relate to infection prevention and control.

**Topic 7: Run for your Life**

Students should:

7.1 Know the way in which muscles, tendons, the skeleton and ligaments interact to enable movement, including antagonistic muscle pairs, extensors and flexors.

7.2 Understand the process of contraction of skeletal muscle in terms of the sliding filament theory, including the role of actin, myosin, troponin, tropomyosin, calcium ions (Ca2+), ATP and ATPase.

7.3 i) Understand the overall reaction of aerobic respiration as splitting of the respiratory substrate, to release carbon dioxide as a waste product and reuniting of hydrogen with atmospheric oxygen with the release of a large amount of energy. ii) Understand that respiration is a many-stepped process with each step controlled and catalysed by a specific intracellular enzyme.

7.4 Understand the roles of glycolysis in aerobic and anaerobic respiration, including the phosphorylation of hexoses, the production of ATP, reduced coenzyme, pyruvate and lactate (details of intermediate stages and compounds are not required).

7.5 Understand the role of the link reaction and the Krebs cycle in the complete oxidation of glucose and formation of carbon dioxide (CO2), ATP, reduced NAD and reduced FAD (names of other compounds are not required) and why these steps take place in the mitochondria, unlike glycolysis which occurs in the cytoplasm.

7.6 Understand how ATP is synthesised by oxidative phosphorylation associated with the electron transport chain in mitochondria, including the role of chemiosmosis and ATP synthase.

7.7 Understand what happens to lactate after a period of anaerobic respiration in animals.

CORE PRACTICAL 16: Investigate rate of respiration.

7.8 i) Know the myogenic nature of cardiac muscle. ii) Understand how the normal electrical activity of the heart coordinates the heart beat, including the roles of the sinoatrial node (SAN), the atrioventricular node (AVN), the bundle of His and the Purkyne fibres. iii) Understand how the use of electrocardiograms (ECGs) can aid the diagnosis of cardiovascular disease (CVD) and other heart conditions.

7.9 i) Be able to calculate cardiac output. ii) Understand how variations in ventilation and cardiac output enable rapid delivery of oxygen to tissues and the removal of carbon dioxide from them, including how the heart rate and ventilation rate are controlled and the roles of the cardiovascular control centre and the ventilation centre in the medulla oblongata.

CORE PRACTICAL 17: Investigate the effects of exercise on tidal volume, breathing rate, respiratory minute ventilation and oxygen consumption using data from spirometer traces.

7.10 i) Know the structure of a muscle fibre. ii) Understand the structural and physiological differences between fast and slow twitch muscle fibres.

7.11 i) Understand what is meant by negative feedback and positive feedback control. ii) Understand the principle of negative feedback in maintaining systems within narrow limits.

7.12 Understand homeostasis and its importance in maintaining the body in a state of dynamic equilibrium during exercise, including the role of the hypothalamus and the mechanisms of thermoregulation.

7.13 Understand the analysis and interpretation of data relating to possible disadvantages of exercising too much (wear and tear on joints, suppression of the immune system) and exercising too little (increased risk of obesity, cardiovascular disease (CVD) and diabetes), recognising correlation and causal relationships.

7.14 Understand how medical technology, including the use of keyhole surgery and prostheses, is enabling those with injuries and disabilities to participate in sports.

7.15 Be able to discuss different ethical positions relating to whether the use of performance-enhancing substances by athletes is acceptable.

7.16 Understand how genes can be switched on and off by DNA transcription factors including hormones.

**Topic 8: Grey Matter**

Students should:

8.1 Know the structure and function of sensory, relay and motor neurones including the role of Schwann cells and myelination.

8.2 i) Understand how the nervous systems of organisms can cause effectors to respond to a stimulus. ii) Understand how the pupil dilates and contracts. 8.3 Understand how a nerve impulse (action potential) is conducted along an axon including changes in membrane permeability to sodium and potassium ions and the role of the myelination in saltatory conduction.

8.4 Know the structure and function of synapses in nerve impulse transmission, including the role of neurotransmitters, including acetylcholine.

8.5 Understand how the nervous systems of organisms can detect stimuli with reference to rods in the retina of mammals, the roles of rhodopsin, opsin, retinal, sodium ions, cation channels and hyperpolarisation of rod cells in forming action potentials in the optic neurones.

8.6 Understand how phytochrome and IAA bring about responses in plants to environmental cues, including their effects on transcription.

8.7 Understand how co-ordination is brought about through nervous and hormonal control in animals.

8.8 Know the location and functions of the cerebral hemispheres, hypothalamus, cerebellum and medulla oblongata in the human brain.

8.9 Understand how magnetic resonance imaging (MRI), functional magnetic resonance imaging (fMRI), positron emission tomography (PET) and computed tomography (CT) scans are used in medical diagnosis and the investigation of brain structure and function.

8.10 Understand what happens during the critical period so that mammals can develop their visual capacities to the full.

8.11 Understand the role animal models have played in the research into human brain development and function, including Hubel and Wiesel’s experiments with monkeys and kittens.

8.12 Be able to discuss moral and ethical issues relating to the use of animals in medical research from two ethical standpoints.

8.13 Understand how animals, including humans, can learn by habituation.

CORE PRACTICAL 18: Investigate habituation to a stimulus.

8.14 Understand how imbalances in certain, naturally occurring brain chemicals can contribute to ill health, including dopamine in Parkinson’s disease and serotonin in depression, and to the development of new drugs.

8.15 Understand the effects of drugs on synaptic transmissions, including the use of L-Dopa in the treatment of Parkinson’s disease and the action of MDMA in Ecstasy.

8.16 Understand how the outcomes of genome sequencing projects are being used in the development of personalised medicine and the social, moral and ethical issues this raises.

8.17 Know how drugs can be produced using genetically modified organisms (plants, animals and microorganisms).

8.18 Understand the risks and benefits associated with the use of genetically modified organisms.

8.19 Understand the methods used to investigate the contributions of nature and nurture to brain development, including evidence from the abilities of new-born babies, animal experiments, studies of individuals with damaged brain areas, twin studies and cross-cultural studies.

1. STEM Education Consultant, angmhall007@gmail.com [↑](#footnote-ref-1)