

4 Biology subject content

This specification is presented in a two column format.

The subject content is split into three sections for each of the subject areas: biology, chemistry and physics.

The left hand column contains the subject content that all students must cover, and that can be assessed in the written papers.

The right hand column exemplifies some of the key opportunities for the following skills to be developed throughout the course: WS refers to [Working scientifically](#) (page 13), MS refers to [Mathematical requirements](#) (page 171) and AT refers to [Use of apparatus and techniques](#) (page 173). These are not the only opportunities. Teachers are encouraged to introduce all of these skills where appropriate throughout the course.

Each topic begins with an overview. The overview puts the topic into a broader context and is intended to encourage an overarching approach to both the teaching and learning of each of the topic areas. It is not directly assessed. Any assessable content in this overview is replicated in the left hand column.

It is good practice to teach and develop all of the mathematical skills throughout the course. Some mathematical skills will only be assessed in certain subject areas. These are detailed in [Mathematical requirements](#) (page 171).

Science is a practical subject. Details of the assessment of required practicals can be found in [Required practical activities](#) (page 175).

[Working scientifically](#) (page 13) and [Use of apparatus and techniques](#) (page 173) skills will be assessed across all papers.

Content that is only applicable to Higher Tier is indicated by (HT only) either next to the topic heading where it applies to the whole topic or immediately preceding each paragraph or bullet point as applicable.

Fundamental biological concepts and principles

Students should have a basic understanding of the following biological principles and be able to apply them in either paper:

- The structure and functioning of cells and how they divide by mitosis and meiosis from sections [Cell biology](#) (page 20) and [Meiosis](#) (page 50).
- That variation occurs when gametes fuse at fertilisation from section [Sexual and asexual reproduction](#) (page 50).
- The two essential reactions for life on Earth: photosynthesis and respiration from sections [Photosynthetic reaction](#) (page 39) and [Aerobic and anaerobic respiration](#) (page 41).
- Metabolism is the sum of all the reactions happening in a cell or organism, in which molecules are made or broken down from section [Metabolism](#) (page 42).
- All molecules are recycled between the living world and the environment to sustain life from section [How materials are cycled](#) (page 63).

Students should be able to recall and use this knowledge in questions that link different areas of the specification to develop coherent arguments and explanations.

4.1 Cell biology

Cells are the basic unit of all forms of life. In this section we explore how structural differences between types of cells enables them to perform specific functions within the organism. These differences in cells are controlled by genes in the nucleus. For an organism to grow, cells must divide by mitosis producing two new identical cells. If cells are isolated at an early stage of growth before they have become too specialised, they can retain their ability to grow into a range of different types of cells. This phenomenon has led to the development of stem cell technology. This is a new branch of medicine that allows doctors to repair damaged organs by growing new tissue from stem cells.

4.1.1 Cell structure

4.1.1.1 Eukaryotes and prokaryotes

Content	Key opportunities for skills development
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.	MS 1b, 2a, 2h WS 4.4 Use prefixes centi, milli, micro and nano.

4.1.1.2 Animal and plant cells

Content	Key opportunities for skills development
<p>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.</p> <p>Most animal cells have the following parts:</p> <ul style="list-style-type: none"> • a nucleus • cytoplasm • a cell membrane • mitochondria • ribosomes. <p>In addition to the parts found in animal cells, plant cells often have:</p> <ul style="list-style-type: none"> • chloroplasts • a permanent vacuole filled with cell sap. <p>Plant and algal cells also have a cell wall made of cellulose, which strengthens the cell.</p>	<p>WS 1.2</p> <p>Recognise, draw and interpret images of cells.</p>
<p>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.</p>	<p>MS 1d, 3a</p> <p>AT 7</p> <p>Images of cells in videos, bioviewers, photographs and micrographs can be used as comparison for students own drawings.</p>

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.

AT skills covered by this practical activity: biology AT 1 and 7.

This practical activity also provides opportunities to develop WS and MS. Details of all skills are given in [Key opportunities for skills development](#) (page 176).

4.1.1.3 Cell specialisation

Content	Key opportunities for skills development
<p>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.</p> <p>Cells may be specialised to carry out a particular function:</p> <ul style="list-style-type: none">• sperm cells, nerve cells and muscle cells in animals• root hair cells, xylem and phloem cells in plants.	

4.1.1.4 Cell differentiation

Content	Key opportunities for skills development
<p>Students should be able to explain the importance of cell differentiation.</p> <p>As an organism develops, cells differentiate to form different types of cells.</p> <ul style="list-style-type: none">• Most types of animal cell differentiate at an early stage.• Many types of plant cells retain the ability to differentiate throughout life. <p>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.</p>	

4.1.1.5 Microscopy

Content	Key opportunities for skills development
<p>Students should be able to:</p> <ul style="list-style-type: none">• understand how microscopy techniques have developed over time• explain how electron microscopy has increased understanding of sub-cellular structures. <p>Limited to the differences in magnification and resolution.</p> <p>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.</p>	WS 1.1

Content	Key opportunities for skills development
<p>Students should be able to carry out calculations involving magnification, real size and image size using the formula:</p> $\text{magnification} = \frac{\text{size of image}}{\text{size of real object}}$ <p>Students should be able to express answers in standard form if appropriate.</p>	<p>MS 1a, 1b, 2h, 3b</p> <p>WS 4.4</p> <p>Use prefixes centi, milli, micro and nano.</p>

4.1.2 Cell division

4.1.2.1 Chromosomes

Content	Key opportunities for skills development
<p>The nucleus of a cell contains chromosomes made of DNA molecules. Each chromosome carries a large number of genes.</p> <p>In body cells the chromosomes are normally found in pairs.</p>	<p>WS 1.2</p> <p>Use models and analogies to develop explanations of how cells divide.</p>

