Cells and protein		
Key area	**Depth of knowledge required**	**Suggested learning activities**
1 Laboratory techniques for biologists (a) Health and safety Substances, organisms, and equipment in a laboratory can present a hazard	Hazards in the lab include toxic or corrosive chemicals, heat or flammable substances, pathogenic organisms, and mechanical equipment.	Become familiar with standard laboratory rules and with risk assessment.
Hazard, risk, and control of risk in the lab by risk assessment	Risk is the likelihood of harm arising from exposure to a hazard. Risk assessment involves identifying control measures to minimise the risk. Control measures include using appropriate handling techniques, protective clothing and equipment, and aseptic technique.	
(b) Liquids and solutions Method and uses of linear and log dilution	Dilutions in a linear dilution series differ by an equal interval, for example 0·1, 0·2, 0·3 and so on. Dilutions in a log dilution series differ by a constant proportion, for example 10^{-1}, 10^{-2}, 10^{-3} and so on.	Become familiar with the use of measuring cylinders, pipettes, burettes, autopipettes, and syringes.

Cells and protein		
Key area	**Depth of knowledge required**	**Suggested learning activities**
Production of a standard curve to determine an unknown	Plotting measured values for known concentrations to produce a line or curve allows the concentration of an unknown to be determined from the standard curve.	
Use of buffers to control pH	Addition of acid or alkali has very small effects on the pH of a buffer, allowing the pH of a reaction mixture to be kept constant.	Practise making solutions using buffers and measuring the pH with a meter or an indicator.
Method and uses of a colorimeter to quantify concentration and turbidity	Calibration with appropriate blank as a baseline; use of absorbance to determine concentration of a coloured solution using suitable wavelength filters; use of percentage transmission to determine turbidity, such as cells in suspension.	Use a colorimeter or spectrophotometer to calibrate a known solution and determine an unknown using, for example, Bradford protein assay.
(c) Separation techniques Use of centrifuge to separate substances of differing density	More dense components settle in the pellet; less dense components remain in the supernatant.	
Paper and thin layer chromatography can be used for separating different substances such as amino acids and sugars	The speed that each solute travels along the chromatogram depends on its differing solubility in the solvent used. Details of how to carry out these procedures are not required.	

Cells and protein		
Key area	**Depth of knowledge required**	**Suggested learning activities**
Principle of affinity chromatography and its use in separating proteins	A solid matrix or gel column is created with specific molecules bound to the matrix or gel. Soluble, target proteins in a mixture, with a high affinity for these molecules, become attached to them as the mixture passes down the column. Other non-target molecules with a weaker affinity are washed out.	
Principle of gel electrophoresis and its use in separating proteins and nucleic acids	Charged macromolecules move through an electric field applied to a gel matrix.	Use protein electrophoresis to identify different muscle proteins.
Native gels separate proteins by their shape, size and charge	Native gels do not denature the molecule so that separation is by shape, size and charge.	
SDS–PAGE separates proteins by size alone	SDS–PAGE gives all the molecules an equally negative charge and denatures them, separating proteins by size alone.	
Proteins can be separated from a mixture using their isoelectric points (IEPs) If the solution is buffered to a specific pH, only the protein(s) that have an IEP of that pH will precipitate	IEP is the pH at which a soluble protein has no net charge and will precipitate out of solution.	Determine the isoelectric point of a soluble protein, such as casein.
Proteins can also be separated using their IEPs in electrophoresis	Soluble proteins can be separated using an electric field and a pH gradient. A protein stops migrating through the gel at its IEP in	

Cells and protein		
Key area	**Depth of knowledge required**	**Suggested learning activities**
	the pH gradient because it has no net charge. Further details of electrophoresis are not required.	
(d)Detecting proteins using antibodies Immunoassay techniques are used to detect and identify specific proteins		
These techniques use stocks of antibodies with the same specificity, known as monoclonal antibodies	Knowledge of monoclonal antibody production is not required.	Research the use of monoclonal antibodies in the diagnosis and detection of disease.
An antibody specific to the protein antigen is linked to a chemical 'label'	The 'label' is often a reporter enzyme producing a colour change, but chemiluminescence, fluorescence and other reporters can be used. In some cases the assay uses a specific antigen to detect the presence of antibodies.	Use the ELISA technique to identify the presence of specific antigens.
Western blotting is a technique, used after SDS–PAGE electrophoresis The separated proteins from the gel are transferred (blotted) onto a solid medium		

Cells and protein		
Key area	**Depth of knowledge required**	**Suggested learning activities**
The proteins can be identified using specific antibodies that have reporter enzymes attached		
(e)Microscopy Bright-field microscopy is commonly used to observe whole organisms, parts of organisms, thin sections of dissected tissue or individual cells Fluorescence microscopy uses specific fluorescent labels to bind to and visualise certain molecules or structures within cells or tissues		Refresh skills in the use of microscopes and making slides. Discuss the ethics of dissection in an educational context.
(f) Aseptic technique and cell culture Aseptic technique eliminates unwanted microbial contaminants when culturing micro-organisms or cells A microbial culture can be started using an inoculum of microbial cells on an agar medium, or in a broth with suitable nutrients	Aseptic technique involves the sterilisation of equipment and culture media by heat or chemical means and subsequent exclusion of microbial contaminants. Many culture media exist that promote the growth of specific types of cells and microbes.	Investigate methods of sterilisation of containers, equipment, and materials. Culture bacterial, yeast, and algal cells using aseptic technique.

Cells and protein		
Key area	**Depth of knowledge required**	**Suggested learning activities**
Animal cells are grown in medium containing growth factors from serum In culture, primary cell lines can divide a limited number of times, whereas tumour cells lines can perform unlimited divisions Plating out of a liquid microbial culture on solid media allows the number of colony-forming units to be counted and the density of cells in the culture estimated Serial dilution is often needed to achieve a suitable colony count Method and use of haemocytometer to estimate cell numbers in a liquid culture Vital staining is required to identify and count viable cells	Growth factors are proteins that promote cell growth and proliferation. Growth factors are essential for the culture of most animal cells.	Investigate some of the different types of culture media and their uses. Use a haemocytometer to make an estimate of cell count.
2 Proteins (a)The proteome The proteome is the entire set of proteins expressed by a genome The proteome is larger than the number of genes, particularly in eukaryotes, because		

Cells and protein		
Key area	**Depth of knowledge required**	**Suggested learning activities**
more than one protein can be produced from a single gene as a result of alternative RNA splicing		
Not all genes are expressed as proteins in a particular cell type The set of proteins expressed by a given cell type can vary over time and under different conditions	Genes that do not code for proteins are called non-coding RNA genes and include those that are transcribed to produce tRNA, rRNA, and RNA molecules that control the expression of other genes. Some factors affecting the set of proteins expressed by a given cell type are the metabolic activity of the cell, cellular stress, the response to signalling molecules, and diseased versus healthy cells.	
(b)The synthesis and transport of proteins (i) Intracellular membranes Eukaryotic cells have a system of internal membranes, which increases the total area of membrane The endoplasmic reticulum (ER) forms a network of membrane tubules continuous with the nuclear membrane The Golgi apparatus is a series of flattened membrane discs	Because of their size, eukaryotes have a relatively small surface area to volume ratio. The plasma membrane of eukaryotic cells is therefore too small an area to carry out all the vital functions carried out by membranes.	

Cells and protein		
Key area	**Depth of knowledge required**	**Suggested learning activities**
Lysosomes are membrane-bound organelles containing a variety of hydrolases that digest proteins, lipids, nucleic acids and carbohydrates Vesicles transport materials between membrane compartments		
(ii) Synthesis of membrane components Lipids and proteins are synthesised in the ER	Rough ER (RER) has ribosomes on its cytosolic face while smooth ER (SER) lacks ribosomes.	
Lipids are synthesised in the smooth endoplasmic reticulum (SER) and inserted into its membrane The synthesis of all proteins begins in cytosolic ribosomes The synthesis of cytosolic proteins is completed there, and these proteins remain in the cytosol		
Transmembrane proteins carry a signal sequence, which halts translation and directs the ribosome synthesising the protein to dock with the ER, forming RER	A signal sequence is a short stretch of amino acids at one end of the polypeptide that determines the eventual location of a protein in a cell.	

