2c. Content of modules 1 to 6

Module 1: Development of practical skills in biology

The development of practical skills is a fundamental and integral aspect of the study of any scientific subject. These skills not only enhance learners' understanding of the subject but also serve as a suitable preparation for the demands of studying biology at a higher level.

1.1 Practical skills assessed in a written examination

Practical skills are embedded throughout all the content of this specification.

Learners will be required to develop a range of practical skills throughout their course in preparation for the written examinations.

1.1.1 Planning

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	experimental design, including to solve problems set in a practical context	Including selection of suitable apparatus, equipment and techniques for the proposed experiment. Learners should be able to apply scientific knowledge based on the content of the specification to the practical context. HSW3
(b)	identification of variables that must be controlled, where appropriate	
(c)	evaluation that an experimental method is appropriate to meet the expected outcomes.	HSW6

1.1.2 Implementing

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	how to use a wide range of practical apparatus and techniques correctly	As outlined in the content of the specification and the skills required for the Practical Endorsement. HSW4
(b)	appropriate units for measurements	*M0.1*
(c)	presenting observations and data in an appropriate format.	HSW8

1.1.3 Analysis

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	processing, analysing and interpreting qualitative and quantitative experimental results	Including reaching valid conclusions, where appropriate. HSW5
(b)	use of appropriate mathematical skills for analysis of quantitative data	Refer to Section 5d for a list of mathematical skills that learners should have acquired competence in as part of their course. HSW3
(c)	appropriate use of significant figures	*M1.1*
(d)	plotting and interpreting suitable graphs from experimental results, including:	
	(i) selection and labelling of axes with appropriate scales, quantities and units	*M3.2*
	(ii) measurement of gradients and intercepts.	*M3.3, M3.4, M3.5*

1.1.4 Evaluation

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	how to evaluate results and draw conclusions	HSW6
(b)	the identification of anomalies in experimental measurements	
(c)	the limitations in experimental procedures	
(d)	precision and accuracy of measurements and data, including margins of error, percentage errors and uncertainties in apparatus	*M1.11*
(e)	the refining of experimental design by suggestion of improvements to the procedures and apparatus.	HSW3

1.2 Practical skills assessed in the practical endorsement

A range of practical experiences is a vital part of a learner's development as part of this course.

Learners should develop and practise a wide range of practical skills throughout the course as preparation for the Practical Endorsement, as well as for the written examinations.

The experiments and skills required for the Practical Endorsement will allow learners to develop and practise their practical skills, preparing learners for the written examinations.

Please refer to Section 5f (the Practical Endorsement) in this specification to see the list of practical experiences all learners should cover during their course. Further advice and guidance on the Practical Endorsement can be found in the Practical Skills Handbook.

1.2.1 Practical skills

	Learning outcomes	Additional guidance
	Practical work carried out throughout the course will enable learners to develop the following skills:	
	Independent thinking	
(a)	apply investigative approaches and methods to practical work	Including how to solve problems in a practical context. HSW3
	Use and application of scientific methods and practices	
(b)	safely and correctly use a range of practical equipment and materials	See Section 5f. Including identification of potential hazards. Learners should understand how to minimise the risks involved. HSW4
(c)	follow written instructions	
(d)	make and record observations/measurements	HSW8
(e)	keep appropriate records of experimental activities	See Section 5f.
(f)	present information and data in a scientific way	HSW8
(g)	use appropriate software and tools to process data, carry out research and report findings	*M3.1* HSW3
	Research and referencing	
(h)	use online and offline research skills including websites, textbooks and other printed scientific sources of information	
(i)	correctly cite sources of information	The Practical Skills Handbook provides guidance on appropriate methods for citing information.
	Instruments and equipment	
(j)	use a wide range of experimental and practical instruments, equipment and techniques appropriate to the knowledge and understanding included in the specification.	See Section 5f. HSW4

1.2.2 Use of apparatus and techniques

	Learning outcomes	Additional guidance
	*Through use of the apparatus and techniques listed below, and a minimum of 12 assessed practicals (see Section 5f), learners should be able to demonstrate all of the practical skills listed within 1.2.1 and CPAC (Section 5f, **Table 2**) as exemplified through:*	
(a)	use of appropriate apparatus to record a range of quantitative measurements (to include mass, time, volume, temperature, length and pH)	HSW4
(b)	use of appropriate instrumentation to record quantitative measurements, such as a colorimeter or potometer	HSW4
(c)	use of laboratory glassware apparatus for a variety of experimental techniques to include serial dilutions	HSW4
(d)	use of a light microscope at high power and low power, including use of a graticule	HSW4
(e)	production of scientific drawings from observations with annotations	HSW8
(f)	use of qualitative reagents to identify biological molecules	HSW4
(g)	separation of biological compounds using thin layer/paper chromatography or electrophoresis	HSW4
(h)	safe and ethical use of organisms to measure: **(i)** plant or animal responses **(ii)** physiological functions	HSW4, HSW10
(i)	use of microbiological aseptic techniques, including the use of agar plates and broth	HSW4
(j)	safe use of instruments for dissection of an animal or plant organ	HSW4
(k)	use of sampling techniques in fieldwork	HSW4
(l)	use of ICT such as computer modelling, or a data logger to collect data, or use of software to process data.	HSW3, HSW4

Module 2: Foundations in biology

All living organisms have similarities in cellular structure, biochemistry and function. An understanding of these similarities is fundamental to the study of the subject.

This module gives learners the opportunity to use microscopy to study the cell structure of a variety of organisms. Biologically important molecules such as carbohydrates, proteins, water and nucleic acids are studied with respect to their structure and function. The structure and mode of action of enzymes in catalysing biochemical reactions is studied.

Membranes form barriers within, and at the surface of, cells. This module also considers the way in which the structure of membranes relates to the different methods by which molecules enter and leave cells and organelles.

The division and subsequent specialisation of cells is studied, together with the potential for the therapeutic use of stem cells.

Learners are expected to apply knowledge, understanding and other skills developed in this module to new situations and/or to solve related problems.

2.1 Foundations in biology

2.1.1 Cell structure

Biology is the study of living organisms. Every living organism is made up of one or more cells, therefore understanding the structure and function of the cell is a fundamental concept in the study of biology. Since Robert Hooke coined the phrase 'cells' in 1665, careful observation using microscopes has revealed details of cell structure and ultrastructure and provided evidence to support hypotheses regarding the roles of cells and their organelles.

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	the use of microscopy to observe and investigate different types of cell and cell structure in a range of eukaryotic organisms	To include an appreciation of the images produced by a range of microscopes; light microscope, transmission electron microscope, scanning electron microscope and laser scanning confocal microscope. HSW1, HSW7
(b)	the preparation and examination of microscope slides for use in light microscopy	Including the use of an eye piece graticule and stage micrometer. **PAG1** HSW4
(c)	the use of staining in light microscopy	To include the use of differential staining to identify different cellular components and cell types. **PAG1** HSW4, HSW5
(d)	the representation of cell structure as seen under the light microscope using drawings and annotated diagrams of whole cells or cells in sections of tissue	**PAG1**

(e)	the use and manipulation of the magnification formula	$magnification = \frac{image\ size}{object\ size}$ *M0.1, M0.2, M0.3, M1.1, M1.8, M2.2, M2.3, M2.4*
(f)	the difference between magnification and resolution	To include an appreciation of the differences in resolution and magnification that can be achieved by a light microscope, a transmission electron microscope and a scanning electron microscope. *M0.2, M0.3* HSW7, HSW8
(g)	the ultrastructure of eukaryotic cells and the functions of the different cellular components	To include the following cellular components and an outline of their functions: nucleus, nucleolus, nuclear envelope, rough and smooth endoplasmic reticulum (ER), Golgi apparatus, ribosomes, mitochondria, lysosomes, chloroplasts, plasma membrane, centrioles, cell wall, flagella and cilia. *M0.2*
(h)	photomicrographs of cellular components in a range of eukaryotic cells	To include interpretation of transmission and scanning electron microscope images.
(i)	the interrelationship between the organelles involved in the production and secretion of proteins	No detail of protein synthesis is required.
(j)	the importance of the cytoskeleton	To include providing mechanical strength to cells, aiding transport within cells and enabling cell movement. HSW2
(k)	the similarities and differences in the structure and ultrastructure of prokaryotic and eukaryotic cells.	**PAG1**

2.1.2 Biological molecules

The cells of all living organisms are composed of biological molecules. Proteins, carbohydrates and lipids are three of the key groups of biological macromolecules that are essential for life. A study of the structure of these macromolecules allows a better understanding of their functions in living organisms.