4.1.2.2 Mitosis and the cell cycle

Content	Key opportunities for skills development
<p>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.</p> <p>During the cell cycle the genetic material is doubled and then divided into two identical cells.</p> <p>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.</p> <p>In mitosis one set of chromosomes is pulled to each end of the cell and the nucleus divides.</p> <p>Finally the cytoplasm and cell membranes divide to form two identical cells.</p> <p>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.</p> <p>Cell division by mitosis is important in the growth and development of multicellular organisms.</p> <p>Students should be able to recognise and describe situations in given contexts where mitosis is occurring.</p>	

4.1.2.3 Stem cells

Content	Key opportunities for skills development
<p>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.</p> <p>Students should be able to describe the function of stem cells in embryos, in adult animals and in the meristems in plants.</p> <p>Stem cells from human embryos can be cloned and made to differentiate into most different types of human cells.</p> <p>Stem cells from adult bone marrow can form many types of cells including blood cells.</p> <p>Meristem tissue in plants can differentiate into any type of plant cell, throughout the life of the plant.</p> <p>Knowledge and understanding of stem cell techniques are not required.</p> <p>Treatment with stem cells may be able to help conditions such as diabetes and paralysis.</p>	
<p>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.</p> <p>The use of stem cells has potential risks such as transfer of viral infection, and some people have ethical or religious objections.</p> <p>Stem cells from meristems in plants can be used to produce clones of plants quickly and economically.</p> <ul style="list-style-type: none">• 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.	<p>WS 1.3</p> <p>Evaluate the practical risks and benefits, as well as social and ethical issues, of the use of stem cells in medical research and treatments.</p>

4.1.3 Transport in cells

4.1.3.1 Diffusion

Content	Key opportunities for skills development
<p>Substances may move into and out of cells across the cell membranes via diffusion.</p> <p>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.</p> <p>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.</p> <p>Students should be able to explain how different factors affect the rate of diffusion.</p> <p>Factors which affect the rate of diffusion are:</p> <ul style="list-style-type: none"> • the difference in concentrations (concentration gradient) • the temperature • the surface area of the membrane. <p>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.</p>	<p>WS 1.2</p> <p>Recognise, draw and interpret diagrams that model diffusion.</p> <p>WS 1.5</p> <p>Use of isotonic drinks and high energy drinks in sport.</p>
<p>Students should be able to calculate and compare surface area to volume ratios.</p> <p>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.</p> <p>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.</p> <p>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:</p> <ul style="list-style-type: none"> • 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. 	<p>MS 1c, 5c</p>

4.1.3.2 Osmosis

Content	Key opportunities for skills development
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.	WS 1.2 Recognise, draw and interpret diagrams that model osmosis.
Students should be able to: <ul style="list-style-type: none">• use simple compound measures of rate of water uptake• use percentages• calculate percentage gain and loss of mass of plant tissue.	MS 1a, 1c
Students should be able to plot, draw and interpret appropriate graphs.	MS 4a, 4b, 4c, 4d

Required practical activity 2: investigate the effect of a range of concentrations of salt or sugar solutions on the mass of plant tissue.

AT skills covered by this practical activity: biology AT 1, 3 and 5.

This practical activity also provides opportunities to develop WS and MS. Details of all skills are given in [Key opportunities for skills development](#) (page 176).

4.1.3.3 Active transport

Content	Key opportunities for skills development
<p>Active transport moves substances from a more dilute solution to a more concentrated solution (against a concentration gradient). This requires energy from respiration.</p> <p>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.</p> <p>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.</p> <p>Students should be able to:</p> <ul style="list-style-type: none">• describe how substances are transported into and out of cells by diffusion, osmosis and active transport• explain the differences between the three processes.	There are links with this content to Cell specialisation (page 22).

4.2 Organisation

In this section we will learn about the human digestive system which provides the body with nutrients and the respiratory system that provides it with oxygen and removes carbon dioxide. In

each case they provide dissolved materials that need to be moved quickly around the body in the blood by the circulatory system. Damage to any of these systems can be debilitating if not fatal. Although there has been huge progress in surgical techniques, especially with regard to coronary heart disease, many interventions would not be necessary if individuals reduced their risks through improved diet and lifestyle. We will also learn how the plant's transport system is dependent on environmental conditions to ensure that leaf cells are provided with the water and carbon dioxide that they need for photosynthesis.

4.2.1 Principles of organisation

Content	Key opportunities for skills development
<p>Cells are the basic building blocks of all living organisms.</p> <p>A tissue is a group of cells with a similar structure and function.</p> <p>Organs are aggregations of tissues performing specific functions.</p> <p>Organs are organised into organ systems, which work together to form organisms.</p>	<p>MS 1c</p> <p>Students should be able to develop an understanding of size and scale in relation to cells, tissues, organs and systems.</p>

4.2.2 Animal tissues, organs and organ systems

4.2.2.1 The human digestive system

Content	Key opportunities for skills development
<p>This section assumes knowledge of the digestive system studied in Key Stage 3 science.</p> <p>The digestive system is an example of an organ system in which several organs work together to digest and absorb food.</p> <p>Students should be able to relate knowledge of enzymes to Metabolism (page 42).</p> <p>Students should be able to describe the nature of enzyme molecules and relate their activity to temperature and pH changes.</p>	
<p>Students should be able to carry out rate calculations for chemical reactions.</p> <p>Enzymes catalyse specific reactions in living organisms due to the shape of their active site.</p>	MS 1a, 1c

Content	Key opportunities for skills development
<p>Students should be able to use the 'lock and key theory' as a simplified model to explain enzyme action.</p> <p>Students should be able to recall the sites of production and the action of amylase, proteases and lipases.</p> <p>Students should be able to understand simple word equations but no chemical symbol equations are required.</p> <p>Digestive enzymes convert food into small soluble molecules that can be absorbed into the bloodstream.</p> <p>Carbohydrases break down carbohydrates to simple sugars. Amylase is a carbohydrase which breaks down starch.</p> <p>Proteases break down proteins to amino acids.</p> <p>Lipases break down lipids (fats) to glycerol and fatty acids.</p> <p>The products of digestion are used to build new carbohydrates, lipids and proteins. Some glucose is used in respiration.</p> <p>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.</p>	<p>WS 1.2</p> <p>Students should be able to use other models to explain enzyme action.</p>

Required practical activity 3: 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.

