Course content

Cells and proteins

The key areas covered are:

- laboratory techniques for biologists
- proteins
- membrane proteins
- communication and signalling
- protein control of cell division

Organisms and evolution

The key areas covered are:

- field techniques for biologists
- evolution
- variation and sexual reproduction
- sex and behaviour
- parasitism

Investigative biology

The key areas covered are:

- scientific principles and process
- experimentation
- reporting and critical evaluation of biological research

Skills, knowledge and understanding

Skills, knowledge and understanding for the course

The following provides a broad overview of the subject skills, knowledge and understanding developed in the course:

- extending and applying knowledge of biology to new situations, interpreting and analysing information to solve complex problems
- planning and designing biological experiments/investigations, using reference materials and including risk assessments to test a hypothesis or to illustrate particular effects
- carrying out complex experiments in biology safely, recording systematic detailed observations and collecting data
- selecting information from a variety of sources and presenting detailed information, appropriately, in a variety of forms

- processing and analysing biological information/data (using calculations, significant figures and units, where appropriate)
- making reasoned predictions and generalisations from a range of evidence/information
- drawing valid conclusions and giving explanations supported by evidence/justification
- critically evaluating experimental procedures by identifying sources of error and suggesting and implementing improvements
- drawing on knowledge and understanding of biology to make accurate statements, describe complex information, provide detailed explanations and integrate knowledge
- communicating biological findings/information fully and effectively
- analysing and evaluating scientific publications and media reports

Skills, knowledge and understanding for the course assessment

The following provides details of skills, knowledge and understanding sampled in the course assessment.

The course support notes provide further detail on the depth of knowledge required for each key area of the course.

The key areas of the course, and the depth of knowledge required for each key area, can be assessed in the question paper.

Cells and proteins
1 Laboratory techniques for biologists
(a) Health and safety Substances, organisms, and equipment in a laboratory can present a hazard Hazard, risk, and control of risk in the lab by risk assessment
(b) Liquids and solutions Method and uses of linear and log dilution Production of a standard curve to determine an unknown Use of buffers to control pH Method and uses of a colorimeter to quantify concentration and turbidity
(c) Separation techniques Use of centrifuge to separate substances of differing density Paper and thin layer chromatography can be used for separating different substances such as amino acids and sugars Principle of affinity chromatography and its use in separating proteins

Cells and proteins
Principle of gel electrophoresis and its use in separating proteins and nucleic acids Native gels separate proteins by their shape, size and charge SDS–PAGE separates 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 Proteins can also be separated using their IEPs in electrophoresis
(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 An antibody specific to the protein antigen is linked to a chemical 'label' Western blotting is a technique, used after SDS–PAGE electrophoresis The separated proteins from the gel are transferred (blotted) onto a solid medium 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
(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 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

Cells and proteins
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
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 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
(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 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 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

Cells and proteins
Transmembrane proteins carry a signal sequence, which halts translation and directs the ribosome synthesising the protein to dock with the ER, forming RER 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 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 (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
(c) Protein structure, ligand binding and conformational change (i) Amino acid sequence determines protein structure Proteins are polymers of amino acid monomers Amino acids are linked by peptide bonds to form polypeptides Amino acids have the same basic structure, differing only in the R group present Amino acids are classified according to their R groups: basic (positively charged); acidic (negatively charged); polar; hydrophobic The wide range of functions carried out by proteins results from the diversity of R groups The primary structure is the sequence in which the amino acids are synthesised into the polypeptide

Cells and proteins
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 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 Quaternary structure exists in proteins with two or more connected polypeptide subunits A prosthetic group is a non-protein unit tightly bound to a protein and necessary for its function Interactions of the R groups can be influenced by temperature and pH (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 Many allosteric proteins consist of multiple subunits (have quaternary structure) 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 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 The binding and release of oxygen in haemoglobin shows co-operativity The influence and physiological importance of temperature and pH on the binding of oxygen

Cells and proteins
(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 Some proteins are activated by phosphorylation while others are inhibited
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 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

Cells and proteins
Some channel proteins are gated and change conformation to allow or prevent diffusion Ligand-gated channels are controlled by the binding of signal molecules, and voltage-gated channels are controlled by changes in ion concentration 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
(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 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 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 The glucose transporter responsible for this glucose symport transports sodium ions and glucose at the same time and in the same direction

Cells and proteins
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 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
(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 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
(c) Hydrophilic signals and transduction Hydrophilic signalling molecules bind to transmembrane receptors and do not enter the cytosol 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 Phosphorylation cascades allow more than one intracellular signalling pathway to be activated

Cells and proteins
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
(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 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 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 Inactivation of the sodium channels and the opening of potassium channels restores the resting membrane potential 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

Cells and proteins
(ii) Initiation of a nerve impulse in response to an environmental stimulus: the vertebrate eye The retina is the area within the eye that detects light and contains two types of photoreceptor cells: rods and cones 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) PDE catalyses the hydrolysis of a molecule called cyclic GMP (cGMP) 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 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