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	Where appropriate, this section should include diagrams to represent molecular structure and bonding.
(a)	how hydrogen bonding occurs between water molecules, and relate this, and other properties of water, to the roles of water for living organisms	A range of roles that relate to the properties of water, including solvent, transport medium, coolant and as a habitat **AND** roles illustrated using examples of prokaryotes and eukaryotes. HSW2, HSW8
(b)	the concept of monomers and polymers and the importance of condensation and hydrolysis reactions in a range of biological molecules	
(c)	the chemical elements that make up biological molecules	To include: C, H and O for carbohydrates C, H and O for lipids C, H, O, N and S for proteins C, H, O, N and P for nucleic acids
(d)	the ring structure and properties of glucose as an example of a hexose monosaccharide and the structure of ribose as an example of a pentose monosaccharide	To include the structural difference between an α- and a β-glucose molecule **AND** the difference between a hexose and a pentose monosaccharide.
(e)	the synthesis and breakdown of a disaccharide and polysaccharide by the formation and breakage of glycosidic bonds	To include the disaccharides sucrose, lactose and maltose.
(f)	the structure of starch (amylose and amylopectin), glycogen and cellulose molecules	HSW8
(g)	how the structures and properties of glucose, starch, glycogen and cellulose molecules relate to their functions in living organisms	HSW2, HSW8
(h)	the structure of a triglyceride and a phospholipid as examples of macromolecules	To include an outline of saturated and unsaturated fatty acids.
(i)	the synthesis and breakdown of triglycerides by the formation (esterification) and breakage of ester bonds between fatty acids and glycerol	

(j)	how the properties of triglyceride, phospholipid and cholesterol molecules relate to their functions in living organisms	To include hydrophobic and hydrophilic regions and energy content **AND** illustrated using examples of prokaryotes and eukaryotes. HSW2, HSW8
(k)	the general structure of an amino acid	
(l)	the synthesis and breakdown of dipeptides and polypeptides, by the formation and breakage of peptide bonds	
(m)	the levels of protein structure	To include primary, secondary, tertiary and quaternary structure **AND** hydrogen bonding, hydrophobic and hydrophilic interactions, disulfide bonds and ionic bonds. HSW8
(n)	the structure and function of globular proteins including a conjugated protein	To include haemoglobin as an example of a conjugated protein (globular protein with a prosthetic group), a named enzyme and insulin. An opportunity to use computer modelling to investigate the levels of protein structure within the molecule. **PAG10**
(o)	the properties and functions of fibrous proteins	To include collagen, keratin and elastin (no details of structure are required).
(p)	the key inorganic ions that are involved in biological processes	To include the correct chemical symbols for the following cations and anions: cations: calcium ions (Ca^{2+}), sodium ions (Na^{+}), potassium ions (K^{+}), hydrogen ions (H^{+}), ammonium ions (NH_4^{+}) anions: nitrate (NO_3^{-}), hydrogencarbonate (HCO_3^{-}), chloride (Cl^{-}), phosphate (PO_4^{3-}), hydroxide, (OH^{-}).
(q)	how to carry out and interpret the results of the following chemical tests: • biuret test for proteins • Benedict's test for reducing and non-reducing sugars • reagent test strips for reducing sugars • iodine test for starch • emulsion test for lipids	**PAG9** HSW3, HSW4, HSW5

(r)		quantitative methods to determine the concentration of a chemical substance in a solution	To include colorimetry and the use of biosensors (an outline only of the mechanism is required). **PAG5** HSW3, HSW4, HSW5
(s)	**(i)**	the principles and uses of paper and thin layer chromatography to separate biological molecules / compounds	To include calculation of retention (*Rf)* values. $Rf = \frac{distance\ moved\ by\ the\ solute}{distance\ moved\ by\ the\ solvent}$
	(ii)	practical investigations to analyse biological solutions using paper or thin layer chromatography.	For example the separation of proteins, carbohydrates, vitamins or nucleic acids. *M0.1, M0.2, M1.1, M1.3, M2.2, M2.3, M2.4* **PAG6** HSW2, HSW3, HSW4

2.1.3 Nucleotides and nucleic acids

Nucleic acids are essential to heredity in living organisms. Understanding the structure of nucleotides and nucleic acids allows an understanding of their roles in the storage and use of genetic information and cell metabolism.

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	the structure of a nucleotide as the monomer from which nucleic acids are made	To include the differences between RNA and DNA nucleotides, the identification of the purines and pyrimidines and the type of pentose sugar. An opportunity to use computer modelling to investigate nucleic acid structure. **PAG10**
(b)	the synthesis and breakdown of polynucleotides by the formation and breakage of phosphodiester bonds	
(c)	the structure of ADP and ATP as phosphorylated nucleotides	Comprising a pentose sugar (ribose), a nitrogenous base (adenine) and inorganic phosphates.
(d)	**(i)** the structure of DNA (deoxyribonucleic acid) **(ii)** practical investigations into the purification of DNA by precipitation	To include how hydrogen bonding between complementary base pairs (A to T, G to C) on two antiparallel DNA polynucleotides leads to the formation of a DNA molecule, and how the twisting of DNA produces its 'double-helix' shape. **PAG9** HSW3, HSW4
(e)	semi-conservative DNA replication	To include the roles of the enzymes helicase and DNA polymerase, the importance of replication in conserving genetic information with accuracy and the occurrence of random, spontaneous mutations. HSW8
(f)	the nature of the genetic code	To include the triplet, non-overlapping, degenerate and universal nature of the code and how a gene determines the sequence of amino acids in a polypeptide (the primary structure of a protein).
(g)	transcription and translation of genes resulting in the synthesis of polypeptides.	To include, the roles of RNA polymerase, messenger (m)RNA, transfer (t)RNA, ribosomal (r)RNA. HSW8

2.1.4 Enzymes

Metabolism in living organisms relies upon enzyme-controlled reactions. Knowledge of how enzymes function and the factors that affect enzyme action has improved our understanding of biological processes and increased our use of enzymes in industry.

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	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	the role of enzymes in catalysing reactions that affect metabolism at a cellular and whole organism level	To include the idea that enzymes affect both structure and function.
(b)	the role of enzymes in catalysing both intracellular and extracellular reactions	To include catalase as an example of an enzyme that catalyses intracellular reactions and amylase and trypsin as examples of enzymes that catalyse extracellular reactions.
(c)	the mechanism of enzyme action	To include the tertiary structure, specificity, active site, lock and key hypothesis, induced-fit hypothesis, enzyme-substrate complex, enzyme-product complex, product formation and lowering of activation energy. HSW1, HSW8
(d) **(i)**	the effects of pH, temperature, enzyme concentration and substrate concentration on enzyme activity	To include reference to the temperature coefficient (Q_{10}). $Q_{10} = \frac{R_2}{R_1}$
(ii)	practical investigations into the effects of pH, temperature, enzyme concentration and substrate concentration on enzyme activity	An opportunity for serial dilutions. *M0.1, M0.2, M0.3, M1.1, M1.3, M1.11, M3.1, M3.2, M3.3, M3.5, M3.6* **PAG4** HSW1, HSW2, HSW4, HSW5, HSW6, HSW8.
(e)	the need for coenzymes, cofactors and prosthetic groups in some enzyme-controlled reactions	To include Cl^- as a cofactor for amylase, Zn^{2+} as a prosthetic group for carbonic anhydrase and vitamins as a source of coenzymes. **PAG4**
(f)	the effects of inhibitors on the rate of enzyme-controlled reactions.	To include competitive and non-competitive and reversible and non-reversible inhibitors with reference to the action of metabolic poisons and some medicinal drugs, and the role of product inhibition **AND** inactive precursors in metabolic pathways (covered at A level only). *M0.1, M0.2, M0.3, M1.1, M1.3, M1.11, M3.1, M3.2, M3.3, M3.5, M3.6* **PAG4** HSW1, HSW2, HSW4, HSW5, HSW6, HSW8

2.1.5 Biological membranes

Membranes are fundamental to the cell theory. The structure of the plasma membrane allows cells to communicate with each other. Understanding this ability to communicate is important as scientists increasingly make use of membrane-bound receptors as sites for the action of medicinal drugs.