AT skills covered by this practical activity: biology AT 2.

This practical activity also provides opportunities to develop WS and MS. Details of all skills are given in [Key opportunities for skills development](#) (page 177).

Required practical activity 4: 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.

AT skills covered by this practical activity: biology AT 1, 2 and 5.

This practical activity also provides opportunities to develop WS and MS. Details of all skills are given in [Key opportunities for skills development](#) (page 177).

4.2.2.2 The heart and blood vessels

Content	Key opportunities for skills development
<p>Students should know the structure and functioning of the human heart and lungs, including how lungs are adapted for gaseous exchange.</p> <p>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.</p> <p>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.</p> <p>Knowledge of the lungs is restricted to the trachea, bronchi, alveoli and the capillary network surrounding the alveoli.</p> <p>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.</p> <p>The body contains three different types of blood vessel:</p> <ul style="list-style-type: none"> • arteries • veins • capillaries. <p>Students should be able to explain how the structure of these vessels relates to their functions.</p>	
<p>Students should be able to use simple compound measures such as rate and carry out rate calculations for blood flow.</p>	MS 1a, 1c

4.2.2.3 Blood

Content	Key opportunities for skills development
<p>Blood is a tissue consisting of plasma, in which the red blood cells, white blood cells and platelets are suspended.</p> <p>Students should know the functions of each of these blood components.</p>	<p>AT 7</p> <p>Observing and drawing blood cells seen under a microscope.</p> <p>WS 1.5</p> <p>Evaluate risks related to use of blood products.</p>

Content	Key opportunities for skills development
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.	WS 3.5

4.2.2.4 Coronary heart disease: a non-communicable disease

Content	Key opportunities for skills development
<p>Students should be able to evaluate the advantages and disadvantages of treating cardiovascular diseases by drugs, mechanical devices or transplant.</p> <p>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.</p> <p>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.</p> <p>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.</p>	<p>WS 1.4</p> <p>WS 1.3</p> <p>Evaluate methods of treatment bearing in mind the benefits and risks associated with the treatment.</p>

4.2.2.5 Health issues

Content	Key opportunities for skills development
<p>Students should be able to describe the relationship between health and disease and the interactions between different types of disease.</p> <p>Health is the state of physical and mental well-being.</p> <p>Diseases, both communicable Communicable diseases (page 35) 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.</p> <p>Different types of disease may interact.</p> <ul style="list-style-type: none"> • 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. 	
<p>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.</p>	MS 2c, 2g, 4a
<p>Students should understand the principles of sampling as applied to scientific data, including epidemiological data.</p>	MS 2d

4.2.2.6 The effect of lifestyle on some non-communicable diseases

Content	Key opportunities for skills development
<p>Students should be able to:</p> <ul style="list-style-type: none"> • 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

Content	Key opportunities for skills development
<p>Risk factors are linked to an increased rate of a disease.</p> <p>They can be:</p> <ul style="list-style-type: none"> • aspects of a person's lifestyle • substances in the person's body or environment. <p>A causal mechanism has been proven for some risk factors, but not in others.</p> <ul style="list-style-type: none"> • 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. <p>Many diseases are caused by the interaction of a number of factors.</p>	<p>WS 1.5</p> <p>Interpret data about risk factors for specified diseases.</p>
<p>Students should be able to understand the principles of sampling as applied to scientific data in terms of risk factors.</p>	<p>MS 2d</p>
<p>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.</p>	<p>MS 2c, 4a</p>
<p>Students should be able to use a scatter diagram to identify a correlation between two variables in terms of risk factors.</p>	<p>MS 2g</p>

4.2.2.7 Cancer

Content	Key opportunities for skills development
<p>Students should be able to describe cancer as the result of changes in cells that lead to uncontrolled growth and division.</p> <p>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.</p> <p>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.</p> <p>Scientists have identified lifestyle risk factors for various types of cancer. There are also genetic risk factors for some cancers.</p>	

4.2.3 Plant tissues, organs and systems

4.2.3.1 Plant tissues

Content	Key opportunities for skills development
<p>Students should be able to explain how the structures of plant tissues are related to their functions.</p> <p>Plant tissues include:</p> <ul style="list-style-type: none"> • epidermal tissues • palisade mesophyll • spongy mesophyll • xylem and phloem • meristem tissue found at the growing tips of shoots and roots. <p>The leaf is a plant organ. Knowledge limited to epidermis, palisade and spongy mesophyll, xylem and phloem, and guard cells surrounding stomata.</p>	<p>AT 7</p> <p>Observation and drawing of a transverse section of leaf.</p>

4.2.3.2 Plant organ system

Content	Key opportunities for skills development
<p>Students should be able to explain how the structure of root hair cells, xylem and phloem are adapted to their functions.</p> <p>Students should be able to explain the effect of changing temperature, humidity, air movement and light intensity on the rate of transpiration.</p>	<p>AT 3, 4, 5</p> <p>Measure the rate of transpiration by the uptake of water.</p> <p>AT 6, 7</p> <p>Investigate the distribution of stomata and guard cells.</p> <p>MS 2a, 2d, 5c</p> <p>Process data from investigations involving stomata and transpiration rates to find arithmetic means, understand the principles of sampling and calculate surface areas and volumes.</p>
<p>Students should be able to understand and use simple compound measures such as the rate of transpiration.</p>	<p>MS 1a, 1c</p>