Cells and protein		
Key area	**Depth of knowledge required**	**Suggested learning activities**
Translation continues after docking, and the protein is inserted into the membrane of the ER (iii) Movement of proteins between membranes Once the proteins are in the ER, they are transported by vesicles that bud off from the ER and fuse with the Golgi apparatus		
As proteins move through the Golgi apparatus they undergo post-translational modification	Molecules move through the Golgi discs in vesicles that bud off from one disc and fuse to the next one in the stack. Enzymes catalyse the addition of various sugars in multiple steps to form the carbohydrates.	Research post-translational modification and activity in trypsinogen and trypsin.
The addition of carbohydrate groups is the major modification Vesicles that leave the Golgi apparatus take proteins to the plasma membrane and lysosomes Vesicles move along microtubules to other membranes and fuse with them within the cell		

Cells and protein		
Key area	**Depth of knowledge required**	**Suggested learning activities**
(iv) The secretory pathway Secreted proteins are translated in ribosomes on the RER and enter its lumen The proteins move through the Golgi apparatus and are then packaged into secretory vesicles These vesicles move to and fuse with the plasma membrane, releasing the proteins out of the cell Many secreted proteins are synthesised as inactive precursors and require proteolytic cleavage to produce active proteins	Peptide hormones and digestive enzymes are examples of secreted proteins. Proteolytic cleavage is another type of post-translational modification. Digestive enzymes are one example of secreted proteins that require proteolytic cleavage to become active. Specific names of digestive enzymes are not required.	
(c) Protein structure, ligand binding and conformational change (i) Amino acid sequence determines protein structure Proteins are polymers of amino acid monomers		Use amino acid chromatography to distinguish between different amino acids.

Cells and protein		
Key area	**Depth of knowledge required**	**Suggested learning activities**
Amino acids are linked by peptide bonds to form polypeptides	Recognise the chemical structure of a peptide bond from a diagram.	
Amino acids have the same basic structure, differing only in the R group present	R groups of amino acids vary in size, shape, charge, hydrogen bonding capacity and chemical reactivity.	
Amino acids are classified according to their R groups: basic (positively charged); acidic (negatively charged); polar; hydrophobic	Classify amino acids according to the R group present. Names and structures of individual amino acids are not required.	Determine the isoelectric point of a protein and explain the result using understanding of protein structure.
The wide range of functions carried out by proteins results from the diversity of R groups		Carry out molecular modelling, for example computer-aided drug design.
The primary structure is the sequence in which the amino acids are synthesised into the polypeptide		Carry out primary structure comparisons of enzymes from different evolutionary backgrounds, for example alcohol dehydrogenase from different organisms.
Hydrogen bonding along the backbone of the protein strand results in regions of secondary structure — alpha helices, parallel or anti-parallel beta-pleated sheets, or turns		

Cells and protein		
Key area	**Depth of knowledge required**	**Suggested learning activities**
The polypeptide folds into a tertiary structure		
This conformation is stabilised by interactions between R groups: hydrophobic interactions; ionic bonds; London dispersion forces; hydrogen bonds; disulfide bridges	Disulfide bridges are covalent bonds between R groups containing sulfur.	
Quaternary structure exists in proteins with two or more connected polypeptide subunits	Quaternary structure describes the spatial arrangement of the subunits.	
A prosthetic group is a non-protein unit tightly bound to a protein and necessary for its function	The ability of haemoglobin to bind oxygen is dependent upon the non-protein haem group.	Analyse haemoglobin dissociation curves.
Interactions of the R groups can be influenced by temperature and pH	Increasing temperature disrupts the interactions that hold the protein in shape; the protein begins to unfold, eventually becoming denatured. The charges on acidic and basic R groups are affected by pH. As pH increases or decreases from the optimum, the normal ionic interactions between charged groups are lost, which gradually changes the conformation of the protein until it becomes denatured.	

Cells and protein		
Key area	**Depth of knowledge required**	**Suggested learning activities**
(ii) Ligand binding changes the conformation of a protein A ligand is a substance that can bind to a protein R groups not involved in protein folding can allow binding to ligands Binding sites will have complementary shape and chemistry to the ligand As a ligand binds to a protein-binding site the conformation of the protein changes This change in conformation causes a functional change in the protein		
Allosteric interactions occur between spatially distinct sites	The binding of a substrate molecule to one active site of an allosteric enzyme increases the affinity of the other active sites for binding of subsequent substrate molecules. This is of biological importance because the activity of allosteric enzymes can vary greatly with small changes in substrate concentration.	
Many allosteric proteins consist of multiple subunits (have quaternary structure)		

Cells and protein		
Key area	**Depth of knowledge required**	**Suggested learning activities**
Allosteric proteins with multiple subunits show co-operativity in binding, in which changes in binding at one subunit alter the affinity of the remaining subunits		
Allosteric enzymes contain a second type of site, called an allosteric site		Investigate the action of aspartate transcarbamoylase as an example of an allosteric enzyme of biological importance.
Modulators regulate the activity of the enzyme when they bind to the allosteric site		
Following binding of a modulator, the conformation of the enzyme changes and this alters the affinity of the active site for the substrate	Positive modulators increase the enzyme’s affinity for the substrate, whereas negative modulators reduce the enzyme’s affinity.	
The binding and release of oxygen in haemoglobin shows co-operativity	Changes in binding of oxygen at one subunit alter the affinity of the remaining subunits for oxygen.	
The influence and physiological importance of temperature and pH on the binding of oxygen	A decrease in pH or an increase in temperature lowers the affinity of haemoglobin for oxygen, so the binding of oxygen is reduced. Reduced pH and increased temperature in actively respiring tissue will reduce the binding of oxygen to haemoglobin promoting increased oxygen delivery to tissue.	

Cells and protein		
Key area	**Depth of knowledge required**	**Suggested learning activities**
(iii) Reversible binding of phosphate and the control of conformation The addition or removal of phosphate can cause reversible conformational change in proteins This is a common form of post-translational modification Protein kinases catalyse the transfer of a phosphate group to other proteins The terminal phosphate of ATP is transferred to specific R groups Protein phosphatases catalyse the reverse reaction Phosphorylation brings about conformational changes, which can affect a protein's activity The activity of many cellular proteins, such as enzymes and receptors, is regulated in this way	Effects of DPG are not required.	Research examples of proteins regulated by phosphorylation, such as glycogen phosphorylase.

Cells and protein		
Key area	**Depth of knowledge required**	**Suggested learning activities**
Some proteins are activated by phosphorylation while others are inhibited	Adding a phosphate group adds negative charges. Ionic interactions in the unphosphorylated protein can be disrupted and new ones created.	
3 Membrane proteins (a) Movement of molecules across membranes Knowledge of the fluid mosaic model of cell membranes Regions of hydrophobic R groups allow strong hydrophobic interactions that hold integral membrane proteins within the phospholipid bilayer Some integral membrane proteins are transmembrane proteins Peripheral membrane proteins have hydrophilic R groups on their surface and are bound to the surface of membranes, mainly by ionic and hydrogen bond interactions Many peripheral membrane proteins interact with the surfaces of integral membrane proteins	Integral membrane proteins interact extensively with the hydrophobic region of membrane phospholipids.	Research the history of evidence-based models of membrane structure as an example of refinement of scientific ideas.

Cells and protein		
Key area	**Depth of knowledge required**	**Suggested learning activities**
The phospholipid bilayer is a barrier to ions and most uncharged polar molecules		
Some small molecules, such as oxygen and carbon dioxide, pass through the bilayer by simple diffusion		
Facilitated diffusion is the passive transport of substances across the membrane through specific transmembrane proteins		
To perform specialised functions, different cell types have different channel and transporter proteins		
Most channel proteins in animal and plant cells are highly selective	Channels are multi-subunit proteins with the subunits arranged to form water-filled pores that extend across the membrane.	
Some channel proteins are gated and change conformation to allow or prevent diffusion		Research CFTR mutation and cystic fibrosis.
Ligand-gated channels are controlled by the binding of signal molecules, and voltage-gated channels are controlled by changes in ion concentration		

Cells and protein		
Key area	**Depth of knowledge required**	**Suggested learning activities**
Transporter proteins bind to the specific substance to be transported and undergo a conformational change to transfer the solute across the membrane Active transport uses pump proteins that transfer substances across the membrane against their concentration gradient A source of metabolic energy is required for active transport Some active transport proteins hydrolyse ATP directly to provide the energy for the conformational change required to move substances across the membrane	Transporters alternate between two conformations so that the binding site for a solute is sequentially exposed on one side of the bilayer, then the other. Pumps that mediate active transport are transporter proteins coupled to an energy source. ATPases hydrolyse ATP.	Research glucose transporters in mammalian cells.
(b)Ion transport pumps and generation of ion gradients For a solute carrying a net charge, the concentration gradient and the electrical potential difference combine to form the electrochemical gradient that determines the transport of the solute Ion pumps, such as the sodium-potassium pump, use energy from the hydrolysis of ATP to establish and maintain ion gradients	A membrane potential (an electrical potential difference) is created when there is a difference in electrical charge on the two sides of the membrane.	