Understanding how different substances enter cells is also crucial to the development of mechanisms for the administration of drugs.

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	the roles of membranes within cells and at the surface of cells	To include the roles of membranes as, • partially permeable barriers between the cell and its environment, between organelles and the cytoplasm and within organelles • sites of chemical reactions • sites of cell communication (cell signalling).
(b)	the fluid mosaic model of membrane structure and the roles of its components	To include phospholipids, cholesterol, glycolipids, proteins and glycoproteins **AND** the role of membrane-bound receptors as sites where hormones and drugs can bind. *M0.2* HSW1
(c) **(i)**	factors affecting membrane structure and permeability	To include the effects of temperature and solvents.
(ii)	practical investigations into factors affecting membrane structure and permeability	*M0.1, M0.2, M1.1, M1.2, M1.3, M1.6, M1.11, M3.1, M3.2, M3.3, M3.5, M3.6* **PAG5, PAG8** HSW1, HSW2, HSW3, HSW4, HSW5, HSW6
(d) **(i)**	the movement of molecules across membranes	To include diffusion and facilitated diffusion as passive methods **AND** active transport, endocytosis and exocytosis as processes requiring adenosine triphosphate (ATP) as an immediate source of energy.
(ii)	practical investigations into the factors affecting diffusion rates in model cells	*M0.1, M0.2, M0.3, M1.1, M1.2, M1.3, M1.6, M1.11, M2.1, M3.1, M3.2, M3.3, M3.5, M3.6, M4.1* **PAG8** HSW1, HSW2, HSW3, HSW4, HSW5, HSW6

(e)	**(i)**	the movement of water across membranes by osmosis and the effects that solutions of different water potential can have on plant and animal cells	Osmosis to be explained in terms of a water potential gradient across a partially-permeable membrane. *M0.1, M0.2, M0.3, M1.1, M1.2, M1.3, M1.6, M1.10, M1.11, M2.1, M3.1, M3.2, M4.1* **PAG8** HSW1, HSW2, HSW3, HSW4, HSW5, HSW6
	(ii)	practical investigations into the effects of solutions of different water potential on plant and animal cells.	

2.1.6 Cell division, cell diversity and cellular organisation

During the cell cycle, genetic information is copied and passed to daughter cells. Microscopes can be used to view the different stages of the cycle.

In multicellular organisms, stem cells are modified to produce many different types of specialised cell.

Understanding how stem cells can be modified has huge potential in medicine.

To understand how a whole organism functions, it is essential to appreciate the importance of cooperation between cells, tissues, organs and organ systems.

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	the cell cycle	To include the processes taking place during interphase (G_1, S and G_2), mitosis and cytokinesis, leading to genetically identical cells. HSW8
(b)	how the cell cycle is regulated	To include an outline of the use of checkpoints to control the cycle.
(c)	the main stages of mitosis	To include the changes in the nuclear envelope, chromosomes, chromatids, centromere, centrioles, spindle fibres and cell membrane. HSW8
(d)	sections of plant tissue showing the cell cycle and stages of mitosis	To include the examination of stained sections and squashes of plant tissue and the production of labelled diagrams to show the stages observed. **PAG1**
(e)	the significance of mitosis in life cycles	To include growth, tissue repair and asexual reproduction in plants, animals and fungi. HSW2
(f)	the significance of meiosis in life cycles	To include the production of haploid cells and genetic variation by independent assortment and crossing over. HSW2, HSW5

(g)	the main stages of meiosis	To include interphase, prophase 1, metaphase 1, anaphase 1, telophase 1, prophase 2, metaphase 2, anaphase 2, telophase 2 (no details of the names of the stages within prophase 1 are required) and the term *homologous chromosomes*. **PAG1** HSW8
(h)	how cells of multicellular organisms are specialised for particular functions	To include erythrocytes, neutrophils, squamous and ciliated epithelial cells, sperm cells, palisade cells, root hair cells and guard cells. **PAG1**
(i)	the organisation of cells into tissues, organs and organ systems	To include squamous and ciliated epithelia, cartilage, muscle, xylem and phloem as examples of tissues.
(j)	the features and differentiation of stem cells	To include stem cells as a renewing source of undifferentiated cells.
(k)	the production of erythrocytes and neutrophils derived from stem cells in bone marrow	
(l)	the production of xylem vessels and phloem sieve tubes from meristems	
(m)	the potential uses of stem cells in research and medicine.	To include the repair of damaged tissues, the treatment of neurological conditions such as Alzheimer's and Parkinson's, and research into developmental biology. HSW2, HSW5, HSW6, HSW7, HSW9, HSW10, HSW11, HSW12

Module 3: Exchange and transport

In this module, learners study the structure and function of gas exchange and transport systems in a range of animals and in terrestrial plants.

The significance of surface area to volume ratio in determining the need for ventilation, gas exchange and transport systems in multicellular organisms is emphasised. The examples of terrestrial green plants and a range of animal phyla are used to illustrate the principle.

Learners are expected to apply knowledge, understanding and other skills developed in this module to new situations and/or to solve related problems.

3.1 Exchange and transport

3.1.1 Exchange surfaces

As animals become larger and more active, ventilation and gas exchange systems become essential to supply oxygen to, and remove carbon dioxide from, their bodies.

Ventilation and gas exchange systems in mammals, bony fish and insects are used as examples of the properties and functions of exchange surfaces in animals.

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	the need for specialised exchange surfaces	To include surface area to volume ratio (SA:V), metabolic activity, single-celled and multicellular organisms. $Ratio = \frac{Surface\ Area}{Volume}$ *M0.1, M0.3, M0.4, M1.1, M2.1, M4.1* HSW1, HSW3, HSW5, HSW8
(b)	the features of an efficient exchange surface	To include, • increased surface area – root hair cells • thin layer – alveoli • good blood supply/ventilation to maintain gradient – gills/alveolus.
(c)	the structures and functions of the components of the mammalian gaseous exchange system	To include the distribution and functions of cartilage, ciliated epithelium, goblet cells, smooth muscle and elastic fibres in the trachea, bronchi, bronchioles and alveoli. **PAG1** HSW8
(d)	the mechanism of ventilation in mammals	To include the function of the rib cage, intercostal muscles (internal and external) and diaphragm. HSW8

(e)	the relationship between vital capacity, tidal volume, breathing rate and oxygen uptake	To include analysis and interpretation of primary and secondary data e.g. from a data logger or spirometer. *M0.1, M0.2, M0.4, M1.3* **PAG10** HSW2, HSW3, HSW4, HSW5, HSW6
(f)	the mechanisms of ventilation and gas exchange in bony fish and insects	To include: • bony fish – changes in volume of the buccal cavity and the functions of the operculum, gill filaments and gill lamellae (gill plates); countercurrent flow • insects – spiracles, trachea, thoracic and abdominal movement to change body volume, exchange with tracheal fluid. HSW8
(g)	the dissection, examination and drawing of the gaseous exchange system of a bony fish and/or insect trachea	**PAG2** HSW4
(h)	the examination of microscope slides to show the histology of exchange surfaces.	**PAG1** HSW4

3.1.2 Transport in animals

As animals become larger and more active, transport systems become essential to supply nutrients to, and remove waste from, individual cells.

Controlling the supply of nutrients and removal of waste requires the coordinated activity of the heart and circulatory system.