Content	Key opportunities for skills development
<p>Students should be able to:</p> <ul style="list-style-type: none"> • 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. 	MS 2c, 4a, 4c
<p>The roots, stem and leaves form a plant organ system for transport of substances around the plant.</p> <p>Students should be able to describe the process of transpiration and translocation, including the structure and function of the stomata.</p> <p>Root hair cells are adapted for the efficient uptake of water by osmosis, and mineral ions by active transport.</p> <p>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.</p> <p>The role of stomata and guard cells are to control gas exchange and water loss.</p> <p>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.</p> <p>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.</p> <p>Detailed structure of phloem tissue or the mechanism of transport is not required.</p>	

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

Content	Key opportunities for skills development
<p>Students should be able to explain how diseases caused by viruses, bacteria, protists and fungi are spread in animals and plants.</p> <p>Students should be able to explain how the spread of diseases can be reduced or prevented.</p> <p>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.</p> <p>Bacteria and viruses may reproduce rapidly inside the body.</p> <p>Bacteria may produce poisons (toxins) that damage tissues and make us feel ill.</p> <p>Viruses live and reproduce inside cells, causing cell damage.</p>	WS 1.4

4.3.1.2 Viral diseases

Content	Key opportunities for skills development
<p>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.</p> <p>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.</p> <p>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.</p>	

4.3.1.3 Bacterial diseases

Content	Key opportunities for skills development
<p>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.</p> <p>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.</p>	

4.3.1.4 Fungal diseases

Content	Key opportunities for skills development
<p>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.</p>	

4.3.1.5 Protist diseases

Content	Key opportunities for skills development
<p>The pathogens that cause malaria are protists.</p> <p>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.</p>	

4.3.1.6 Human defence systems

Content	Key opportunities for skills development
<p>Students should be able to describe the non-specific defence systems of the human body against pathogens, including the:</p> <ul style="list-style-type: none"> • skin • nose • trachea and bronchi • stomach. <p>Students should be able to explain the role of the immune system in the defence against disease.</p> <p>If a pathogen enters the body the immune system tries to destroy the pathogen.</p> <p>White blood cells help to defend against pathogens by:</p> <ul style="list-style-type: none"> • phagocytosis • antibody production • antitoxin production. 	

4.3.1.7 Vaccination

Content	Key opportunities for skills development
<p>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.</p> <p>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.</p> <p>Students do not need to know details of vaccination schedules and side effects associated with specific vaccines.</p>	<p>WS 1.4</p> <p>Evaluate the global use of vaccination in the prevention of disease.</p>

4.3.1.8 Antibiotics and painkillers

Content	Key opportunities for skills development
<p>Students should be able to explain the use of antibiotics and other medicines in treating disease.</p> <p>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.</p>	<p>WS 1.4</p>

Content	Key opportunities for skills development
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 Resistant bacteria (page 58).
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

Content	Key opportunities for skills development
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. <ul style="list-style-type: none"> • The heart drug digitalis originates from foxgloves. • The painkiller aspirin originates from willow. • Penicillin was discovered by Alexander Fleming from the <i>Penicillium</i> 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. <ul style="list-style-type: none"> • 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. 	WS 1.6 Understand that the results of testing and trials are published only after scrutiny by peer review.

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

Content	Key opportunities for skills development
<p>Photosynthesis is represented by the equation:</p> $\text{carbon dioxide} + \text{water} \xrightarrow{\text{light}} \text{glucose} + \text{oxygen}$ <p>Students should recognise the chemical symbols: CO₂, H₂O, O₂ and C₆H₁₂O₆.</p>	
<p>Students should be able to describe photosynthesis as an endothermic reaction in which energy is transferred from the environment to the chloroplasts by light.</p>	<p>There are links with this content to Plant tissues (page 33), the leaf.</p>

4.4.1.2 Rate of photosynthesis

Content	Key opportunities for skills development
<p>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.</p>	
<p>Students should be able to:</p> <ul style="list-style-type: none"> • 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. 	<p>MS 3d</p> <p>Solve simple algebraic equations.</p> <p>MS 1a, 1c, 2c, 3d, 4a, 4c</p>

Content	Key opportunities for skills development
<p>(HT only) These factors interact and any one of them may be the factor that limits photosynthesis.</p> <p>(HT only) Students should be able to explain graphs of photosynthesis rate involving two or three factors and decide which is the limiting factor.</p>	
<p>(HT only) Students should understand and use inverse proportion – the inverse square law and light intensity in the context of photosynthesis.</p> <p>(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.</p>	<p>MS 3a, 3d</p> <p>(HT only) WS 1.4</p> <p>Use data to relate limiting factors to the cost effectiveness of adding heat, light or carbon dioxide to greenhouses.</p>

Required practical activity 5: 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: biology AT 1, 2, 3, 4 and 5.

This practical activity also provides opportunities to develop WS and MS. Details of all skills are given in [Key opportunities for skills development](#) (page 178).