Cells and protein		
Key area	**Depth of knowledge required**	**Suggested learning activities**
The sodium-potassium pump transports ions against a steep concentration gradient using energy directly from ATP hydrolysis It actively transports sodium ions out of the cell and potassium ions into the cell		
The pump has high affinity for sodium ions inside the cell; binding occurs; phosphorylation by ATP; conformation changes; affinity for sodium ions decreases; sodium ions released outside of the cell; potassium ions bind outside the cell; dephosphorylation; conformation changes; potassium ions taken into cell; affinity returns to start	For each ATP hydrolysed, three sodium ions are transported out of the cell and two potassium ions are transported into the cell. This establishes both concentration gradients and an electrical gradient.	
The sodium-potassium pump is found in most animal cells, accounting for a high proportion of the basal metabolic rate in many organisms		
In the small intestine, the sodium gradient created by the sodium-potassium pump drives the active transport of glucose	In intestinal epithelial cells the sodium-potassium pump generates a sodium ion gradient across the plasma membrane.	
The glucose transporter responsible for this glucose symport transports sodium ions and	Sodium ions enter the cell down their concentration gradient; the simultaneous	

Cells and protein		
Key area	**Depth of knowledge required**	**Suggested learning activities**
glucose at the same time and in the same direction	transport of glucose pumps glucose into the cell against its concentration gradient. Details of the apical and basal membranes are not required.	
4 Communication and signalling (a) Co-ordination Multicellular organisms signal between cells using extracellular signalling molecules Receptor molecules of target cells are proteins with a binding site for a specific signal molecule Binding changes the conformation of the receptor, which initiates a response within the cell	Steroid hormones, peptide hormones, and neurotransmitters are examples of extracellular signalling molecules.	
Different cell types produce specific signals that can only be detected and responded to by cells with the specific receptor In a multicellular organism, different cell types may show a tissue-specific response to the same signal	Signalling molecules may have different effects on different target cell types due to differences in the intracellular signalling molecules and pathways that are involved.	Research examples of degenerative diseases.

Cells and protein		
Key area	**Depth of knowledge required**	**Suggested learning activities**
(b) Hydrophobic signals and control of transcription Hydrophobic signalling molecules can diffuse directly through the phospholipid bilayers of membranes, and so bind to intracellular receptors		
The receptors for hydrophobic signalling molecules are transcription factors	Transcription factors are proteins that when bound to DNA can either stimulate or inhibit initiation of transcription.	
The steroid hormones oestrogen and testosterone are examples of hydrophobic signalling molecules		
Steroid hormones bind to specific receptors in the cytosol or the nucleus		
The hormone-receptor complex moves to the nucleus where it binds to specific sites on DNA and affects gene expression	The hormone-receptor complex binds to specific DNA sequences called hormone response elements (HREs). Binding at these sites influences the rate of transcription, with each steroid hormone affecting the gene expression of many different genes.	Research sex hormone disorders.

Cells and protein		
Key area	**Depth of knowledge required**	**Suggested learning activities**
(c) Hydrophilic signals and transduction Hydrophilic signalling molecules bind to transmembrane receptors and do not enter the cytosol	Peptide hormones and neurotransmitters are examples of hydrophilic extracellular signalling molecules.	
Transmembrane receptors change conformation when the ligand binds to the extracellular face; the signal molecule does not enter the cell, but the signal is transduced across the plasma membrane		
Transmembrane receptors act as signal transducers by converting the extracellular ligand-binding event into intracellular signals, which alters the behaviour of the cell		
Transduced hydrophilic signals often involve G-proteins or cascades of phosphorylation by kinase enzymes	G-proteins relay signals from activated receptors (receptors that have bound a signalling molecule) to target proteins such as enzymes and ion channels. Details of G-proteins subunits are not required.	
Phosphorylation cascades allow more than one intracellular signalling pathway to be activated	Phosphorylation cascades involve a series of events with one kinase activating the next in the sequence and so on. Phosphorylation cascades can result in the phosphorylation of many proteins as a result of the original signalling event.	

Cells and protein		
Key area	**Depth of knowledge required**	**Suggested learning activities**
Binding of the peptide hormone insulin to its receptor results in an intracellular signalling cascade that triggers recruitment of GLUT4 glucose transporter proteins to the cell membrane of fat and muscle cells Diabetes mellitus can be caused by failure to produce insulin (type 1) or loss of receptor function (type 2) Type 2 is generally associated with obesity Exercise also triggers recruitment of GLUT4, so can improve uptake of glucose to fat and muscle cells in subjects with type 2	Binding of insulin to its receptor causes a conformational change that triggers phosphorylation of the receptor. This starts a phosphorylation cascade inside the cell, which eventually leads to GLUT4-containing vesicles being transported to the cell membrane.	Research data from glucose tolerance tests. Research health effects associated with type 2 diabetes and the success rate of treatment programmes. Write a review of data from studies of health and wellbeing, considering the importance of publishing negative results.
(d) Nerve impulse transmission (i) Generation of a nerve impulse Resting membrane potential is a state where there is no net flow of ions across the membrane The transmission of a nerve impulse requires changes in the membrane potential of the neuron’s plasma membrane		

Cells and protein		
Key area	**Depth of knowledge required**	**Suggested learning activities**
An action potential is a wave of electrical excitation along a neuron's plasma membrane		
Neurotransmitters initiate a response by binding to their receptors at a synapse	Neurotransmitter receptors are ligand-gated ion channels.	
Depolarisation of the plasma membrane as a result of the entry of positive ions triggers the opening of voltage-gated sodium channels, and further depolarisation occurs	Depolarisation is a change in the membrane potential to a less negative value inside.	Carry out *Daphnia* heart rate investigation. The action of chemical agonists can be assessed. This could provide an opportunity to focus on aspects of experimental design associated with pilot studies, measurement accuracy, sample size and replication.
Inactivation of the sodium channels and the opening of potassium channels restores the resting membrane potential	Binding of a neurotransmitter triggers the opening of ligand-gated ion channels at a synapse. Ion movement occurs and there is depolarisation of the plasma membrane. If sufficient ion movement occurs, and the membrane is depolarised beyond a threshold value, the opening of voltage-gated sodium channels is triggered and sodium ions enter the cell down their electrochemical gradient. This leads to a rapid and large change in the membrane potential. A short time after opening, the sodium channels become inactivated. Voltage-gated potassium channels then open to allow potassium ions to move out of the cell to restore the resting membrane potential.	

Cells and protein		
Key area	**Depth of knowledge required**	**Suggested learning activities**
Depolarisation of a patch of membrane causes neighbouring regions of membrane to depolarise and go through the same cycle, as adjacent voltage-gated sodium channels are opened When the action potential reaches the end of the neuron it causes vesicles containing neurotransmitter to fuse with the membrane — this releases neurotransmitter, which stimulates a response in a connecting cell Restoration of the resting membrane potential allows the inactive voltage-gated sodium channels to return to a conformation that allows them to open again in response to depolarisation of the membrane		
Ion concentration gradients are re-established by the sodium-potassium pump, which actively transports excess ions in and out of the cell	Following repolarisation the sodium and potassium ion concentration gradients are reduced. The sodium-potassium pump restores the sodium and potassium ions back to resting potential levels.	
(ii) Initiation of a nerve impulse in response to an environmental stimulus: the vertebrate eye		Investigate vision experimentally.

Cells and protein		
Key area	**Depth of knowledge required**	**Suggested learning activities**
The retina is the area within the eye that detects light and contains two types of photoreceptor cells: rods and cones	Rods function in dim light but do not allow colour perception. Cones are responsible for colour vision and only function in bright light.	Carry out a fish eye dissection.
In animals the light-sensitive molecule retinal is combined with a membrane protein, opsin, to form the photoreceptors of the eye		
In rod cells the retinal-opsin complex is called rhodopsin		
Retinal absorbs a photon of light and rhodopsin changes conformation to photoexcited rhodopsin		
A cascade of proteins amplifies the signal		
Photoexcited rhodopsin activates a G-protein, called transducin, which activates the enzyme phosphodiesterase (PDE)	A single photoexcited rhodopsin activates hundreds of molecules of G-protein. Each activated G-protein activates one molecule of PDE.	
PDE catalyses the hydrolysis of a molecule called cyclic GMP (cGMP)	Each active PDE molecule breaks down thousands of cGMP molecules per second. The reduction in cGMP concentration as a result of its hydrolysis affects the function of ion channels in the membrane of rod cells.	

Cells and protein		
Key area	**Depth of knowledge required**	**Suggested learning activities**
This results in the closure of ion channels in the membrane of the rod cells, which triggers nerve impulses in neurons in the retina A very high degree of amplification results in rod cells being able to respond to low intensities of light In cone cells, different forms of opsin combine with retinal to give different photoreceptor proteins, each with a maximal sensitivity to specific wavelengths: red, green, blue or UV		
5 Protein control of cell division (a) The cytoskeleton and cell division The cytoskeleton gives mechanical support and shape to cells It consists of different protein structures including microtubules, which are found in all eukaryotic cells	Microtubules are hollow cylinders composed of the protein tubulin. They radiate from the microtubule organising centre (MTOC) or centrosome. Knowledge of other cytoskeleton proteins is not required.	Research and consider the effects of colchicine and paclitaxel on the cytoskeleton.

Cells and protein		
Key area	**Depth of knowledge required**	**Suggested learning activities**
Microtubules control the movement of membrane-bound organelles and chromosomes Cell division requires remodelling of the cytoskeleton Formation and breakdown of microtubules involves polymerisation and depolymerisation of tubulin Microtubules form the spindle fibres that are active during cell division		
(b)The cell cycle The cell cycle consists of interphase and mitotic (M) phase Mitotic phase involves mitosis and cytokinesis	Interphase involves growth and DNA synthesis including G1, a growth phase; S phase, during which the DNA is replicated; and G2, a further growth phase. In mitosis the chromosomal material is separated by the spindle microtubules. This is followed by cytokinesis, in which the cytoplasm is separated into two daughter cells.	Stain actively dividing plant meristem tissue and calculate a mitotic index.