	Learning outcomes	**Additional guidance**
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	the need for transport systems in multicellular animals	To include an appreciation of size, metabolic rate and surface area to volume ratio (SA:V). *M0.1, M0.3, M0.4, M1.1, M2.1, M4.1* HSW1, HSW3, HSW5, HSW8
(b)	the different types of circulatory systems	To include single, double, open and closed circulatory systems in insects, fish and mammals.
(c)	the structure and functions of arteries, arterioles, capillaries, venules and veins	To include the distribution of different tissues within the vessel walls. **PAG2**

(d)	the formation of tissue fluid from plasma	To include reference to hydrostatic pressure, oncotic pressure and an explanation of the differences in the composition of blood, tissue fluid and lymph. HSW8
(e)	**(i)** the external and internal structure of the mammalian heart **(ii)** the dissection, examination and drawing of the external and internal structure of the mammalian heart	**PAG2** HSW4
(f)	the cardiac cycle	To include the role of the valves and the pressure changes occurring in the heart and associated vessels. $cardiac\ output = heart\ rate \times stroke\ volume$ HSW2, HSW5, HSW8
(g)	how heart action is initiated and coordinated	To include the roles of the sino-atrial node (SAN), atrio-ventricular node (AVN), purkyne tissue and the myogenic nature of cardiac muscle (no detail of hormonal and nervous control is required at AS level). HSW2, HSW5, HSW8
(h)	the use and interpretation of electrocardiogram (ECG) traces	To include normal and abnormal heart activity e.g. tachycardia, bradycardia, fibrillation and ectopic heartbeat. *M0.1, M1.1, M1.3, M2.4* HSW2, HSW5
(i)	the role of haemoglobin in transporting oxygen and carbon dioxide	To include the reversible binding of oxygen molecules, carbonic anhydrase, haemoglobinic acid, HCO_3^- and the chloride shift. HSW8
(j)	the oxygen dissociation curve for fetal and adult human haemoglobin.	To include the significance of the different affinities for oxygen **AND** the changes to the dissociation curve at different carbon dioxide concentrations (the Bohr effect). *M3.1* HSW2, HSW8

3.1.3 Transport in plants

As plants become larger and more complex, transport systems become essential to supply nutrients to, and remove waste from, individual cells.

The supply of nutrients from the soil relies upon the flow of water through a vascular system, as does the movement of the products of photosynthesis.

		Learning outcomes	Additional guidance
		Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)		the need for transport systems in multicellular plants	To include an appreciation of size, metabolic rate and surface area to volume ratio (SA:V). *M0.1, M0.3, M0.4, M1.1, M2.1, M4.1* HSW1, HSW3, HSW5, HSW8
(b)	**(i)**	the structure and function of the vascular system in the roots, stems and leaves of herbaceous dicotyledonous plants	To include xylem vessels, sieve tube elements and companion cells.
	(ii)	the examination and drawing of stained sections of plant tissue to show the distribution of xylem and phloem	**PAG1** HSW4
	(iii)	the dissection of stems, both longitudinally and transversely, and their examination to demonstrate the position and structure of xylem vessels	**PAG2** HSW4
(c)	**(i)**	the process of transpiration and the environmental factors that affect transpiration rate	To include an appreciation that transpiration is a consequence of gaseous exchange.
	(ii)	practical investigations to estimate transpiration rates	To include the use of a potometer. *M0.1, M0.2, M1.1, M1.2, M1.3, M1.6, M1.11, M3.1, M3.2, M3.3, M3.5, M3.6, M4.1* **PAG5, PAG11** HSW2, HSW3, HSW4, HSW5, HSW6, HSW8
(d)		the transport of water into the plant, through the plant and to the air surrounding the leaves	To include details of the pathways taken by water **AND** the mechanisms of movement, in terms of water potential, adhesion, cohesion and the transpiration stream. HSW2, HSW8
(e)		adaptations of plants to the availability of water in their environment	To include xerophytes (cacti and marram grass) and hydrophytes (water lilies). HSW2

(f)	the mechanism of translocation.	To include translocation as an energy-requiring process transporting assimilates, especially sucrose, in the phloem between sources (e.g. leaves) and sinks (e.g. roots, meristem) **AND** details of active loading at the source and removal at the sink. HSW2, HSW8

Module 4: Biodiversity, evolution and disease

In this module the learners study the biodiversity of organisms; how they are classified and the ways in which biodiversity can be measured. It serves as an introduction to ecology, emphasising practical techniques and an appreciation of the need to maintain biodiversity. The learners also gain an understanding of the variety of organisms that are pathogenic and the way in which plants and animals have evolved defences to deal with disease. The impact of the evolution of pathogens on the treatment of disease is also considered.

The relationships between organisms are studied, considering variation, evolution and phylogeny.

Learners are expected to apply knowledge, understanding and other skills developed in this module to new situations and/or to solve related problems.

4.1 Communicable diseases, disease prevention and the immune system

4.1.1 Communicable diseases, disease prevention and the immune system

Organisms are surrounded by pathogens and have evolved defences against them. Medical intervention can be used to support these natural defences.

The mammalian immune system is introduced.

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	the different types of pathogen that can cause communicable diseases in plants and animals	To include, • bacteria – tuberculosis (TB), bacterial meningitis, ring rot (potatoes, tomatoes) • viruses – HIV/AIDS (human), influenza (animals), Tobacco Mosaic Virus (plants) • protoctista – malaria, potato/tomato late blight • fungi – black sigatoka (bananas), ringworm (cattle), athlete's foot (humans).

(b)	the means of transmission of animal and plant communicable pathogens	To include direct and indirect transmission, reference to vectors, spores and living conditions – e.g. climate, social factors (no detail of the symptoms of specific diseases is required). *M0.1, M0.2, M0.3, M1.1, M1.2, M1.3, M1.5, M1.7, M3.1, M3.2* HSW1, HSW2, HSW3, HSW5, HSW6, HSW7, HSW8, HSW11, HSW12
(c)	plant defences against pathogens	To include production of chemicals **AND** plant responses that limit the spread of the pathogen (e.g. callose deposition).
(d)	the primary non-specific defences against pathogens in animals	Non-specific defences to include skin, blood clotting, wound repair, inflammation, expulsive reflexes and mucous membranes (no detail of skin structure or all the steps involved in the clotting cascade are required). HSW2, HSW8
(e)	**(i)** the structure and mode of action of phagocytes **(ii)** examination and drawing of cells observed in blood smears	To include neutrophils and antigen-presenting cells **AND** the roles of cytokines, opsonins, phagosomes and lysosomes. **PAG1** HSW4, HSW8
(f)	the structure, different roles and modes of action of B and T lymphocytes in the specific immune response	To include the significance of cell signalling (reference to interleukins), clonal selection and clonal expansion, plasma cells, T helper cells, T killer cells and T regulator cells. HSW8
(g)	the primary and secondary immune responses	To include T memory cells and B memory cells. *M1.3* HSW2
(h)	the structure and general functions of antibodies	To include the general protein structure of an antibody molecule.
(i)	an outline of the action of opsonins, agglutinins and anti-toxins	
(j)	the differences between active and passive immunity, and between natural and artificial immunity	To include examples of each type of immunity.
(k)	autoimmune diseases	To include an appreciation of the term *autoimmune disease* and a named example e.g. arthritis, lupus.

(l)	the principles of vaccination and the role of vaccination programmes in the prevention of epidemics	To include routine vaccinations **AND** reasons for changes to vaccines and vaccination programmes (including global issues). *M0.1, M0.2, M0.3, M1.1, M1.2, M1.3, M1.5, M1.7, M3.1, M3.2* HSW1, HSW2, HSW3, HSW5, HSW6, HSW7, HSW8, HSW9, HSW11, HSW12
(m)	possible sources of medicines	To include examples of microorganisms and plants (and so the need to maintain biodiversity) **AND** the potential for personalised medicines and synthetic biology. HSW7, HSW9, HSW11, HSW12
(n)	the benefits and risks of using antibiotics to manage bacterial infection.	To include the wide use of antibiotics following the discovery of penicillin in the mid-20th century **AND** the increase in bacterial resistance to antibiotics (examples to include *Clostridium difficile* and MRSA) and its implications. HSW2, HSW5, HSW9, HSW12

4.2 Biodiversity

4.2.1 Biodiversity

Biodiversity refers to the variety and complexity of life. It is an important indicator in the study of habitats.