4.4.1.3 Uses of glucose from photosynthesis

Content	Key opportunities for skills development
<p>The glucose produced in photosynthesis may be:</p> <ul style="list-style-type: none"> • 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. <p>To produce proteins, plants also use nitrate ions that are absorbed from the soil.</p>	

4.4.2 Respiration

4.4.2.1 Aerobic and anaerobic respiration

Content	Key opportunities for skills development
<p>Students should be able to describe cellular respiration as an exothermic reaction which is continuously occurring in living cells.</p> <p>The energy transferred supplies all the energy needed for living processes.</p> <p>Respiration in cells can take place aerobically (using oxygen) or anaerobically (without oxygen), to transfer energy.</p> <p>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.</p> <p>Organisms need energy for:</p> <ul style="list-style-type: none"> • chemical reactions to build larger molecules • movement • keeping warm. <p>Aerobic respiration is represented by the equation:</p> <p>glucose + oxygen → carbon dioxide + water</p> <p>Students should recognise the chemical symbols: C₆H₁₂O₆, O₂, CO₂ and H₂O.</p> <p>Anaerobic respiration in muscles is represented by the equation:</p> <p>glucose → lactic acid</p> <p>As the oxidation of glucose is incomplete in anaerobic respiration much less energy is transferred than in aerobic respiration.</p> <p>Anaerobic respiration in plant and yeast cells is represented by the equation:</p> <p>glucose → ethanol + carbon dioxide</p> <p>Anaerobic respiration in yeast cells is called fermentation and has economic importance in the manufacture of bread and alcoholic drinks.</p>	

4.4.2.2 Response to exercise

Content	Key opportunities for skills development
<p>During exercise the human body reacts to the increased demand for energy.</p> <p>The heart rate, breathing rate and breath volume increase during exercise to supply the muscles with more oxygenated blood.</p> <p>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.</p>	<p>AT 1, 3, 4</p> <p>Investigations into the effect of exercise on the body.</p>
<p>(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.</p>	

4.4.2.3 Metabolism

Content	Key opportunities for skills development
<p>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.</p> <p>Metabolism is the sum of all the reactions in a cell or the body.</p> <p>The energy transferred by respiration in cells is used by the organism for the continual enzyme controlled processes of metabolism that synthesise new molecules.</p> <p>Metabolism includes:</p> <ul style="list-style-type: none">• 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. <p>All of these aspects are covered in more detail in the relevant specification section but are linked together here.</p>	

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

Content	Key opportunities for skills development
<p>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.</p> <p>Homeostasis maintains optimal conditions for enzyme action and all cell functions.</p> <p>In the human body, these include control of:</p> <ul style="list-style-type: none"> • blood glucose concentration • body temperature • water levels. <p>These automatic control systems may involve nervous responses or chemical responses.</p> <p>All control systems include:</p> <ul style="list-style-type: none"> • 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

Content	Key opportunities for skills development
<p>Students should be able to explain how the structure of the nervous system is adapted to its functions.</p> <p>The nervous system enables humans to react to their surroundings and to coordinate their behaviour.</p> <p>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.</p> <p>stimulus → receptor → coordinator → effector → response</p> <p>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.</p> <p>Reflex actions are automatic and rapid; they do not involve the conscious part of the brain.</p>	
<p>Students should be able to extract and interpret data from graphs, charts and tables, about the functioning of the nervous system.</p>	MS 2c
<p>Students should be able to translate information about reaction times between numerical and graphical forms.</p>	MS 4a

Required practical activity 6: plan and carry out an investigation into the effect of a factor on human reaction time.

AT skills covered by this practical activity: biology AT 1, 3 and 4.

This practical activity also provides opportunities to develop WS and MS. Details of all skills are given in [Key opportunities for skills development](#) (page 179).

4.5.3 Hormonal coordination in humans

4.5.3.1 Human endocrine system

Content	Key opportunities for skills development
<p>Students should be able to describe the principles of hormonal coordination and control by the human endocrine system.</p> <p>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.</p> <p>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.</p> <p>Students should be able to identify the position of the following on a diagram of the human body:</p> <ul style="list-style-type: none">• pituitary gland• pancreas• thyroid• adrenal gland• ovary• testes.	

4.5.3.2 Control of blood glucose concentration

Content	Key opportunities for skills development
<p>Blood glucose concentration is monitored and controlled by the pancreas.</p> <p>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.</p> <p>Students should be able to explain how insulin controls blood glucose (sugar) levels in the body.</p> <p>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.</p> <p>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.</p> <p>Students should be able to compare Type 1 and Type 2 diabetes and explain how they can be treated.</p>	<p>WS 1.3</p> <p>Evaluate information around the relationship between obesity and diabetes, and make recommendations taking into account social and ethical issues.</p>
<p>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.</p>	<p>MS 2c</p>
<p>(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.</p> <p>(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.</p>	

4.5.3.3 Hormones in human reproduction

Content	Key opportunities for skills development
<p>Students should be able to describe the roles of hormones in human reproduction, including the menstrual cycle.</p> <p>During puberty reproductive hormones cause secondary sex characteristics to develop.</p> <p>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.</p> <p>Testosterone is the main male reproductive hormone produced by the testes and it stimulates sperm production.</p> <p>Several hormones are involved in the menstrual cycle of a woman.</p> <ul style="list-style-type: none"> • 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.	MS 2c

4.5.3.4 Contraception

Content	Key opportunities for skills development
<p>Students should be able to evaluate the different hormonal and non-hormonal methods of contraception.</p> <p>Fertility can be controlled by a variety of hormonal and non-hormonal methods of contraception.</p> <p>These include:</p> <ul style="list-style-type: none"> • 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. 	<p>WS 1.3</p> <p>Show why issues around contraception cannot be answered by science alone.</p> <p>WS 1.4</p> <p>Explain everyday and technological applications of science; evaluate associated personal, social, economic and environmental implications; and make decisions based on the evaluation of evidence and arguments.</p>

4.5.3.5 The use of hormones to treat infertility (HT only)

Content	Key opportunities for skills development
<p>Students should be able to explain the use of hormones in modern reproductive technologies to treat infertility.</p> <p>This includes giving FSH and LH in a 'fertility drug' to a woman. She may then become pregnant in the normal way.</p> <p>In Vitro Fertilisation (IVF) treatment.</p> <ul style="list-style-type: none"> • 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). 	<p>WS 1.1</p> <p>Developments of microscopy techniques have enabled IVF treatments to develop.</p> <p>WS 1.3</p> <p>Understand social and ethical issues associated with IVF treatments.</p>