Cells and protein		
Key area	**Depth of knowledge required**	**Suggested learning activities**
Mitosis consists of prophase, metaphase, anaphase and telophase	Prophase — DNA condenses into chromosomes each consisting of two sister chromatids. Nuclear membrane breaks down; spindle microtubules extend from the MTOC by polymerisation and attach to chromosomes via their kinetochores in the centromere region. Metaphase — chromosomes are aligned at the metaphase plate (equator of the spindle). Anaphase — as spindle microtubules shorten by depolymerisation, sister chromatids are separated, and the chromosomes are pulled to opposite poles. Telophase — the chromosomes decondense and nuclear membranes are formed around them.	
(c) Control of the cell cycle Progression through the cell cycle is controlled by checkpoints	Checkpoints are mechanisms within the cell that assess the condition of the cell during the cell cycle and halt progression to the next phase until certain requirements are met.	Use an online simulation of mitotic checkpoint control.

Cells and protein		
Key area	**Depth of knowledge required**	**Suggested learning activities**
Cyclin proteins that accumulate during cell growth are involved in regulating the cell cycle	Cyclins combine with and activate cyclin-dependent kinases (CDKs). Active cyclin-CDK complexes phosphorylate proteins that regulate progression through the cycle. If sufficient phosphorylation is reached, progression occurs.	Investigate cell cycle mutation in yeast *Schizosaccharomyces pombe*.
At the G1 checkpoint, retinoblastoma protein (Rb) acts as a tumour suppressor by inhibiting the transcription of genes that code for proteins needed for DNA replication		
Phosphorylation by G1 cyclin-CDK inhibits the retinoblastoma protein (Rb)	This allows transcription of the genes that code for proteins needed for DNA replication. Cells progress from G1 to S phase.	
At the G2 checkpoint, the success of DNA replication and any damage to DNA is assessed		
DNA damage triggers the activation of several proteins including p53 that can stimulate DNA repair, arrest the cell cycle or cause cell death		

Cells and protein		
Key area	**Depth of knowledge required**	**Suggested learning activities**
A metaphase checkpoint controls progression from metaphase to anaphase An uncontrolled reduction in the rate of the cell cycle may result in degenerative disease An uncontrolled increase in the rate of the cell cycle may result in tumour formation A proto-oncogene is a normal gene, usually involved in the control of cell growth or division, which can mutate to form a tumour-promoting oncogene	At the metaphase checkpoint, progression is halted until the chromosomes are aligned correctly on the metaphase plate and attached to the spindle microtubules.	Research the role of cell cycle regulators in degenerative diseases such as Alzheimer's and Parkinson's. Research the types of mutations associated with cancer, for example the influence of environmental factors and viruses, the conversion of proto-oncogenes into oncogenes, and mutations in tumour-suppressing genes.
(d) Control of programmed cell death (apoptosis) Apoptosis is triggered by cell death signals that can be external or internal External death signal molecules bind to a surface receptor protein and trigger a protein cascade within the cytoplasm	The production of death signal molecules from lymphocytes is an example of an external death signal. DNA damage is an example of an internal death signal.	

Cells and protein		
Key area	**Depth of knowledge required**	**Suggested learning activities**
An internal death signal resulting from DNA damage causes activation of p53 tumour-suppressor protein Both types of death signal result in the activation of caspases (types of protease enzyme) that cause the destruction of the cell Apoptosis is essential during development of an organism to remove cells no longer required as development progresses or during metamorphosis Cells may initiate apoptosis in the absence of growth factors		Research and consider apoptosis in development of tetrapod limbs. Research the challenges in overcoming apoptosis in maintaining animal cell culture lines.

Organisms and evolution		
Key area	**Depth of knowledge required**	**Suggested learning activities**
1 Field techniques for biologists (a) Health and safety Aspects of fieldwork can present a hazard Hazard, risk, and control of risk by risk assessment	Hazards in fieldwork include adverse weather conditions, difficult terrain, problems associated with isolation, and contact with harmful organisms. Risk is the likelihood of harm arising from exposure to a hazard. Risk assessment involves identifying control measures to minimise risk. Control measures include appropriate equipment, clothing, footwear, and means of communication.	Discuss standard rules for fieldwork safety.
(b)Sampling of wild organisms Sampling should be carried out in a manner that minimises impact on wild species and habitats Consideration must be given to rare and vulnerable species and habitats that are protected by legislation		Participate in fieldwork, using a variety of techniques. Research protected species in Scotland.

Organisms and evolution		
Key area	**Depth of knowledge required**	**Suggested learning activities**
The chosen technique, point count, transect or remote detection must be appropriate to the species being sampled Quadrats, of suitable size and shape, or transects are used for plants and other sessile or slow-moving organisms Capture techniques, such as traps and nets, are used for mobile species Elusive species can be sampled directly using camera traps or an indirect method, such as scat sampling	A point count involves the observer recording all individuals seen from a fixed point count location. This can be compared to other point count locations or with data from the same location gathered at other times.	
(c) Identification and taxonomy Identification of an organism in a sample can be made using classification guides, biological keys, or analysis of DNA or protein Organisms can be classified by both taxonomy and phylogenetics		In the context of fieldwork, sample organisms from a variety of habitats and attempt to classify and catalogue them using keys, guides, and other materials.

Organisms and evolution		
Key area	**Depth of knowledge required**	**Suggested learning activities**
Taxonomy involves the identification and naming of organisms and their classification into groups based on shared characteristics	Classic taxonomy classification is based on morphology.	Research the taxonomic groups. Visit a botanic garden to learn more about the major divisions of plants. Visit a zoological park to learn more about the animal phyla.
Phylogenetics is the study of the evolutionary history and relationships among individuals or groups of organisms Phylogenetics is changing the traditional classification of many organisms	Phylogenetics uses heritable traits such as morphology, DNA sequences, and protein structure to make inferences about an organism's evolutionary history and create a phylogeny (or phylogenetic tree) — a diagrammatic hypothesis of its relationships to other organisms. Genetic evidence can reveal relatedness obscured by divergent or convergent evolution.	Read excerpts from Bryan Sykes's book, *The Seven Daughters of Eve*. [Sykes B. (2001), *The Seven Daughters of Eve*, New York: W. W. Norton & Company] Research the evolution of the pentadactyl limb.
Familiarity with taxonomic groupings allows predictions and inferences to be made about the biology of an organism from better-known (model) organisms	Nematodes, arthropods and chordates are examples of taxonomic groups.	

Organisms and evolution		
Key area	**Depth of knowledge required**	**Suggested learning activities**
Model organisms are those that are either easily studied or have been well studied Information obtained from them can be applied to other species that are more difficult to study directly	Model organisms, such as the bacterium *E. coli*; the flowering plant *Arabidopsis thaliana*; the nematode *C. elegans*; the arthropod *Drosophila melanogaster* (a fruit fly); mice, rats, and zebrafish, which are all chordates, have been very important in the advancement of modern biology.	
(d)Monitoring populations Presence, absence or abundance of indicator species can give information of environmental qualities, such as presence of a pollutant Susceptible and favoured species can be used to monitor an ecosystem	Absence or reduced population indicates a species is susceptible to some factor in the environment. Abundance or increased population indicates it is favoured by the conditions.	Identify relevant indicator species to classify a habitat, using the British National Vegetation Classification.

Organisms and evolution		
Key area	**Depth of knowledge required**	**Suggested learning activities**
Procedure for the mark and recapture technique as a method for estimating population size using the formula $N=\frac{MC}{R}$ Methods of marking animals such as: banding, tagging, surgical implantation, painting and hair clipping The method of marking and subsequent observation must minimise the impact on the study species	A sample of the population is captured and marked (M) and released. After an interval of time, a second sample is captured (C). If some of the individuals in this second sample are recaptured (R), then the total population $N=\frac{MC}{R}$ This method assumes that all individuals have an equal chance of capture, that there is no immigration or emigration, and that individuals that are marked and released can mix fully and randomly with the total population.	Carry out a mark and recapture experiment using a wild species. Carry out a mark and recapture simulation in the laboratory.
(e) Measuring and recording animal behaviour Some of the measurements used to quantify animal behaviour are latency, frequency and duration	Latency is the time between the stimulus occurring and the response behaviour.	