Maintaining biodiversity is important for many reasons. Actions to maintain biodiversity must be taken at local, national and global levels.

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	how biodiversity may be considered at different levels	To include habitat biodiversity (e.g. sand dunes, woodland, meadows, streams), species biodiversity (species richness and species evenness) and genetic biodiversity (e.g. different breeds within a species).
(b)	**(i)** how sampling is used in measuring the biodiversity of a habitat and the importance of sampling **(ii)** practical investigations collecting random and non-random samples in the field	To include how sampling can be carried out i.e. random sampling and non-random sampling (e.g. opportunistic, stratified and systematic) and the importance of sampling the range of organisms in a habitat. Techniques to include: use of sweeping nets, pitfall traps, pooters, Tullgren funnel and kick-sampling for collecting different samples. *M0.2, M1.3, M1.5, M1.4, M1.6, M1.7, M1.9, M1.10, M3.2* **PAG3** HSW4, HSW5, HSW6
(c)	how to measure species richness and species evenness in a habitat	*M1.1, M1.5, M2.3, M2.4*
(d)	the use and interpretation of Simpson's Index of Diversity (*D*) to calculate the biodiversity of a habitat	The formula will be provided where needed in assessments and does not need to be recalled $D = 1 - \left(\Sigma\left(\frac{n}{N}\right)^2\right)$ **AND** the interpretation of both high and low values of Simpson's Index of Diversity (*D*). *M1.1, M1.5, M2.3, M2.4* HSW5

(e) how genetic biodiversity may be assessed, including calculations

To include calculations of genetic diversity within isolated populations, for example the percentage of gene variants (alleles) in a genome.

$$\textit{proportion of polymorphic gene loci} = \frac{\textit{number of polymorphic gene loci}}{\textit{total number of loci}}$$

Suitable populations include zoos (captive breeding), rare breeds and pedigree animals.

M1.1, M1.5, M2.3, M2.4
HSW5

(f) the factors affecting biodiversity

To include human population growth, agriculture (monoculture) and climate change.

M1.3, M1.7, M3.1
HSW5, HSW10, HSW12

(g) the ecological, economic and aesthetic reasons for maintaining biodiversity

- Ecological, including protecting keystone species (interdependence of organisms) and maintaining genetic resource
- economic, including reducing soil depletion (continuous monoculture)
- aesthetic, including protecting landscapes.

HSW12

(h) *in situ* and *ex situ* methods of maintaining biodiversity

- *In situ* conservation including marine conservation zones and wildlife reserves
- *ex situ* conservation including seed banks, botanic gardens and zoos.

HSW7, HSW9, HSW10, HSW12

(i) international and local conservation agreements made to protect species and habitats.

Historic and/or current agreements, including the Convention on International Trade in Endangered Species (CITES), the Rio Convention on Biological Diversity (CBD) and the Countryside Stewardship Scheme (CSS).

HSW11, HSW12

4.2.2 Classification and evolution

Evolution has generated a very wide variety of organisms. The fact that all organisms share a common ancestry allows them to be classified. Classification is an attempt to impose a hierarchy on the complex and dynamic variety of life on Earth.

Classification systems have changed and will continue to change as our knowledge of the biology of organisms develops.

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	the biological classification of species	To include the taxonomic hierarchy of kingdom, phylum, class, order, family, genus and species **AND** domain. HSW1, HSW5, HSW6, HSW7
(b)	the binomial system of naming species and the advantage of such a system	
(c)	**(i)** the features used to classify organisms into the five kingdoms: Prokaryotae, Protoctista, Fungi, Plantae, Animalia	To include the use of similarities in observable features in original classification.
	(ii) the evidence that has led to new classification systems, such as the three domains of life, which clarifies relationships	To include the more recent use of similarities in biological molecules and other genetic evidence **AND** details of the three domains and a comparison of the kingdom and domain classification systems. HSW1, HSW5, HSW6, HSW7, HSW11, HSW12
(d)	the relationship between classification and phylogeny	Cladistics and phylogenetic definition of species not covered at AS level. HSW5, HSW7
(e)	the evidence for the theory of evolution by natural selection	To include the contributions of Darwin and Wallace in formulating the theory of evolution by natural selection **AND** fossil, DNA (only genomic DNA at AS level) and molecular evidence. HSW1, HSW2, HSW5, HSW6, HSW7

(f)	the different types of variation	To include intraspecific and interspecific variation **AND** the differences between continuous and discontinuous variation, using examples of a range of characteristics found in plants, animals and microorganisms **AND** both genetic and environmental causes of variation. An opportunity to use standard deviation to measure the spread of a set of data **and/or** Student's *t*-test to compare means of data values of two populations **and/or** the Spearman's rank correlation coefficient to consider the relationship of the data. *M1.2, M1.3, M1.6, M1.7, M1.9, M1.10* HSW4
(g)	the different types of adaptations of organisms to their environment	Anatomical, physiological and behavioural adaptations **AND** why organisms from different taxonomic groups may show similar anatomical features, including the marsupial mole and placental mole. HSW5
(h)	the mechanism by which natural selection can affect the characteristics of a population over time	To include an appreciation that genetic variation, selection pressure and reproductive success (or failure) results in an increased proportion of the population possessing the advantageous characteristic(s). *M0.3* HSW8
(i)	how evolution in some species has implications for human populations.	To include the evolution of pesticide resistance in insects and drug resistance in microorganisms. HSW8, HSW9, HSW12

Module 5: Communication, homeostasis and energy

It is important that organisms, both plants and animals are able to respond to stimuli. This is achieved by communication within the body, which may be chemical and/or electrical. Both systems are covered in detail in this module. Communication is also fundamental to homeostasis with control of temperature, blood sugar and blood water potential being studied as examples.

In this module, the biochemical pathways of photosynthesis and respiration are considered, with an emphasis on the formation and use of ATP as the source of energy for biochemical processes and synthesis of biological molecules.

Learners are expected to apply knowledge, understanding and other skills developed in this module to new situations and/or to solve related problems.

5.1 Communication and homeostasis

5.1.1 Communication and homeostasis

Organisms use both chemical and electrical systems to monitor and respond to any deviation from the body's steady state.

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	the need for communication systems in multicellular organisms	To include the need for animals and plants to respond to changes in the internal and external environment and to coordinate the activities of different organs.
(b)	the communication between cells by cell signalling	To include signalling between adjacent cells and signalling between distant cells.
(c)	the principles of homeostasis	To include the differences between receptors and effectors, and the differences between negative feedback and positive feedback. HSW8
(d)	the physiological and behavioural responses involved in temperature control in ectotherms and endotherms.	To include, • endotherms – peripheral temperature receptors, the role of the hypothalamus and effectors in skin and muscles; behavioural responses • ectotherms – behavioural responses. An opportunity to monitor physiological functions in ectotherms and/or endotherms. **PAG11** HSW2

5.1.2 Excretion as an example of homeostatic control

The kidneys, liver and lungs are all involved in the removal of toxic products of metabolism from the blood and therefore contribute to homeostasis. The kidneys play a major role in the control of the water potential of the blood.

The liver also metabolises some toxins that are ingested.