Content	Key opportunities for skills development
<p>Although fertility treatment gives a woman the chance to have a baby of her own:</p> <ul style="list-style-type: none"> • 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. 	<p>WS 1.4</p> <p>Evaluate from the perspective of patients and doctors the methods of treating infertility.</p>

4.5.3.6 Feedback systems (HT only)

Content	Key opportunities for skills development
<p>Students should be able to explain the roles of thyroxine and adrenaline in the body.</p> <p>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'.</p> <p>Thyroxine from the thyroid gland stimulates the basal metabolic rate. It plays an important role in growth and development.</p>	
<p>Thyroxine levels are controlled by negative feedback.</p>	<p>WS 1.2, MS 2c</p> <p>Interpret and explain simple diagrams of negative feedback control.</p>

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

Content	Key opportunities for skills development
<p>Students should understand that meiosis leads to non-identical cells being formed while mitosis leads to identical cells being formed.</p> <p>Sexual reproduction involves the joining (fusion) of male and female gametes:</p> <ul style="list-style-type: none">• sperm and egg cells in animals• pollen and egg cells in flowering plants. <p>In sexual reproduction there is mixing of genetic information which leads to variety in the offspring. The formation of gametes involves meiosis.</p> <p>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.</p>	<p>There are links with this content to Mitosis and the cell cycle (page 23).</p>

4.6.1.2 Meiosis

Content	Key opportunities for skills development
<p>Students should be able to explain how meiosis halves the number of chromosomes in gametes and fertilisation restores the full number of chromosomes.</p> <p>Cells in reproductive organs divide by meiosis to form gametes.</p> <p>When a cell divides to form gametes:</p> <ul style="list-style-type: none">• 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. <p>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.</p> <p>Knowledge of the stages of meiosis is not required.</p>	<p>WS 1.2</p> <p>Modelling behaviour of chromosomes during meiosis.</p>

4.6.1.3 DNA and the genome

Content	Key opportunities for skills development
<p>Students should be able to describe the structure of DNA and define genome.</p> <p>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.</p> <p>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.</p> <p>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.</p>	
<p>Students should be able to discuss the importance of understanding the human genome.</p> <p>This is limited to the:</p> <ul style="list-style-type: none"> • search for genes linked to different types of disease • understanding and treatment of inherited disorders • use in tracing human migration patterns from the past. 	WS 1.1, 1.4

4.6.1.4 Genetic inheritance

Content	Key opportunities for skills development
<p>Students should be able to explain the terms:</p> <ul style="list-style-type: none"> • gamete • chromosome • gene • allele • dominant • recessive • homozygous • heterozygous • genotype • phenotype. <p>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.</p> <p>The alleles present, or genotype, operate at a molecular level to develop characteristics that can be expressed as a phenotype.</p> <p>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).</p> <p>If the two alleles present are the same the organism is homozygous for that trait, but if the alleles are different they are heterozygous.</p> <p>Most characteristics are a result of multiple genes interacting, rather than a single gene.</p>	
<p>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.</p>	MS 2e
<p>Students should be able to use direct proportion and simple ratios to express the outcome of a genetic cross.</p>	MS 1c, 3a
<p>Students should be able to complete a Punnett square diagram and extract and interpret information from genetic crosses and family trees.</p>	MS 2c, 4a
<p>(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.</p>	MS 2e, WS 1.2

4.6.1.5 Inherited disorders

Content	Key opportunities for skills development
<p>Some disorders are inherited. These disorders are caused by the inheritance of certain alleles.</p> <ul style="list-style-type: none"> • 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. <p>Students should make informed judgements about the economic, social and ethical issues concerning embryo screening, given appropriate information.</p>	<p>WS 1.3</p> <p>Appreciate that embryo screening and gene therapy may alleviate suffering but consider the ethical issues which arise.</p>

4.6.1.6 Sex determination

Content	Key opportunities for skills development
<p>Ordinary human body cells contain 23 pairs of chromosomes.</p> <p>22 pairs control characteristics only, but one of the pairs carries the genes that determine sex.</p> <ul style="list-style-type: none"> • In females the sex chromosomes are the same (XX). • In males the chromosomes are different (XY). 	
<p>Students should be able to carry out a genetic cross to show sex inheritance.</p> <p>Students should understand and use direct proportion and simple ratios in genetic crosses.</p>	MS 1c, 3a

4.6.2 Variation and evolution

4.6.2.1 Variation

Content	Key opportunities for skills development
<p>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.</p> <p>Differences in the characteristics of individuals in a population is called variation and may be due to differences in:</p> <ul style="list-style-type: none"> • the genes they have inherited (genetic causes) • the conditions in which they have developed (environmental causes) • a combination of genes and the environment. 	

Content	Key opportunities for skills development
<p>Students should be able to:</p> <ul style="list-style-type: none"> 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. <p>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.</p>	

4.6.2.2 Evolution

Content	Key opportunities for skills development
<p>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.</p> <p>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.</p> <p>Students should be able to explain how evolution occurs through natural selection of variants that give rise to phenotypes best suited to their environment.</p> <p>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.</p>	<p>WS 1.2</p> <p>Use the theory of evolution by natural selection in an explanation.</p>

4.6.2.3 Selective breeding

Content	Key opportunities for skills development
<p>Students should be able to explain the impact of selective breeding of food plants and domesticated animals.</p> <p>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.</p> <p>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.</p> <p>The characteristic can be chosen for usefulness or appearance:</p> <ul style="list-style-type: none"> • Disease resistance in food crops. • Animals which produce more meat or milk. • Domestic dogs with a gentle nature. • Large or unusual flowers. <p>Selective breeding can lead to ‘inbreeding’ where some breeds are particularly prone to disease or inherited defects.</p>	<p>WS 1.3, 1.4</p> <p>Explain the benefits and risks of selective breeding given appropriate information and consider related ethical issues.</p>