Organisms and evolution		
Key area	**Depth of knowledge required**	**Suggested learning activities**
	Frequency is the number of times a behaviour occurs within the observation period. Duration is the length of time each behaviour occurs during the observation period.	
An ethogram of the behaviours shown by a species in a wild context allows the construction of time budgets	An ethogram lists species-specific behaviours to be observed and recorded in the study. Recording the duration of each of the behaviours in the ethogram, together with the total time of observation, allows the proportion of time spent on each behaviour to be calculated in the time budget.	Use an ethogram and time sampling to compare the behaviour of different individuals of a species.
The importance of avoiding anthropomorphism when analysing behaviour	Anthropomorphism can lead to invalid conclusions.	
2 Evolution (a) Drift and selection Evolution is the change over time in the proportion of individuals in a population differing in one or more inherited traits During evolution, changes in allele frequency occur through the non-random processes of natural selection and sexual selection, and the random process of genetic drift		

Organisms and evolution		
Key area	**Depth of knowledge required**	**Suggested learning activities**
Natural selection acts on genetic variation in populations	Variation in traits arises as a result of mutation. Mutation is the original source of new sequences of DNA. These new sequences can be novel alleles. Most mutations are harmful or neutral, but in rare cases they may be beneficial to the fitness of an individual.	
Populations produce more offspring than the environment can support		
Individuals with variations that are better suited to their environment tend to survive longer and produce more offspring, breeding to pass on those alleles that conferred an advantage to the next generation	Selection results in the non-random increase in the frequency of advantageous alleles and the non-random decrease in the frequency of deleterious alleles.	
Sexual selection is the non-random process involving the selection of alleles that increase the individual's chances of mating and producing offspring		
Sexual selection may lead to sexual dimorphism		

Organisms and evolution		
Key area	**Depth of knowledge required**	**Suggested learning activities**
Sexual selection can be due to male-male rivalry and female choice	Male-male rivalry: large size or weaponry increases access to females through conflict. Female choice involves females assessing the fitness of males.	
Genetic drift occurs when chance events cause unpredictable fluctuations in allele frequencies from one generation to the next		
Genetic drift is more important in small populations, as alleles are more likely to be lost from the gene pool		
The importance of bottleneck and founder effects on genetic drift	Population bottlenecks occur when a population size is reduced for at least one generation. Founder effects occur through the isolation of a few members of a population from a larger population. The gene pool of the new population is not representative of that in the original gene pool.	
A gene pool is altered by genetic drift because certain alleles may be under-represented or over-represented and allele frequencies change		

Organisms and evolution		
Key area	**Depth of knowledge required**	**Suggested learning activities**
Where selection pressures are strong, the rate of evolution can be rapid	Selection pressures are the environmental factors that influence which individuals in a population pass on their alleles. They can be biotic: competition, predation, disease, parasitism; or abiotic: changes in temperature, light, humidity, pH, salinity.	Study cladograms of MRSA and primate evolution to compare the effect of generation time on rates of evolution.
The Hardy-Weinberg (HW) principle states that, in the absence of evolutionary influences, allele and genotype frequencies in a population will remain constant over the generations	The conditions for maintaining the HW equilibrium are: no natural selection, random mating, no mutation, large population size and no gene flow (through migration, in or out).	
The HW principle can be used to determine whether a change in allele frequency is occurring in a population over time Changes suggest evolution is occurring	Use the HW principle to calculate allele, genotype and phenotype frequencies in populations. $p^2 + 2pq + q^2 = 1$ p = frequency of dominant allele q = frequency of recessive allele p^2 = frequency of homozygous dominant genotype $2pq$ = frequency of heterozygous genotype q^2 = frequency of homozygous recessive genotype	Research the application of the HW principle in medical research.

Organisms and evolution		
Key area	**Depth of knowledge required**	**Suggested learning activities**
(b) Fitness Fitness is an indication of an individual's ability to be successful at surviving and reproducing	Fitness is a measure of the tendency of some organisms to produce more surviving offspring than competing members of the same species.	
It refers to the contribution made to the gene pool of the next generation by individual genotypes		
Fitness can be defined in absolute or relative terms		
Absolute fitness is the ratio between the frequency of individuals of a particular genotype after selection, to those before selection	$\dfrac{\text{frequency of a particular genotype after selection}}{\text{frequency of a particular genotype before selection}}$ If the absolute fitness is 1, then the frequency of that genotype is stable. A value greater than 1 conveys an increase in the genotype and a value less than 1 conveys a decrease.	
Relative fitness is the ratio of the number of surviving offspring per individual of a particular genotype to the number of surviving offspring per individual of the most successful genotype	$\dfrac{\text{number of surviving offspring per individual of a particular genotype}}{\text{number of surviving offspring per individual of the most successful genotype}}$	

Organisms and evolution		
Key area	**Depth of knowledge required**	**Suggested learning activities**
(c) Co-evolution Co-evolution is the process by which two or more species evolve in response to selection pressures imposed by each other A change in the traits of one species acts as a selection pressure on the other species		
Co-evolution is frequently seen in pairs of species that have symbiotic interactions The impacts of these relationships can be positive (+), negative (-) or neutral (0) for the individuals involved	Symbiosis: co-evolved intimate relationships between members of two different species.	Research examples of co-evolved symbiotic relationships.
Mutualism, commensalism, and parasitism are types of symbiotic interactions	Mutualism: both organisms in the interaction are interdependent on each other for resources or other services. As both organisms gain from the relationship, the interaction is (+/+). Commensalism: only one of the organisms benefits (+/0). Parasitism: the parasite benefits in terms of energy or nutrients and the host is harmed as the result of the loss of these resources (+/-).	

Organisms and evolution		
Key area	**Depth of knowledge required**	**Suggested learning activities**
The Red Queen hypothesis states that, in a co-evolutionary relationship, change in the traits of one species can act as a selection pressure on the other species This means that species in these relationships must adapt to avoid extinction		Read excerpts from Matt Ridley's book, *The Red Queen: Sex and the Evolution of Human Nature*. [Ridley M. (2003), *The Red Queen: Sex and the Evolution of Human Nature*, London: Harper Perennial]
3 Variation and sexual reproduction (a) Costs and benefits of sexual and asexual reproduction Costs of sexual reproduction: males unable to produce offspring; only half of each parent's genome passed onto offspring, disrupting successful parental genomes Benefits outweigh costs due to an increase in genetic variation in the population		Research how the evolutionary importance of sexual reproduction influences experimental design in the life sciences. The natural variation generated means that biologists have to take care when sampling a population and analysing data to make sure that they can distinguish this 'noise' from any experimental result or 'signal'. Investigate the paradox of the existence of males.

Organisms and evolution		
Key area	**Depth of knowledge required**	**Suggested learning activities**
Genetic variation provides the raw material required for adaptation, giving sexually reproducing organisms a better chance of survival under changing selection pressures		
The Red Queen hypothesis to explain the persistence of sexual reproduction		
Co-evolutionary interactions between parasites and hosts may select for sexually reproducing hosts	Hosts better able to resist and tolerate parasitism have greater fitness. Parasites better able to feed, reproduce and find new hosts have greater fitness.	
If hosts reproduce sexually, the genetic variability in their offspring reduces the chances that all will be susceptible to infection by parasites		
Asexual reproduction can be a successful reproductive strategy as whole genomes are passed on from parent to offspring	In asexual reproduction, just one parent can produce daughter cells and establish a colony of virtually unlimited size over time.	
Maintaining the genome of the parent is an advantage particularly in very narrow, stable niches or when re-colonising disturbed habitats		

Organisms and evolution		
Key area	**Depth of knowledge required**	**Suggested learning activities**
Vegetative cloning in plants and parthenogenesis in lower plants and animals that lack fertilisation are examples of asexual reproduction in eukaryotes Offspring can be reproduced more often and in larger numbers with asexual reproduction	Parthenogenesis is reproduction from a female gamete without fertilisation.	
Parthenogenesis is more common in cooler climates, which are disadvantageous to parasites, or regions of low parasite density or diversity		Examine reproduction in a parthenogenic organism, such as the laboratory stick insect *Carausius morosus* (in which offspring are female), and compare with the Komodo dragon (in which offspring are male).
Asexually reproducing populations are not able to adapt easily to changes in their environment, but mutations can occur that provide some degree of variation and enable some natural selection and evolution to occur		
Organisms that reproduce principally by asexual reproduction also often have mechanisms for horizontal gene transfer between individuals to increase variation, for example the plasmids of bacteria and yeasts	Prokaryotes can exchange genetic material horizontally, resulting in faster evolutionary change than in organisms that only use vertical transfer. Mechanisms of horizontal gene transfer are not required.	

Organisms and evolution		
Key area	**Depth of knowledge required**	**Suggested learning activities**
(b)Meiosis Meiosis is the division of the nucleus that results in the formation of haploid gametes from a diploid gametocyte In diploid cells, chromosomes typically appear as homologous pairs Meiosis I The chromosomes, which have replicated prior to meiosis I, each consist of two genetically identical chromatids attached at the centromere The chromosomes condense and the homologous chromosomes pair up Chiasmata form at points of contact between the non-sister chromatids of a homologous pair and sections of DNA are exchanged	Names of stages are not required. Homologous chromosomes are chromosomes of the same size, same centromere position and with the same sequence of genes at the same loci. Linked genes are those on the same chromosome. Crossing over can result in new combinations of the alleles of these genes.	Use microscopy to examine gamete formation or gametes in plants or invertebrates.