2

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	the term *excretion* and its importance in maintaining metabolism and homeostasis	To include reference to the importance of removing metabolic wastes, including carbon dioxide and nitrogenous waste, from the body.
(b)	**(i)** the structure and functions of the mammalian liver **(ii)** the examination and drawing of stained sections to show the histology of liver tissue	To include the gross structure and histology of the liver **AND** the roles of the liver in storage of glycogen, detoxification and the formation of urea (the ornithine cycle covered in outline only). **PAG1** HSW4
(c)	**(i)** the structure, mechanisms of action and functions of the mammalian kidney **(ii)** the dissection, examination and drawing of the external and internal structure of the kidney **(iii)** the examination and drawing of stained sections to show the histology of nephrons	To include the gross structure and histology of the kidney including the detailed structure of a nephron and its associated blood vessels **AND** the processes of ultrafiltration, selective reabsorption and the production of urine. *M0.1, M0.3, M1.1, M1.3, M2.1, M3.1* **PAG1, PAG2** HSW4, HSW6, HSW8
(d)	the control of the water potential of the blood	To include the role of osmoreceptors in the hypothalamus, the posterior pituitary gland, ADH and its effect on the walls of the collecting ducts. HSW8
(e)	the effects of kidney failure and its potential treatments	To include the problems that arise from kidney failure including the effect on glomerular filtration rate (GFR) and electrolyte balance **AND** the use of renal dialysis (both haemodialysis and peritoneal dialysis) and transplants for the treatment of kidney failure. HSW7, HSW9, HSW12

(f)	how excretory products can be used in medical diagnosis.	To include the use of urine samples in diagnostic tests, with reference to the use of monoclonal antibodies in pregnancy testing and testing for anabolic steroids and drugs. **PAG9** HSW7, HSW9, HSW11, HSW12

5.1.3 Neuronal communication

The stimulation of sensory receptors leads to the generation of an action potential in a neurone.

Transmission between neurones takes place at synapses.

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	the roles of mammalian sensory receptors in converting different types of stimuli into nerve impulses	To include an outline of the roles of sensory receptors (e.g. Pacinian corpuscle) in responding to specific types of stimuli and their roles as transducers.
(b)	the structure and functions of sensory, relay and motor neurones	To include differences between the structure and function of myelinated and non-myelinated neurones.
(c)	the generation and transmission of nerve impulses in mammals	To include how the resting potential is established and maintained and how an action potential is generated (including reference to positive feedback) and transmitted in a myelinated neurone **AND** the significance of the frequency of impulse transmission. *M1.3, M3.1*
(d)	the structure and roles of synapses in neurotransmission.	To include the structure of a cholinergic synapse **AND** the action of neurotransmitters at the synapse and the importance of synapses in summation and control, including inhibitory and excitatory synapses.

5.1.4 Hormonal communication

The ways in which specific hormones bring about their effects are used to exemplify endocrine communication and control. Treatment of diabetes is used as an example of the use of medical technology in overcoming defects in hormonal control systems.

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	endocrine communication by hormones	To include secretion of hormones into the blood, transport by the blood, and detection by target cells or tissues.
(b)	the structure and functions of the adrenal glands	Adrenal glands as an example of endocrine glands, to include the hormones secreted by the cortex and medulla and their functions.
(c)	**(i)** the histology of the pancreas	To include the endocrine tissues.
	(ii) the examination and drawing of stained sections of the pancreas to show the histology of the endocrine tissues	**PAG1** HSW4
(d)	how blood glucose concentration is regulated	To include the action of insulin and glucagon as an example of negative feedback, and the role of the liver **AND** the control of insulin secretion, with reference to potassium channels and calcium channels in the beta cells of the pancreas. HSW12
(e)	the differences between Type 1 and Type 2 diabetes mellitus	To include the causes of Type 1 and Type 2 diabetes and the treatments used for each. HSW12
(f)	the potential treatments for diabetes mellitus.	To include the use of insulin produced by genetically modified bacteria and the potential use of stem cells to treat diabetes mellitus. HSW12

5.1.5 Plant and animal responses

Plant responses to environmental changes are coordinated by hormones, some of which are important commercially.

In animals, responding to changes in the environment is a complex and continuous process, involving nervous, hormonal and muscular coordination.

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	**(i)** the types of plant responses **(ii)** practical investigations into phototropism and geotropism	To include the response to abiotic stress and herbivory e.g. chemical defences (such as tannins, alkaloids and pheromones), folding in response to touch (*Mimosa pudica*) **AND** the range of tropisms in plants. *M1.3, M1.6* **PAG11** HSW4
(b)	the roles of plant hormones	To include the role of hormones in leaf loss in deciduous plants, seed germination and stomatal closure.
(c)	the experimental evidence for the role of auxins in the control of apical dominance	HSW5
(d)	the experimental evidence for the role of gibberellin in the control of stem elongation and seed germination	HSW5
(e)	practical investigations into the effect of plant hormones on growth	An opportunity for serial dilution. An opportunity to use standard deviation to measure the spread of a set of data. *M0.2, M1.1, M1.2, M1.3, M1.4, M1.6, M1.9, M1.10, M3.1, M3.2* **PAG11** HSW4
(f)	the commercial use of plant hormones	To include the use of hormones to control ripening, the use of rooting powders and hormonal weed killers. HSW12
(g)	the organisation of the mammalian nervous system	To include the structural organisation of the nervous system into the central and peripheral systems **AND** the functional organisation into the somatic and autonomic nervous systems.

(h)	the structure of the human brain and the functions of its parts	To include the gross structure of the human brain **AND** the functions of the cerebrum, cerebellum, medulla oblongata, hypothalamus and pituitary gland.
(i)	reflex actions	To include knee jerk reflex and blinking reflex, with reference to the survival value of reflex actions. *M0.1, M0.2, M1.1, M1.2, M1.3, M1.6* **PAG11** HSW4
(j)	the coordination of responses by the nervous and endocrine systems	To include the 'fight or flight' response to environmental stimuli in mammals **AND** the action of hormones in cell signalling (studied in outline only) with reference to adrenaline (first messenger), activation of adenylyl cyclase, and cyclic AMP (second messenger).
(k)	the effects of hormones and nervous mechanisms on heart rate	An opportunity to monitor physiological functions, for example with pulse rate measurements before, during and after exercise or sensors to record electrical activity in the heart. An opportunity to use standard deviation to measure the spread of a set of data and/or Student's *t*-test to compare means of data values of two sets of data. *M0.1, M0.2, M0.3, M1.1, M1.2, M1.3, M1.6, M1.10, M3.1* **PAG10, PAG11** HSW4
(l) **(i)**	the structure of mammalian muscle and the mechanism of muscular contraction	To include the structural and functional differences between skeletal, involuntary and cardiac muscle **AND** the action of neuromuscular junctions **AND** the sliding filament model of muscular contraction and the role of ATP, and how the supply of ATP is maintained in muscles by creatine phosphate. An opportunity to monitor muscle contraction and fatigue using sensors to record electrical activity. **PAG1, PAG10, PAG11** HSW4
(ii)	the examination of stained sections or photomicrographs of skeletal muscle.	

5.2 Energy for biological processes

5.2.1 Photosynthesis

Photosynthesis is the process whereby light from the Sun is harvested and used to drive the production of chemicals, including ATP, and used to synthesise large organic molecules from inorganic molecules.

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	the interrelationship between the process of photosynthesis and respiration	To include the relationship between the raw materials and products of the two processes. *M0.1, M0.3, M0.4, M3.4*
(b)	the structure of a chloroplast and the sites of the two main stages of photosynthesis	The components of a chloroplast including outer membrane, lamellae, grana, thylakoid, stroma and DNA.
(c)	**(i)** the importance of photosynthetic pigments in photosynthesis	To include reference to light harvesting systems and photosystems.
	(ii) practical investigations using thin layer chromatography (TLC) to separate photosynthetic pigments	*M0.1, M0.2, M1.1, M1.3, M2.2, M2.3, M2.4* **PAG6** HSW4
(d)	the light-dependent stage of photosynthesis	To include how energy from light is harvested and used to drive the production of chemicals which can be used as a source of energy for other metabolic processes (ATP and reduced NADP) with reference to electron carriers and cyclic and non-cyclic photophosphorylation **AND** the role of water. HSW8
(e)	the fixation of carbon dioxide and the light-independent stage of photosynthesis	To include how the products of the light-dependent stage are used in the light-independent stage (Calvin cycle) to produce triose phosphate (TP) with reference to ribulose bisphosphate (RuBP), ribulose bisphosphate carboxylase (RuBisCO) and glycerate 3-phosphate (GP) – **no** other biochemical detail is required. HSW8
(f)	the uses of triose phosphate (TP)	To include the use of TP as a starting material for the synthesis of carbohydrates, lipids and amino acids **AND** the recycling of TP to regenerate the supply of RuBP.