4.6.2.4 Genetic engineering

Content	Key opportunities for skills development
<p>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.</p> <p>Plant crops have been genetically engineered to be resistant to diseases or to produce bigger better fruits.</p>	
<p>Bacterial cells have been genetically engineered to produce useful substances such as human insulin to treat diabetes.</p>	

Content	Key opportunities for skills development
<p>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.</p> <p>In genetic engineering, genes from the chromosomes of humans and other organisms can be ‘cut out’ and transferred to cells of other organisms.</p> <p>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.</p> <p>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.</p> <p>Modern medical research is exploring the possibility of genetic modification to overcome some inherited disorders.</p>	<p>WS 1.3, 1.4</p>
<p>(HT only) Students should be able to describe the main steps in the process of genetic engineering.</p> <p>(HT only) In genetic engineering:</p> <ul style="list-style-type: none"> • 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. 	<p>(HT only) WS 1.4</p> <p>Interpret information about genetic engineering techniques and to make informed judgements about issues concerning cloning and genetic engineering, including GM crops.</p>

4.6.3 The development of understanding of genetics and evolution

4.6.3.1 Evidence for evolution

Content	Key opportunities for skills development
<p>Students should be able to describe the evidence for evolution including fossils and antibiotic resistance in bacteria.</p> <p>The theory of evolution by natural selection is now widely accepted.</p> <p>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.</p>	<p>WS 1.3</p> <p>Data is now available to support the theory of evolution.</p>

4.6.3.2 Fossils

Content	Key opportunities for skills development
<p>Fossils are the 'remains' of organisms from millions of years ago, which are found in rocks.</p> <p>Fossils may be formed:</p> <ul style="list-style-type: none"> • 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. 	<p>MS 2c, 4a</p> <p>Extract and interpret information from charts, graphs and tables.</p>
<p>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.</p>	<p>WS 1.3</p> <p>Appreciate why the fossil record is incomplete.</p>
<p>We can learn from fossils how much or how little different organisms have changed as life developed on Earth.</p>	<p>WS 1.1</p> <p>Understand how scientific methods and theories develop over time.</p>
<p>Students should be able to extract and interpret information from charts, graphs and tables such as evolutionary trees.</p>	<p>MS 2c, 4a</p>

4.6.3.3 Extinction

Content	Key opportunities for skills development
<p>Extinctions occur when there are no remaining individuals of a species still alive.</p> <p>Students should be able to describe factors which may contribute to the extinction of a species.</p>	

4.6.3.4 Resistant bacteria

Content	Key opportunities for skills development
<p>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.</p>	
<p>MRSA is resistant to antibiotics.</p> <p>To reduce the rate of development of antibiotic resistant strains:</p> <ul style="list-style-type: none">• 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. <p>The development of new antibiotics is costly and slow. It is unlikely to keep up with the emergence of new resistant strains.</p>	<p>There are links with this content to Antibiotics and painkillers (page 37).</p>

4.6.4 Classification of living organisms

Content	Key opportunities for skills development
<p>Traditionally living things have been classified into groups depending on their structure and characteristics in a system developed by Carl Linnaeus.</p> <p>Linnaeus classified living things into kingdom, phylum, class, order, family, genus and species. Organisms are named by the binomial system of genus and species.</p>	

Content	Key opportunities for skills development
<p>Students should be able to use information given to show understanding of the Linnaean system.</p> <p>Students should be able to describe the impact of developments in biology on classification systems.</p> <p>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.</p> <p>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:</p> <ul style="list-style-type: none"> • Archaea (primitive bacteria usually living in extreme environments) • Bacteria (true bacteria) • Eukaryota (which includes protists, fungi, plants and animals). 	<p>WS 1.1</p> <p>Understand how scientific methods and theories develop over time.</p>
<p>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.</p>	<p>WS 1.2</p> <p>Interpret evolutionary trees.</p>

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 Communities

Content	Key opportunities for skills development
<p>Students should be able to describe:</p> <ul style="list-style-type: none">• different levels of organisation in an ecosystem from individual organisms to the whole ecosystem• the importance of interdependence and competition in a community. <p>Students should be able to, when provided with appropriate information:</p> <ul style="list-style-type: none">• suggest the factors for which organisms are competing in a given habitat• suggest how organisms are adapted to the conditions in which they live. <p>An ecosystem is the interaction of a community of living organisms (biotic) with the non-living (abiotic) parts of their environment.</p> <p>To survive and reproduce, organisms require a supply of materials from their surroundings and from the other living organisms there.</p> <p>Plants in a community or habitat often compete with each other for light and space, and for water and mineral ions from the soil.</p> <p>Animals often compete with each other for food, mates and territory.</p> <p>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.</p>	<p>WS 2.6</p> <p>Recording first-hand observations of organisms.</p>
<p>Students should be able to extract and interpret information from charts, graphs and tables relating to the interaction of organisms within a community.</p>	<p>MS 2c, 4a</p> <p>Extract and interpret information from charts, graphs and tables.</p>

4.7.1.2 Abiotic factors

Content	Key opportunities for skills development
<p>Students should be able to explain how a change in an abiotic factor would affect a given community given appropriate data or context.</p> <p>Abiotic (non-living) factors which can affect a community are:</p> <ul style="list-style-type: none"> • light intensity • temperature • moisture levels • soil pH and mineral content • wind intensity and direction • carbon dioxide levels for plants • oxygen levels for aquatic animals. 	<p>WS 1.2</p>
<p>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.</p>	<p>MS 2c, 4a</p> <p>Extract and interpret information from charts, graphs and tables.</p>

