Locally Developed Courses

Biology (Higher)

For the 2023-2024 School Year

Introduction to the Biology (Higher) Course Sequence

Subject: Sciences - Discipline: Biology

Biology is a branch of science that is concerned with the study of life on earth. Biology (Higher) offers students the opportunity to further and more deeply study biology beyond the provincial Biology program of study. In Biology (Higher), students engage in the process of scientific inquiry as a means of gaining an understanding of life and living organisms. Students in this course develop and apply conceptual understanding, exploring knowledge across a range of disciplines and engaging with issues and ideas that have local and global significance. Biology (Higher) fosters students' curiosity about the natural world and enables them to develop their inquiry and research skills.

Biology (Higher) contains only those outcomes that are part of the IB Biology Diploma Programme and not currently provided in Alberta programs of study. Learning outcomes in this course are based on the IB Diploma Programme Biology Guide (First Assessment 2025) (International Baccalaureate, 2023).

Note about structure of learning outcomes:
The content statement indicates the content to be taught. There is also a statement that provides information about the scope and requirements of the content statement and applications of the skills. NOS indicates how the content relates to the nature of science.

Student Need

Biology (Higher) enables students in the International Baccalaureate (IB) Diploma Programme to meet IB program requirements that are beyond the provincial curriculum through additional instruction and opportunities to further study experimental sciences. Throughout this course, there is a focus on fostering the development of skills relating to scientific literacy and students are encouraged to become informed creators of solutions to scientific problems. Students in Biology (Higher) have opportunities to develop a range of competencies, such as problem solving, critical thinking and managing information. There is an emphasis in Biology (Higher) on the development of a repertoire of skills that students can apply to real-life situations. Biology (Higher) also provides opportunities for students to explore possible career interests and pathways that could capitalize on their knowledge, skills and abilities in scientific inquiry.

Courses in the Biology (Higher) Course Sequence

Biology (Higher) 25 (LDC2428)

In Biology (Higher) 25, students have the opportunity to further enhance their understanding of biology through the study of content from the IB Biology (HL) program that is not covered in current provincial science programs of study. Students in Biology (Higher) 25 engage in scientific investigation, critical thinking, problem solving and analysis as they examine the following themes:

- Unity and diversity
- Form and function
- Interaction and interdependence
- Continuity and change

> **Facility and Equipment**
> Access to science lab and equipment

Prerequisites:

- All of the following:
  - Science 10 (SCN1270)

Versions Available: (Each version must be locally approved by Board Motion prior to offering to students.)

Credit Level	First School Year	Last School Year
3	2023-2024	2026-2027
5	2023-2024	2026-2027

Curriculum Outline

Curriculum Elements		Biology (Higher) 25-3	Biology (Higher) 25-5
1	Topic Unity and diversity—Molecules—Water	✓	✓
1.1	General Outcome What physical and chemical properties of water make it essential for life?	✓	✓
1.1.1	Specific Outcome Hydrogen bonds as a consequence of the polar covalent bonds within water molecules Students should understand that polarity of covalent bonding within water molecules is due to unequal sharing of electrons and that hydrogen bonding due to this polarity occurs between water molecules. Students should be able to represent two or more water molecules and hydrogen bonds between them with the notation shown below to indicate polarity.	✓	✓
1.1.2	Specific Outcome Extraplanetary origin of water on Earth and reasons for its retention The abundance of water over billions of years of Earth's history has allowed life to evolve. Limit hypotheses for the origin of water on Earth to asteroids and reasons for retention to gravity and temperatures low enough to condense water.	✓	✓
1.1.3	Specific Outcome Relationship between the search for extraterrestrial life and the presence of water Include the idea of the "Goldilocks zone".	✓	✓
2	Topic Unity and diversity—Cells—Origins of cells	✓	✓
2.1	General Outcome What plausible hypothesis could account for the origin of life? What intermediate stages could there have been between non-living matter and the first living cells?	✓	✓
2.1.1	Specific Outcome Conditions on early Earth and the pre-biotic formation of carbon compounds Include the lack of free oxygen and therefore ozone, higher concentrations of carbon dioxide and methane, resulting in higher temperatures and ultraviolet light penetration. The conditions may have caused a variety of carbon compounds to form spontaneously by chemical processes that do not now occur.	✓	
2.1.2	Specific Outcome Evidence for the origin of carbon compounds Evaluate the Miller–Urey experiment.	✓	
2.1.3	Specific Outcome Spontaneous formation of vesicles by coalescence of fatty acids into spherical bilayers Formation of a membrane-bound compartment is needed to allow internal chemistry to become different from that outside the compartment.	✓	✓