(g)	**(i)**	factors affecting photosynthesis	To include limiting factors in photosynthesis with reference to carbon dioxide concentration, light intensity and temperature, and the implications of water stress (stomatal closure) **AND** the effect on the rate of photosynthesis, and on levels of GP, RuBP and TP, of changing carbon dioxide concentration, light intensity and temperature.
	(ii)	practical investigations into factors affecting the rate of photosynthesis.	An opportunity to use sensors, data loggers and software to process data. *M0.1, M0.2, M0.3, M1.1, M1.3, M1.11, M3.1, M3.2, M3.4, M3.5, M3.6, M4.1* **PAG4, PAG10, PAG11** HSW3, HSW4, HSW5, HSW12

5.2.2 Respiration

Respiration is the process whereby energy stored in complex organic molecules is transferred to ATP. ATP provides the immediate source of energy for biological processes.

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	the need for cellular respiration	To include examples of why plants, animals and microorganisms need to respire (suitable examples could include active transport and an outline of named metabolic reactions).
(b)	the structure of the mitochondrion	The components of a mitochondrion including inner and outer mitochondrial membranes, cristae, matrix and mitochondrial DNA.
(c)	the process and site of glycolysis	To include the phosphorylation of glucose to hexose bisphosphate, the splitting of hexose bisphosphate into two triose phosphate molecules and further oxidation to pyruvate **AND** the production of a small yield of ATP and reduced NAD. HSW8
(d)	the link reaction and its site in the cell	To include the formation of Acetyl CoA by the decarboxylation of pyruvate and the reduction of NAD to NADH.

(e)	the process and site of the Krebs cycle	To include the formation of citrate from the acetyl group of acetyl CoA and oxaloacetate and the reconversion of citrate to oxaloacetate (names of intermediate compounds are not required) **AND** the importance of decarboxylation, dehydrogenation, the reduction of NAD and FAD, and substrate level phosphorylation. HSW8
(f)	the importance of coenzymes in cellular respiration	With reference to NAD, FAD and coenzyme A.
(g)	the process and site of oxidative phosphorylation	To include the roles of electron carriers, oxygen and the mitochondrial cristae.
(h)	the chemiosmotic theory	To include the electron transport chain, proton gradients and ATP synthase in oxidative phosphorylation and photophosphorylation.
(i)	**(i)** the process of anaerobic respiration in eukaryotes **(ii)** practical investigations into respiration rates in yeast, under aerobic and anaerobic conditions	To include anaerobic respiration in mammals and yeast and the benefits of being able to respire anaerobically **AND** why anaerobic respiration produces a much lower yield of ATP than aerobic respiration. An opportunity to use sensors, data loggers and software to process data. *M0.1, M0.2, M1.1, M1.3, M2.4, M3.1, M3.2* **PAG4, PAG10, PAG11** HSW3, HSW4
(j)	the difference in relative energy values of carbohydrates, lipids and proteins as respiratory substrates	
(k)	the use and interpretation of the respiratory quotient (RQ)	To include calculating the respiratory quotient (RQ) using the formula: $RQ = \frac{CO_2\ produced}{O_2\ consumed}$ *M0.1, M0.2, M1.1, M1.3, M2.3*

(l)	practical investigations into the effect of factors such as temperature, substrate concentration and different respiratory substrates on the rate of respiration.	For example the use of respirometers. An opportunity to use sensors, data loggers and software to process data. An opportunity to use standard deviation to measure the spread of a set of data and/or Student's *t*-test to compare means of data values of two sets of data. *M0.1, M0.2, M1.1, M1.2, M1.3, M1.6, M1.10, M2.4, M3.2, M3.3, M3.5, M3.6* **PAG4, PAG10, PAG11** HSW3, HSW4

Module 6: Genetics, evolution and ecosystems

This module covers the role of genes in regulating and controlling cell function and development. Heredity and the mechanisms of evolution and speciation are also covered.

Some of the practical techniques used to manipulate DNA such as sequencing and amplification are considered and their therapeutic medical use. The use of microorganisms in biotechnology is also covered. Both of these have associated ethical considerations and it is important that learners develop a balanced understanding of such issues.

Learners gain an appreciation of the role of microorganisms in recycling materials within the environment and maintaining balance within ecosystems. The need to conserve environmental resources in a sustainable fashion is considered, whilst appreciating the potential conflict arising from the needs of an increasing human population. Learners also consider the impacts of human activities on the natural environment and biodiversity.

Learners are expected to apply knowledge, understanding and other skills developed in this module to new situations and/or to solve related problems.

6.1 Genetics and evolution

6.1.1 Cellular control

The way in which cells control metabolic reactions determines how organisms, grow, develop and function.

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	types of gene mutations and their possible effects on protein production and function	To include substitution, insertion or deletion of one or more nucleotides **AND** the possible effects of these gene mutations (i.e. beneficial, neutral or harmful).

(b)	the regulatory mechanisms that control gene expression at the transcriptional level, post-transcriptional level and post-translational level	To include control at the, • transcriptional level: *lac* operon, and transcription factors in eukaryotes. • post-transcriptional level: the editing of primary mRNA and the removal of introns to produce mature mRNA. • post-translational level: the activation of proteins by cyclic AMP. HSW2
(c)	the genetic control of the development of body plans in different organisms	Homeobox gene sequences in plants, animals and fungi are similar and highly conserved **AND** the role of Hox genes in controlling body plan development. HSW7
(d)	the importance of mitosis and apoptosis as mechanisms controlling the development of body form.	To include an appreciation that the genes which regulate the cell cycle and apoptosis are able to respond to internal and external cell stimuli e.g. stress.

6.1.2 Patterns of inheritance

Isolating mechanisms can lead to the accumulation of different genetic information in populations, potentially leading to new species. Over a prolonged period of time, organisms have changed and some have become extinct. The theory of evolution explains these changes. Humans use artificial selection to produce similar changes in plants and animals.

		Learning outcomes	Additional guidance
		Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	**(i)**	the contribution of both environmental and genetic factors to phenotypic variation	To include examples of both genetic and environmental contributions – environmental examples could include diet in animals and etiolation or chlorosis in plants.
	(ii)	how sexual reproduction can lead to genetic variation within a species	Meiosis and the random fusion of gametes at fertilisation.
(b)	**(i)**	genetic diagrams to show patterns of inheritance	To include monogenic inheritance, dihybrid inheritance, multiple alleles, sex linkage and codominance.
	(ii)	the use of phenotypic ratios to identify linkage (autosomal and sex linkage) and epistasis	To include explanations of linkage and epistasis. *M0.3, M1.4* HSW2, HSW8

(c)	using the chi-squared (χ^2) test to determine the significance of the difference between observed and expected results	The formula for the chi-squared (χ^2) test will be provided. *M0.3, M1.4, M1.9, M2.1*
(d)	the genetic basis of continuous and discontinuous variation	To include reference to the number of genes that influence each type of variation.
(e)	the factors that can affect the evolution of a species	To include stabilising selection and directional selection, genetic drift, genetic bottleneck and founder effect.
(f)	the use of the Hardy–Weinberg principle to calculate allele frequencies in populations	The equations for the Hardy–Weinberg principle will be provided where needed in assessments and do not need to be recalled. $p^2 + 2pq + q^2 = 1$ $p + q = 1$ *M0.2, M2.1, M2.2, M2.3*
(g)	the role of isolating mechanisms in the evolution of new species	To include geographical mechanisms (allopatric speciation) and reproductive mechanisms (sympatric speciation).
(h) **(i)**	the principles of artificial selection and its uses	To include examples of selective breeding in plants and animals **AND** an appreciation of the importance of maintaining a resource of genetic material for use in selective breeding including wild types.
(ii)	the ethical considerations surrounding the use of artificial selection.	To include a consideration of the more extreme examples of the use of artificial selection to 'improve' domestic species e.g. dog breeds. HSW2, HSW8, HSW10, HSW12

6.1.3 Manipulating genomes

Genome sequencing gives information about the location of genes and provides evidence for the evolutionary links between organisms.