Cells and proteins
(b) The cell cycle The cell cycle consists of interphase and mitotic (M) phase Mitotic phase involves mitosis and cytokinesis Mitosis consists of prophase, metaphase, anaphase and telophase
(c) Control of the cell cycle Progression through the cell cycle is controlled by checkpoints Cyclin proteins that accumulate during cell growth are involved in regulating the cell cycle 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) 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 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
(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 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

Organisms and evolution
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
(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 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
(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 Taxonomy involves the identification and naming of organisms and their classification into groups based on shared characteristics 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 Familiarity with taxonomic groupings allows predictions and inferences to be made about the biology of an organism from better-known (model) organisms 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

Organisms and evolution
(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 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
(e) Measuring and recording animal behaviour Some of the measurements used to quantify animal behaviour are latency, frequency and duration An ethogram of the behaviours shown by a species in a wild context allows the construction of time budgets The importance of avoiding anthropomorphism when analysing behaviour
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 Natural selection acts on genetic variation in populations 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 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 Sexual selection can be due to male-male rivalry and female choice

Organisms and evolution
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 A gene pool is altered by genetic drift because certain alleles may be under-represented or over-represented and allele frequencies change Where selection pressures are strong, the rate of evolution can be rapid 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 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
(b)Fitness Fitness is an indication of an individual's ability to be successful at surviving and reproducing 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 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
(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

Organisms and evolution
Mutualism, commensalism, and parasitism are types of symbiotic interactions 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
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 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 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 Maintaining the genome of the parent is an advantage particularly in very narrow, stable niches or when re-colonising disturbed habitats 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 more common in cooler climates, which are disadvantageous to parasites, or regions of low parasite density or diversity 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

Organisms and evolution
(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 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 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
(c) Sex determination The sex of birds, mammals and some insects is determined by the presence of sex chromosomes In most mammals the SRY gene on the Y chromosome determines development of male characteristics Heterogametic (XY) males lack most of the corresponding homologous alleles on the shorter (Y) chromosome 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

Organisms and evolution
X chromosome inactivation prevents a double dose of gene products, which could be harmful to cells 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 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 Sex can change within individuals of some species as a result of size, competition, or parasitic infection 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 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

Organisms and evolution
(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 Many animals have mate-selection courtship rituals Successful courtship behaviour in birds and fish can be a result of species-specific sign stimuli and fixed action pattern responses Sexual selection selects for characteristics that have little survival benefit for the individual, but increase their chances of mating Many species exhibit sexual dimorphism as a product of sexual selection Reversed sexual dimorphism occurs in some species Female choice involves females assessing honest signals of the fitness of males In lekking species, males gather to display at a lek, where female choice occurs Success in male-male rivalry through conflict (real or ritualised), increases access to females for mating
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 (+/-) A parasite gains benefit in terms of nutrients at the expense of its host

Organisms and evolution
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
(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 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 Schistosomes cause the human disease schistosomiasis 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
(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

Organisms and evolution
Ectoparasites are generally transmitted through direct contact or by consumption of intermediate hosts Endoparasites of the body tissues are often transmitted by vectors 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 Host behaviour is often exploited and modified by parasites to maximise transmission 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 Specific cellular defences A range of white blood cells constantly circulates, 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 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

Organisms and evolution
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
(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
(f) Challenges in treatment and control 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 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 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

Investigative biology
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
(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 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
(c) Scientific ethics Importance of integrity and honesty — unbiased presentation of results, citing and providing references, avoiding plagiarism 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

Investigative biology
2 Experimentation
Validity, reliability, accuracy and precision
(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 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 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 (ii) Confounding variables Due to the complexities of biological systems, other variables besides the independent variable may affect the dependent variable 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 In cases where confounding variables cannot easily be controlled, a randomised block design could be used (iii) Controls Control results are used for comparison with the results of treatment groups Negative and positive controls may be used Use of placebos and the placebo effect

Investigative biology
(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
(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 Random, systematic and stratified sampling
(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 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

Investigative biology
(e) Presentation of data Discrete and continuous variables give rise to qualitative, quantitative, or ranked data 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 Interpret error bars on graphical data Correlation exists if there is a relationship between two variables Positive and negative correlations Strong and weak correlations
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
(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 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
(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 A statistically significant result is one that is unlikely to be due to chance alone

Investigative biology
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

Skills, knowledge and understanding included in the course are appropriate to the SCQF level of the course. The SCQF level descriptors give further information on characteristics and expected performance at each SCQF level, and are available on the SCQF website.

Skills for learning, skills for life and skills for work

This course helps candidates to develop broad, generic skills. These skills are based on SQA's Skills Framework: Skills for Learning, Skills for Life and Skills for Work and draw from the following main skills areas:

1 Literacy
1.1 Reading
1.2 Writing

2 Numeracy
2.1 Number processes
2.2 Money, time and measurement
2.3 Information handling

5 Thinking skills
5.3 Applying
5.4 Analysing and evaluating
5.5 Creating

Teachers and/or lecturers must build these skills into the course at an appropriate level, where there are suitable opportunities.