Organisms and evolution		
Key area	**Depth of knowledge required**	**Suggested learning activities**
This crossing over of DNA is random and produces genetically different recombinant chromosomes Spindle fibres attach to the homologous pairs and line them up at the equator of the spindle		
The orientation of the pairs of homologous chromosomes at the equator is random	Each pair of homologous chromosomes is positioned independently of the other pairs, irrespective of their maternal and paternal origin. This is known as independent assortment.	Breed model organisms in the laboratory (for example *Drosophila* or rapid-cycling *Brassica*) to demonstrate independent assortment or, if possible, recombination.
The chromosomes of each homologous pair are separated and move towards opposite poles Cytokinesis occurs and two daughter cells form		
Meiosis II Each of the two cells produced in meiosis I undergoes a further division during which the sister chromatids of each chromosome are separated	A total of four haploid cells are produced.	

Organisms and evolution		
Key area	**Depth of knowledge required**	**Suggested learning activities**
(c) Sex determination		Examine data on sex determination in a variety of organisms.
The sex of birds, mammals and some insects is determined by the presence of sex chromosomes		Use *Drosophila* to investigate sex-linked inheritance patterns.
In most mammals the SRY gene on the Y chromosome determines development of male characteristics		Examine data on inheritance patterns of tortoiseshell cats.
Heterogametic (XY) males lack most of the corresponding homologous alleles on the shorter (Y) chromosome		Research X-linked agammaglobulinemia and colour vision defect.
This can result in sex-linked patterns of inheritance as seen with carrier females (X^BX^b) and affected males (X^bY)		
In homogametic females (XX) one of the two X chromosomes present in each cell is randomly inactivated at an early stage of development	X chromosome inactivation is a process by which most of one X chromosome is inactivated.	
X chromosome inactivation prevents a double dose of gene products, which could be harmful to cells		

Organisms and evolution		
Key area	**Depth of knowledge required**	**Suggested learning activities**
Carriers are less likely to be affected by any deleterious mutations on these X chromosomes		
As the X chromosome inactivated in each cell is random, half of the cells in any tissue will have a working copy of the gene in question		
Hermaphrodites are species that have functioning male and female reproductive organs in each individual		Compare the flowers of hermaphroditic and unisexual plants.
They produce both male and female gametes and usually have a partner with which to exchange gametes		
The benefit to the individual organism is that if the chance of encountering a partner is an uncommon event, there is no requirement for that partner to be of the opposite sex		
For other species, environmental rather than genetic factors determine sex and sex ratio	Environmental sex determination in reptiles is controlled by environmental temperature of egg incubation.	
Sex can change within individuals of some species as a result of size, competition, or parasitic infection		

Organisms and evolution		
Key area	**Depth of knowledge required**	**Suggested learning activities**
In some species the sex ratio of offspring can be adjusted in response to resource availability		
4 Sex and behaviour (a) Parental investment Comparison of sperm and egg production in relation to number and energy store Greater investment by females Parental investment is costly but increases the probability of production and survival of young Classification of r-selected (r-strategists) and K-selected (K-strategists) organisms based on level of parental investment in offspring and number of offspring produced	 Female investment in the egg structure in non-mammals or in the uterus and during gestation in mammals. Characteristics of r-selected species: smaller; have a shorter generation time; mature more rapidly; reproduce earlier in their lifetime, often only once; produce a larger number of smaller offspring, each of which receives only a smaller energy input; limited parental care; most offspring will not reach adulthood.	

Organisms and evolution		
Key area	**Depth of knowledge required**	**Suggested learning activities**
	Characteristics of K-selected species: larger and live longer; mature more slowly; can reproduce many times in their lifetime; produce relatively few, larger offspring; high level of parental care; many offspring have a high probability of surviving to adulthood.	
r-selection tends to occur in unstable environments where the species has not reached its reproductive capacity, whereas K-selection tends to occur in stable environments		
Comparison of costs and benefits of external and internal fertilisation	External fertilisation ♦ benefits: very large numbers of offspring can be produced ♦ costs: many gametes predated or not fertilised; no or limited parental care; few offspring survive Internal fertilisation ♦ benefits: increased chance of successful fertilisation; fewer eggs needed; offspring can be retained internally for protection and/or development; higher offspring survival rate ♦ costs: a mate must be located, which requires energy expenditure; requires direct transfer of gametes from one partner to another	

Organisms and evolution		
Key area	**Depth of knowledge required**	**Suggested learning activities**
(b)Reproductive behaviours and mating systems in animals Mating systems are based on how many mates an individual has during one breeding season		
These range from polygamy (polygyny and polyandry) to monogamy	Monogamy: the mating of a pair of animals to the exclusion of all others. Polygamy: individuals of one sex have more than one mate. Polygyny: one male mates exclusively with a group of females. Polyandry: one female mates with a number of males in the same breeding season.	
Many animals have mate-selection courtship rituals		Courtship in the field: create an ethogram observing the ritualised courtship displays of water birds, such as grebes or ducks.
Successful courtship behaviour in birds and fish can be a result of species-specific sign stimuli and fixed action pattern responses		

Organisms and evolution		
Key area	**Depth of knowledge required**	**Suggested learning activities**
Sexual selection selects for characteristics that have little survival benefit for the individual, but increase their chances of mating		Courtship in the laboratory: observe stickleback or *Drosophila* courtship; investigate sexual selection in different *Drosophila* varieties.
Many species exhibit sexual dimorphism as a product of sexual selection	Females are generally inconspicuous; males usually have more conspicuous markings, structures and behaviours.	
Reversed sexual dimorphism occurs in some species		
Female choice involves females assessing honest signals of the fitness of males	Honest signals can indicate favourable alleles that increase the chances of survival of offspring (fitness) or a low parasite burden suggesting a healthy individual.	Research honest signalling in lekking species.
In lekking species, males gather to display at a lek, where female choice occurs	Some bird species exhibit lekking behaviour. Dominant males occupy the centre of the lek, with subordinates and juveniles at the fringes as ‘satellite’ males. During the display, female choice occurs.	
Success in male-male rivalry through conflict (real or ritualised), increases access to females for mating	Males will fight for dominance and access to females, often using elaborate ‘weapons’ such as antlers, tusks, horns.	

Organisms and evolution		
Key area	**Depth of knowledge required**	**Suggested learning activities**
5 Parasitism (a) (i) Niche An ecological niche is a multi-dimensional summary of tolerances and requirements of a species A species has a fundamental niche that it occupies in the absence of any interspecific competition A realised niche is occupied in response to interspecific competition As a result of interspecific competition, competitive exclusion can occur, where the niches of two species are so similar that one declines to local extinction Where the realised niches are sufficiently different, potential competitors can co-exist by resource partitioning (ii) The parasite niche Parasitism is a symbiotic interaction between a parasite and its host (+/-)		Research the niche of *C. difficile* and the use of faecal transplants.

Organisms and evolution		
Key area	**Depth of knowledge required**	**Suggested learning activities**
A parasite gains benefit in terms of nutrients at the expense of its host Unlike in a predator–prey relationship, the reproductive potential of the parasite is greater than that of the host Most parasites have a narrow (specialised) niche as they are very host-specific As the host provides so many of the parasite's needs, many parasites are degenerate, lacking structures and organs found in other organisms An ectoparasite lives on the surface of its host, whereas an endoparasite lives within the tissues of its host		Research the ecology, evolution, reproduction, and physiology of a selected human parasite.
(b) Parasitic life cycles Some parasites require only one host to complete their life cycle Many parasites require more than one host to complete their life cycle	The definitive host is the organism on or in which the parasite reaches sexual maturity. Intermediate hosts may also be required for the parasite to complete its life cycle.	

Organisms and evolution		
Key area	**Depth of knowledge required**	**Suggested learning activities**
A vector plays an active role in the transmission of the parasite and may also be a host		
The human disease malaria is caused by Plasmodium	An infected mosquito, acting as a vector, bites a human. Plasmodium enters the human bloodstream. Asexual reproduction occurs in the liver and then in the red blood cells. When the red blood cells burst gametocytes are released into the bloodstream. Another mosquito bites an infected human and the gametocytes enter the mosquito, maturing into male and female gametes, allowing sexual reproduction to now occur. The mosquito can then infect another human host.	
Schistosomes cause the human disease schistosomiasis	Schistosomes reproduce sexually in the human intestine. The fertilised eggs pass out via faeces into water where they develop into larvae. The larvae then infect water snails, where asexual reproduction occurs. This produces another type of motile larvae, which escape the snail and penetrate the skin of a human, entering the bloodstream.	

Organisms and evolution		
Key area	**Depth of knowledge required**	**Suggested learning activities**
Viruses are parasites that can only replicate inside a host cell Viruses contain genetic material in the form of DNA or RNA, packaged in a protective protein coat Some viruses are surrounded by a phospholipid membrane derived from host cell materials The outer surface of a virus contains antigens that a host cell may or may not be able to detect as foreign Viral life cycle stages: infection of host cell with genetic material, host cell enzymes replicate viral genome, transcription of viral genes and translation of viral proteins, assembly and release of new viral particles RNA retroviruses use the enzyme reverse transcriptase to form DNA, which is then inserted into the genome of the host cell Viral genes can then be expressed to form new viral particles	Specific examples of viral life cycles are not required.	Investigate the effects of a phage virus on bacterial growth.