Curriculum Elements		Biology (Higher) 25-3	Biology (Higher) 25-5
2.1.4	Specific Outcome RNA as a presumed first genetic material RNA can be replicated and has some catalytic activity so it may have acted initially as both the genetic material and the enzymes of the earliest cells. Ribozymes in the ribosome are still used to catalyse peptide bond formation during protein synthesis.	✓	✓
2.1.5	Specific Outcome Evidence for a last universal common ancestor Include the universal genetic code, several hundred types of genes. Include the likelihood of other forms of life having evolved but becoming extinct due to competition from the last universal common ancestor (LUCA) and descendants of LUCA.	✓	✓
2.1.6	Specific Outcome Approaches used to estimate dates of the first living cells and the last universal common ancestor Students should develop an appreciation of the immense length of time over which life has been evolving on Earth.	✓	
2.1.7	Specific Outcome Evidence for the evolution of the last universal common ancestor in the vicinity of hydrothermal vents Include fossilized evidence of life from ancient seafloor hydrothermal vent precipitates and evidence of conserved sequences from genomic analysis.	✓	
3	Topic Unity and diversity—Cells—Cell structure	✓	✓
3.1	General Outcome What are the features common to all cells and the features that differ? How is microscopy used to investigate cell structure?	✓	✓
3.1.1	Specific Outcome Prokaryote cell structure Include these cell components: cell wall, plasma membrane, cytoplasm, naked DNA in a loop and 70S ribosomes. The type of prokaryotic cell structure required is that of Gram-positive eubacteria such as Bacillus and Staphylococcus. Students should appreciate that prokaryote cell structure varies. However, students are not required to know details of the variations such as the lack of cell walls in phytoplasmas and mycoplasmas.	✓	✓
3.1.2	Specific Outcome Eukaryote cell structure Students should be familiar with features common to eukaryote cells: a plasma membrane enclosing a compartmentalized cytoplasm with 80S ribosomes; a nucleus with chromosomes made of DNA bound to histones, contained in a double membrane with pores; membrane-bound cytoplasmic organelles including mitochondria, endoplasmic reticulum, Golgi apparatus and a variety of vesicles or vacuoles including lysosomes; and a cytoskeleton of microtubules and microfilaments.		✓