4.7.1.3 Biotic factors

Content	Key opportunities for skills development
<p>Students should be able to explain how a change in a biotic factor might affect a given community given appropriate data or context.</p> <p>Biotic (living) factors which can affect a community are:</p> <ul style="list-style-type: none"> • availability of food • new predators arriving • new pathogens • one species outcompeting another so the numbers are no longer sufficient to breed. 	<p>WS 1.2</p>
<p>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.</p>	<p>MS 2c, 4a</p> <p>Extract and interpret information from charts, graphs and tables.</p>

4.7.1.4 Adaptations

Content	Key opportunities for skills development
<p>Students should be able to explain how organisms are adapted to live in their natural environment, given appropriate information.</p> <p>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.</p>	
<p>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.</p>	

4.7.2 Organisation of an ecosystem

4.7.2.1 Levels of organisation

Content	Key opportunities for skills development
<p>Students should understand that photosynthetic organisms are the producers of biomass for life on Earth.</p> <p>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.</p> <p>A range of experimental methods using transects and quadrats are used by ecologists to determine the distribution and abundance of species in an ecosystem.</p>	
<p>In relation to abundance of organisms students should be able to:</p> <ul style="list-style-type: none"> • understand the terms mean, mode and median • calculate arithmetic means • plot and draw appropriate graphs selecting appropriate scales for the axes. 	MS 2b, 2f, 4a, 4c
<p>Producers are eaten by primary consumers, which in turn may be eaten by secondary consumers and then tertiary consumers.</p>	
<p>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.</p>	WS 1.2 Interpret graphs used to model predator-prey cycles.
<p>Students should be able to interpret graphs used to model these cycles.</p>	MS 4a

Required practical activity 7: 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.

AT skills covered by this practical activity: biology AT 1, 3, 4 and 6.

This practical activity also provides opportunities to develop WS and MS. Details of all skills are given in [Key opportunities for skills development](#) (page 179).

4.7.2.2 How materials are cycled

Content	Key opportunities for skills development
<p>Students should:</p> <ul style="list-style-type: none"> 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. <p>All materials in the living world are recycled to provide the building blocks for future organisms.</p> <p>The carbon cycle returns carbon from organisms to the atmosphere as carbon dioxide to be used by plants in photosynthesis.</p> <p>The water cycle provides fresh water for plants and animals on land before draining into the seas. Water is continuously evaporated and precipitated.</p> <p>Students are not expected to study the nitrogen cycle.</p> <p>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.</p>	<p>WS 1.2</p> <p>Interpret and explain the processes in diagrams of the carbon cycle, the water cycle.</p> <p>There are links with the water cycle to GCSE Chemistry The Earth's early atmosphere.</p> <p>WS 1.2</p>

4.7.3 Biodiversity and the effect of human interaction on ecosystems

4.7.3.1 Biodiversity

Content	Key opportunities for skills development
<p>Biodiversity is the variety of all the different species of organisms on earth, or within an ecosystem.</p> <p>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.</p> <p>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.</p>	<p>WS 1.4</p> <p>Explain how waste, deforestation and global warming have an impact on biodiversity.</p>

4.7.3.2 Waste management

Content	Key opportunities for skills development
<p>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.</p> <p>Pollution can occur:</p> <ul style="list-style-type: none">• in water, from sewage, fertiliser or toxic chemicals• in air, from smoke and acidic gases• on land, from landfill and from toxic chemicals. <p>Pollution kills plants and animals which can reduce biodiversity.</p>	<p>There are links with this content to GCSE Chemistry 5.9.3.1 Atmospheric pollutants from fuels.</p>

4.7.3.3 Land use

Content	Key opportunities for skills development
<p>Humans reduce the amount of land available for other animals and plants by building, quarrying, farming and dumping waste.</p>	
<p>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).</p> <p>The decay or burning of the peat releases carbon dioxide into the atmosphere.</p>	<p>WS 1.4, 1.5</p> <p>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.</p> <p>There are links within this section to Global warming (page 65).</p>

4.7.3.4 Deforestation

Content	Key opportunities for skills development
<p>Large-scale deforestation in tropical areas has occurred to:</p> <ul style="list-style-type: none">• provide land for cattle and rice fields• grow crops for biofuels	<p>WS 1.4</p> <p>Evaluate the environmental implications of deforestation.</p>

4.7.3.5 Global warming

Content	Key opportunities for skills development
<p>Students should be able to describe some of the biological consequences of global warming.</p> <p>Levels of carbon dioxide and methane in the atmosphere are increasing, and contribute to 'global warming'.</p>	<p>WS 1.6</p> <p>Understand that the scientific consensus about global warming and climate change is based on systematic reviews of thousands of peer reviewed publications.</p> <p>WS 1.3</p> <p>Explain why evidence is uncertain or incomplete in a complex context.</p>

4.7.3.6 Maintaining biodiversity

Content	Key opportunities for skills development
<p>Students should be able to describe both positive and negative human interactions in an ecosystem and explain their impact on biodiversity.</p> <p>Scientists and concerned citizens have put in place programmes to reduce the negative effects of humans on ecosystems and biodiversity.</p> <p>These include:</p> <ul style="list-style-type: none"> • 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. 	<p>WS 1.4, 1.5</p> <p>Evaluate given information about methods that can be used to tackle problems caused by human impacts on the environment.</p> <p>Explain and evaluate the conflicting pressures on maintaining biodiversity given appropriate information.</p>

4.8 Key ideas

The complex and diverse phenomena of the natural world can be described in terms of a small number of key ideas in biology.

These key ideas are of universal application, and we have embedded them throughout the subject content. They underpin many aspects of the science assessment.