Organisms and evolution		
Key area	**Depth of knowledge required**	**Suggested learning activities**
(c) Transmission and virulence Transmission is the spread of a parasite to a host Virulence is the harm caused to a host species by a parasite Ectoparasites are generally transmitted through direct contact Endoparasites of the body tissues are often transmitted by vectors or by consumption of intermediate hosts Factors that increase transmission rates: ♦ the overcrowding of hosts when they are at high density ♦ mechanisms, such as vectors and waterborne dispersal stages, that allow the parasite to spread even if infected hosts are incapacitated		Investigate the spread of a plant pathogen in a variety of planting densities and humidities.
Host behaviour is often exploited and modified by parasites to maximise transmission	Alteration of host foraging, movement, sexual behaviour, habitat choice or anti-predator behaviour.	

Organisms and evolution		
Key area	**Depth of knowledge required**	**Suggested learning activities**
The host behaviour becomes part of the extended phenotype of the parasite Parasites often suppress the host immune system and modify host size and reproductive rate in ways that benefit the parasite growth, reproduction or transmission		
(d)Defence against parasitic attack Immune response in mammals has both non-specific and specific aspects Non-specific defences Physical barriers, chemical secretions, inflammatory response, phagocytes, and natural killer cells destroying cells infected with viruses are examples of non-specific defences	Epithelial tissue blocks the entry of parasites; hydrolytic enzymes in mucus, saliva and tears destroy bacterial cell walls; low pH environments of the secretions of stomach, vagina and sweat glands denatures cellular proteins of pathogens. Injured cells release signalling molecules. This results in enhanced blood flow to the site, bringing antimicrobial proteins and phagocytes.	

Organisms and evolution		
Key area	**Depth of knowledge required**	**Suggested learning activities**
	Killing of parasites using powerful enzymes contained in lysosomes, by engulfing them and storing them inside a vacuole in the process of phagocytosis. Natural killer cells can identify and attach to cells infected with viruses, releasing chemicals that lead to cell death by inducing apoptosis.	
Specific cellular defences A range of white blood cells constantly circulate, monitoring the tissues If tissues become damaged or invaded, cells release cytokines that increase blood flow resulting in non-specific and specific white blood cells accumulating at the site of infection or tissue damage		
Mammals contain many different lymphocytes, each possessing a receptor on its surface, which can potentially recognise a parasite antigen	Specific lymphocyte names are not required.	

Organisms and evolution		
Key area	**Depth of knowledge required**	**Suggested learning activities**
Binding of an antigen to a lymphocyte's receptor selects that lymphocyte to then divide and produce a clonal population of this lymphocyte Some selected lymphocytes will produce antibodies, others can induce apoptosis in parasite-infected cells Antibodies possess regions where the amino acid sequence varies greatly between different antibodies This variable region gives the antibody its specificity for binding antigen When the antigen binds to this binding site the antigen-antibody complex formed can result in inactivation of the parasite, rendering it susceptible to a phagocyte, or can stimulate a response that results in cell lysis		
Memory lymphocyte cells are also formed	Initial antigen exposure produces memory lymphocyte cells specific for that antigen that can produce a secondary response when the same antigen enters the body in the future. When this occurs antibody production is	

Organisms and evolution		
Key area	**Depth of knowledge required**	**Suggested learning activities**
	enhanced in terms of speed of production, concentration in blood and duration.	
(e) Immune evasion Parasites have evolved ways of evading the immune system Endoparasites mimic host antigens to evade detection and modify host immune response to reduce their chances of destruction Antigenic variation in some parasites allows them to change between different antigens during the course of infection of a host It may also allow re-infection of the same host with the new variant Some viruses escape immune surveillance by integrating their genome into host genomes, existing in an inactive state known as latency The virus becomes active again when favourable conditions arise		Compare antigenic variation in trypanosomes with antigenic variation in the influenza virus.

Organisms and evolution		
Key area	**Depth of knowledge required**	**Suggested learning activities**
(f) Challenges in treatment and control		Research how attempts to disrupt the lifecycle of Plasmodium in the control of malaria have resulted in the loss of apex predators due to bio-magnification of the organochloride insecticide, DDT.
Epidemiology is the study of the outbreak and spread of infectious disease		
The herd immunity threshold is the density of resistant hosts in the population required to prevent an epidemic		
Vaccines contain antigens that will elicit an immune response		
The similarities between host and parasite metabolism makes it difficult to find drug compounds that only target the parasite		
Antigenic variation has to be reflected in the design of vaccines		
Some parasites are difficult to culture in the laboratory making it difficult to design vaccines		Research the problems associated with the development of successful vaccines for HIV and malaria.

Organisms and evolution		
Key area	**Depth of knowledge required**	**Suggested learning activities**
Challenges arise where parasites spread most rapidly as a result of overcrowding or tropical climates These conditions make co-ordinated treatment and control programs difficult to achieve Civil engineering projects to improve sanitation combined with co-ordinated vector control may often be the only practical control strategies	Overcrowding can occur in refugee camps that result from war or natural disaster or rapidly growing cities in LEDCs.	Research the decline of effectiveness of chemical treatments over time.
Improvements in parasite control reduce child mortality and result in population-wide improvements in child development and intelligence, as individuals have more resources for growth and development		Research parasitism and childhood. Research the impact of parasitism on child mortality rates in different parts of the world. Consider the benefits of intervention programmes in terms of childhood development and intelligence.

Investigative biology		
Key area	**Depth of knowledge required**	**Suggested learning activities**
1 Scientific principles and process (a) Scientific method Scientific cycle — observation; construction of a testable hypothesis; experimental design; gathering, recording, and analysis of data; evaluation of results and conclusions; the formation of a revised hypothesis where necessary The null hypothesis proposes that there will be no statistically significant effect as a result of the experiment treatment If there is evidence for an effect, unlikely due to chance, then the null hypothesis is rejected Scientific ideas only become accepted once they have been checked independently	In science, refinement of ideas is the norm, and scientific knowledge can be thought of as the current best explanation, which may then be updated after evaluation of further experimental evidence. Failure to find an effect (a negative result) is a valid finding, as long as an experiment is well designed. Conflicting data or conclusions can be resolved through careful evaluation or can lead to further experimentation. Effects must be reproducible; one-off results are treated with caution.	Research Karl Popper's concept of falsifiability as the basis for scientific thinking. Research recent examples of scientific breakthroughs to identify any examples of unexpected results, conflicting data, or creative experimentation.
(b) Scientific literature and communication The importance of publication of methods, data, analysis, and conclusions in scientific reports so that others are able to repeat an experiment	Common methods of sharing original scientific findings include seminars, talks and posters at conferences, and publishing in academic journals.	

Investigative biology		
Key area	**Depth of knowledge required**	**Suggested learning activities**
The importance of peer review and critical evaluation by specialists with expertise in the relevant field The use of review articles, which summarise current knowledge and recent findings in a particular field Critical evaluation of science coverage in the wider media Increasing the public understanding of science, and the issue of misrepresentation of science	Most scientific publications use peer review. Specialists with expertise in the relevant field assess the scientific quality of a submitted manuscript and make recommendations regarding its suitability for publication.	Compare the dispassionate approach taken in presenting scientific results with the passionate reality of scientific investigation, described in Frederick Grinnell's book, *The Everyday Practice of Science: Where Intuition and Passion Meet Objectivity and Logic*. [Grinnell F. (2008), *The Everyday Practice of Science: Where Intuition and Passion Meet Objectivity and Logic,* Oxford: Oxford University Press]
(c) Scientific ethics Importance of integrity and honesty — unbiased presentation of results, citing and providing references, avoiding plagiarism	While judgements and interpretations of scientific evidence may be disputed, integrity and honesty are of key importance in science. The replication of experiments by others reduces the opportunity for dishonesty or the deliberate misuse of science.	Discuss excerpts from Ben Goldacre's book, *Bad Science* Goldacre B. (2008), *Bad Science,* London: Fourth Estate Use a standard system, such as Harvard or Vancouver, to make appropriate citations in a piece of scientific writing and to construct a

Investigative biology		
Key area	**Depth of knowledge required**	**Suggested learning activities**
		reference list that allows another investigator to locate your source material.
In animal studies, the concepts of replacement, reduction, and refinement are used to avoid, reduce or minimise the harm to animals Informed consent, the right to withdraw, and confidentiality in human studies The justification for scientific research and the assessment of any risks The risk to and safety of subject species, individuals, investigators and the environment must be taken into account Legislation, regulation, policy and funding can all influence scientific research	The value or quality of science investigations must be justifiable in terms of the benefits of its outcome, including the pursuit of scientific knowledge. As a result of the risks involved, many areas of scientific research are highly regulated and licensed by governments. Legislation limits the potential for the misuse of studies and data.	Discuss the implications of the British Psychological Society's ethical guidelines on school-based investigations on humans.