Genetic engineering involves the manipulation of naturally occurring processes and enzymes. The capacity to manipulate genes has many potential benefits, but the implications of genetic techniques are subject to much public debate

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	the principles of DNA sequencing and the development of new DNA sequencing techniques	To include the rapid advancements of the techniques used in sequencing, which have increased the speed of sequencing and allowed whole genome sequencing e.g. high-throughput sequencing. HSW7
(b)	**(i)** how gene sequencing has allowed for genome-wide comparisons between individuals and between species **(ii)** how gene sequencing has allowed for the sequences of amino acids in polypeptides to be predicted **(iii)** how gene sequencing has allowed for the development of synthetic biology	With reference to bioinformatics and computational biology and how these fields are contributing to biological research into genotype–phenotype relationships, epidemiology and searching for evolutionary relationships. **PAG10** HSW7, HSW9
(c)	the principles of DNA profiling and its uses	To include forensics and analysis of disease risk. HSW9
(d)	the principles of the polymerase chain reaction (PCR) and its application in DNA analysis	
(e)	the principles and uses of electrophoresis for separating nucleic acid fragments or proteins	Opportunity for practical use of electrophoresis. **PAG6** HSW4
(f)	**(i)** the principles of genetic engineering	To include the isolation of genes from one organism and the placing of these genes into another organism using suitable vectors.
	(ii) the techniques used in genetic engineering	To include the use of restriction enzymes, plasmids and DNA ligase to form recombinant DNA with the desired gene and electroporation. HSW2

(g)	the ethical issues (both positive and negative) relating to the genetic manipulation of animals (including humans), plants and microorganisms	To include insect resistance in genetically modified soya, genetically modified pathogens for research and 'pharming' i.e. genetically modified animals to produce pharmaceuticals **AND** issues relating to patenting and technology transfer e.g. making genetically modified seed available to poor farmers. HSW10
(h)	the principles of, and potential for, gene therapy in medicine.	To include the differences between somatic cell gene therapy and germ line cell gene therapy. HSW9, HSW12

6.2 Cloning and biotechnology

6.2.1 Cloning and biotechnology

Farmers and growers exploit "natural" vegetative propagation in the production of uniform crops. Artificial clones of plants and animals can now be produced.

Biotechnology is the industrial use of living organisms (or parts of living organisms) to produce food, drugs or other product.

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	**(i)** natural clones in plants and the production of natural clones for use in horticulture **(ii)** how to take plant cuttings as an example of a simple cloning technique	To include examples of natural cloning and the methods used to produce clones (various forms of vegetative propagation). Dissection of a selection of plant material to produce cuttings. **PAG2** HSW4
(b)	**(i)** the production of artificial clones of plants by micropropagation and tissue culture **(ii)** the arguments for and against artificial cloning in plants	To include an evaluation of the uses of plant cloning in horticulture and agriculture. HSW9, HSW12
(c)	natural clones in animal species	To include examples of natural clones (twins formed by embryo splitting).
(d)	**(i)** how artificial clones in animals can be produced by artificial embryo twinning or by enucleation and somatic cell nuclear transfer (SCNT) **(ii)** the arguments for and against artificial cloning in animals	To include an evaluation of the uses of animal cloning (examples including in agriculture and medicine, and issues of longevity of cloned animals). HSW9, HSW10, HSW12

(e)		the use of microorganisms in biotechnological processes	To include reasons why microorganisms are used e.g. economic considerations, short life cycle, growth requirements **AND** processes including brewing, baking, cheese making, yoghurt production, penicillin production, insulin production and bioremediation.
(f)		the advantages and disadvantages of using microorganisms to make food for human consumption	To include bacterial and fungal sources. HSW9, HSW12
(g)	**(i)**	how to culture microorganisms effectively, using aseptic techniques	An opportunity for serial dilutions and culturing on agar plates. **PAG7** HSW4
	(ii)	the importance of manipulating the growing conditions in batch and continuous fermentation in order to maximise the yield of product required	
(h)	**(i)**	the standard growth curve of a microorganism in a closed culture	To include the formula for number of individual organisms $N = N_0 \times 2^n$
	(ii)	practical investigations into the factors affecting the growth of microorganisms	An opportunity for serial dilutions and the use of broth. *M0.1, M0.3, M0.5, M1.1, M1.3, M2.5, M3.1, M3.2, M3.4, M3.5, M3.6* **PAG7** HSW4

(i)	the uses of immobilised enzymes in biotechnology and the different methods of immobilisation.	To include methods of enzyme immobilisation **AND** an evaluation of the use of immobilised enzymes in biotechnology examples could include: • glucose isomerase for the conversion of glucose to fructose • penicillin acylase for the formation of semi-synthetic penicillins (to which some penicillin-resistant organisms are not resistant) • lactase for the hydrolysis of lactose to glucose and galactose • aminoacylase for production of pure samples of L-amino acids • glucoamylase for the conversion of dextrins to glucose *M0.2, M0.3, M1.2, M1.3, M1.4, M1.6, M1.10, M3.2, M4.1* **PAG4** HSW4

6.3 Ecosystems

6.3.1 Ecosystems

Organisms do not live in isolation but engage in complex interactions, not just with other organisms but also with their environment.

The efficiency of biomass transfer limits the number of organisms that can exist in a particular ecosystem.

Ecosystems are dynamic and tend towards some form of climax community.

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	ecosystems, which range in size, are dynamic and are influenced by both biotic and abiotic factors	To include reference to a variety of ecosystems of different sizes (e.g. a rock pool, a playing field, a large tree) and named examples of biotic and abiotic factors.

(b)	biomass transfers through ecosystems	To include how biomass transfers between trophic levels can be measured **AND** the efficiency of biomass transfers between trophic levels $efficiency = \frac{biomass\ transferred}{biomass\ intake} \times 100$ **AND** how human activities can manipulate the transfer of biomass through ecosystems. *M0.1, M0.2, M0.3, M0.4, M1.1, M1.3, M1.6* HSW12
(c)	recycling within ecosystems	To include the role of decomposers and the roles of microorganisms in recycling nitrogen within ecosystems (including *Nitrosomonas*, *Nitrobacter*, *Azotobacter* and *Rhizobium*) **AND** the importance of the carbon cycle to include the role of organisms (decomposition, respiration and photosynthesis) and physical and chemical effects in the cycling of carbon within ecosystems. HSW2, HSW12
(d)	the process of primary succession in the development of an ecosystem	To include succession from pioneer species to a climax community **AND** deflected succession. HSW12
(e)	**(i)** how the distribution and abundance of organisms in an ecosystem can be measured **(ii)** the use of sampling and recording methods to determine the distribution and abundance of organisms in a variety of ecosystems.	*M1.3, M1.4, M1.5, M1.7, M1.9, M1.10, M3.1, M3.2* **PAG3** HSW4

6.3.2 Populations and sustainability

There are many factors that determine the size of a population.

For economic, social and ethical reasons ecosystems may need to be carefully managed.

To support an increasing human population, we need to use biological resources in a sustainable way.

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	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	the factors that determine size of a population	To include the significance of limiting factors in determining the carrying capacity of a given environment and the impact of these factors on final population size. *M0.1, M0.2, M0.3, M0.4, M0.5, M1.3, M2.5, M3.1, M3.2* HSW1, HSW2
(b)	interactions between populations	To include predator–prey relationships considering the effects on both predator and prey populations **AND** interspecific and intraspecific competition.
(c)	the reasons for, and differences between, conservation and preservation	To include the economic, social and ethical reasons for conservation of biological resources. HSW7, HSW9, HSW10, HSW12
(d)	how the management of an ecosystem can provide resources in a sustainable way	Examples to include timber production and fishing. HSW12
(e)	the management of environmental resources and the effects of human activities.	To include how ecosystems can be managed to balance the conflict between conservation/ preservation and human needs e.g. the Masai Mara region in Kenya and the Terai region of Nepal, peat bogs **AND** the effects of human activities on the animal and plant populations and how these are controlled in environmentally sensitive ecosystems e.g. the Galapagos Islands, Antarctica, Snowdonia National Park, the Lake District. HSW7, HSW12