Investigative biology		
Key area	**Depth of knowledge required**	**Suggested learning activities**
2 Experimentation Validity, reliability, accuracy and precision	Validity: variables controlled so that any measured effect is likely to be due to the independent variable. Reliability: consistent values in repeats and independent replicates. Accuracy: data, or means of data sets, are close to the true value. Precision: measured values are close to each other.	
(a) Pilot study Integral to the development of an investigation, a pilot study is used to help plan procedures, assess validity and check techniques This allows evaluation and modification of experimental design The use of a pilot study can ensure an appropriate range of values for the independent variable		Follow a multi-step protocol, such as protein electrophoresis, mitotic index, or cell cycle mutation in yeast, to appreciate the need to practise difficult techniques. Use a pilot study to establish ranges for variables in an investigation, such as enzyme activity or *Daphnia* heart rate.

Investigative biology		
Key area	**Depth of knowledge required**	**Suggested learning activities**
In addition, it allows the investigator to establish the number of repeat measurements required to give a representative value for each independent datum point		
(b) Experimental design (i) Independent and dependent variables Independent and dependent variables can be continuous or discrete Experiments involve the manipulation of the independent variable by the investigator The experimental treatment group is compared to a control group The use and limitations of simple (one independent variable) and multifactorial (more than one independent variable) experimental designs	An independent variable is the variable that is changed in a scientific experiment. A dependent variable is the variable being measured in a scientific experiment. The control of laboratory conditions allows simple experiments to be conducted more easily than in the field. However, a drawback of a simple experiment is that its findings may not be applicable to a wider setting.	

Investigative biology		
Key area	**Depth of knowledge required**	**Suggested learning activities**
	A multifactorial experiment involves a combination of more than one independent variable or combination of treatments.	
Investigators may use groups that already exist, so there is no truly independent variable		
Observational studies are good at detecting correlation, but since they do not directly test a hypothesis, they are less useful for determining causation	In observational studies the independent variable is not directly controlled by the investigator, for ethical or logistical reasons.	Carry out an observational study in which the investigator groups the independent variable, such as a study of the effect of gender in a human study.
(ii) Confounding variables Due to the complexities of biological systems, other variables besides the independent variable may affect the dependent variable		Design and carry out a simple laboratory true experiment, such as an enzyme experiment, where confounding variables are tightly controlled.
These confounding variables must be held constant if possible, or at least monitored so that their effect on the results can be accounted for in the analysis		Design and carry out a field observational study, such as an environmental transect, where the independent variable is not under direct control and where confounding variables cannot be tightly controlled.

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In cases where confounding variables cannot easily be controlled, a randomised block design could be used	Randomised blocks of treatment and control groups can be distributed in such a way that the influence of any confounding variable is likely to be the same across the treatment and control groups.	
(iii) Controls Control results are used for comparison with the results of treatment groups		
Negative and positive controls may be used	The negative control provides results in the absence of a treatment. A positive control is a treatment that is included to check that the system can detect a positive result when it occurs.	Design an experiment with positive and negative controls, such as a laboratory investigation using an enzyme.
Use of placebos and the placebo effect	Placebos can be included as a treatment without the presence of the independent variable being investigated. Placebo effect is a measurable change in the dependent variable as a result of a patient's expectations, rather than changes in the independent variable.	

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(iv) *In vivo* and *in vitro* studies *In vitro* refers to the technique of performing a given procedure in a controlled environment outside of a living organism *In vivo* refers to experimentation using a whole, living organism Advantages and disadvantages of *in vivo* and *in vitro* studies	Examples of *in vitro* experiments: cells growing in culture medium, proteins in solution, purified organelles.	
(c) Sampling Where it is impractical to measure every individual, a representative sample of the population is selected The extent of the natural variation within a population determines the appropriate sample size More variable populations require a larger sample size A representative sample should share the same mean and the same degree of variation about the mean as the population as a whole		

Investigative biology		
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Random, systematic and stratified sampling	In random sampling, members of the population have an equal chance of being selected. In systematic sampling, members of a population are selected at regular intervals. In stratified sampling, the population is divided into categories that are then sampled proportionally.	In ecological studies, use random numbers to select quadrats for sampling. Establish sample size by determining a travelling mean or the cumulative total of species in quadrats. Use line or belt transects to systematically sample an environment. Use stratified sampling to sample habitats that are not uniform, using a standard formula to calculate the number of samples from each area.
(d)Reliability Variation in experimental results may be due to the reliability of measurement methods and/or inherent variation in the specimens The precision and accuracy of repeated measurements	The reliability of measuring instruments or procedures can be determined by repeated measurements or readings of an individual datum point. The variation observed indicates the precision of the measurement instrument or procedure but not necessarily its accuracy.	Determine the precision of a measuring procedure by repeated measurements, and the accuracy of a measuring procedure by calibration against a known standard.

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The natural variation in the biological material being used can be determined by measuring a sample of individuals from the population The mean of these repeated measurements will give an indication of the true value being measured The range of values is a measure of the extent of variation in the results If there is a narrow range then the variation is low Independent replication should be carried out to produce independent data sets These independent data sets should be compared to determine the reliability of the results	Overall results can only be considered reliable if they can be achieved consistently.	
(e)Presentation of data Discrete and continuous variables give rise to qualitative, quantitative, or ranked data	Qualitative data is subjective and descriptive. Quantitative data can be measured objectively, usually with a numerical value.	

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	Ranked data refers to the data transformation in which numerical values are replaced by their rank when the data are sorted from lowest to highest.	
The type of variable being investigated has consequences for any graphical display or statistical tests that may be used		
Identification and calculation of mean, median and mode		
Use of box plots to show variation within and between data sets	Median, lower quartile, upper quartile and inter-quartile range.	
Interpret error bars on graphical data		
Correlation exists if there is a relationship between two variables	Correlation is an association and does not imply causation. Causation exists if the changes in the values of the independent variable are known to cause changes to the value of the dependent variable	
Positive and negative correlations	A positive correlation exists when an increase in one variable is accompanied by an increase in the other variable.	

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Strong and weak correlations	A negative correlation exists when an increase in one variable is accompanied by a decrease in the other variable. Strength of correlation is proportional to spread of values from line of best fit. Correlation values are not required.	
3 Reporting and critical evaluation of biological research (a) Background information Scientific reports should contain an explanatory title, an abstract including aims and findings, an introduction explaining the purpose and context of the study including the use of several sources, supporting statements, citations, and references	Background information should be clear, relevant and unambiguous. A title should provide a succinct explanation of the study. An abstract should outline the aims and findings of the study. An aim must link the independent and dependent variables. The introduction should provide any information required to support: choices of method, results, and discussion. An introduction should explain why the study has been carried out and place the study in the context of existing understanding. Key points should be summarised and supporting and	

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	contradictory information identified. Several sources should be selected to support statements, and citations and references should be in a standard form. Decisions regarding basic selection of study methods and organisms should be covered, as should the aims and hypotheses.	
(b) Reporting and evaluating experimental design A method section should contain sufficient information to allow another investigator to repeat the work Experimental design should address the intended aim and test the hypothesis Treatment effects should be compared to controls Any confounding variables should be taken into account or standardised across treatments	The validity and reliability of the experimental design should be evaluated. An experimental design that does not address the intended aim or test the hypothesis is invalid.	

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The validity of an experiment may be compromised when factors other than the independent variable influence the value of the dependent variable The effect of selection bias and sample size on representative sampling	 Selection bias is the selection of a sample in a non-random way, so that the sample is not representative of the whole population. Selection bias may have prevented a representative sample being selected. Sample size may not be sufficient to decide without bias whether the change to the independent variable has caused an effect in the dependent variable.	
(c) Data analysis The appropriate use of graphs, mean, median, mode, standard deviation and range in interpreting data Statistical tests are used to determine whether the differences between the means are likely or unlikely to have occurred by chance	 In results, data should be presented in a clear, logical manner suitable for analysis. Consideration should be given to the validity of outliers and anomalous results. Knowledge of specific statistical tests is not required.	 Explore error bars showing standard deviation, standard errors, or range. These could be used in project work, where appropriate.

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A statistically significant result is one that is unlikely to be due to chance alone Error bars indicate the variability of data around a mean If the treatment mean differs from the control mean sufficiently for their error bars not to overlap, this indicates that the difference may be significant		
(d)Evaluating results and conclusions Conclusions should refer to the aim, the results and the hypothesis The validity and reliability of the experimental design should be taken into account Consideration should be given as to whether the results can be attributed to correlation or causation Evaluation of conclusions should also refer to existing knowledge and the results of other investigations	Meaningful scientific discussion would include consideration of findings in the context of existing knowledge and the results of other investigations. Scientific writing should reveal an awareness of the contribution of scientific research to	

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	increasing scientific knowledge, and to the social, economic and industrial life of the community.	