Curriculum Elements		Biology (Higher) 25-3	Biology (Higher) 25-5
3.1.3	**Specific Outcome** Differences in eukaryotic cell structure between animals, fungi and plants Include presence and composition of cell walls, differences in size and function of vacuoles, presence of chloroplasts and other plastids, and presence of centrioles, cilia and flagella.		✓
3.1.4	**Specific Outcome** Atypical cell structure in eukaryotes Use numbers of nuclei to illustrate one type of atypical cell structure in aseptate fungal hyphae, skeletal muscle, red blood cells and phloem sieve tube elements.		✓
3.1.5	**Specific Outcome** Cell types and cell structures viewed in light and electron micrographs Application of skills: Students should be able to identify cells in light or electron micrographs as prokaryote, plant or animal. In electron micrographs, students should be able to identify these structures: nucleoid region, prokaryotic cell wall, nucleus, mitochondrion, chloroplast, sap vacuole, Golgi apparatus, rough and smooth endoplasmic reticulum, chromosomes, ribosomes, cell wall, plasma membrane and microvilli.	✓	
3.1.6	**Specific Outcome** Drawing and annotation based on electron micrographs Application of skills: Students should be able to draw and annotate diagrams of organelles (nucleus, mitochondria, chloroplasts, sap vacuole, Golgi apparatus, rough and smooth endoplasmic reticulum and chromosomes) as well as other cell structures (cell wall, plasma membrane, secretory vesicles and microvilli) shown in electron micrographs. Students are required to include the functions in their annotations.	✓	
3.1.7	**Specific Outcome** Origin of eukaryotic cells by endosymbiosis Evidence suggests that all eukaryotes evolved from a common unicellular ancestor that had a nucleus and reproduced sexually. Mitochondria then evolved by endosymbiosis. In some eukaryotes, chloroplasts subsequently also had an endosymbiotic origin. Evidence should include the presence in mitochondria and chloroplasts of 70S ribosomes, naked circular DNA and the ability to replicate. *NOS:* Students should recognize that the strength of a theory comes from the observations the theory explains and the predictions it supports. A wide range of observations are accounted for by the theory of endosymbiosis.	✓	
3.1.8	**Specific Outcome** Cell differentiation as the process for developing specialized tissues in multicellular organisms Students should be aware that the basis for differentiation is different patterns of gene expression often triggered by changes in the environment.		✓
3.1.9	**Specific Outcome** Evolution of multicellularity Students should be aware that multicellularity has evolved repeatedly. Many fungi and eukaryotic algae and all plants and animals are multicellular. Multicellularity has the advantages of allowing larger body size and cell specialization.	✓	✓

Curriculum Elements		Biology (Higher) 25-3	Biology (Higher) 25-5
4	Topic Unity and diversity—Cells—Viruses	✓	✓
4.1	General Outcome How can viruses exist with so few genes? In what ways do viruses vary?	✓	✓
4.1.1	Specific Outcome Structural features common to viruses Relatively few features are shared by all viruses: small, fixed size; nucleic acid (DNA or RNA) as genetic material; a capsid made of protein; no cytoplasm; and few or no enzymes.	✓	
4.1.2	Specific Outcome Diversity of structure in viruses Students should understand that viruses are highly diverse in their shape and structure. Genetic material may be RNA or DNA, which can be either single- or double-stranded. Some viruses are enveloped in host cell membrane and others are not enveloped. Virus examples include bacteriophage lambda, coronaviruses and HIV.	✓	✓
4.1.3	Specific Outcome Lytic cycle of a virus Students should appreciate that viruses rely on a host cell for energy supply, nutrition, protein synthesis and other life functions. Use bacteriophage lambda as an example of the phases in a lytic cycle.	✓	✓
4.1.4	Specific Outcome Lysogenic cycle of a virus Use bacteriophage lambda as an example.	✓	✓
4.1.5	Specific Outcome Evidence for several origins of viruses from other organisms The diversity of viruses suggests several possible origins. Viruses share an extreme form of obligate parasitism as a mode of existence, so the structural features that they have in common could be regarded as convergent evolution. The genetic code is shared between viruses and living organisms.	✓	✓
4.1.6	Specific Outcome Rapid evolution in viruses Consider reasons for very rapid rates of evolution in some viruses. Use two examples of rapid evolution: evolution of influenza viruses and of HIV. Consider the consequences for treating diseases caused by rapidly evolving viruses.	✓	✓
5	Topic Unity and diversity—Organisms—Diversity of organisms	✓	
5.1	General Outcome What patterns are seen in the diversity of genomes within and between species?	✓	

Curriculum Elements		Biology (Higher) 25-3	Biology (Higher) 25-5
5.1.1	Specific Outcome Comparison of genome sizes Application of skills: Students should extract information about genome size for different taxonomic groups from a database to compare genome size to organism complexity.	✓	
5.1.2	Specific Outcome Difficulties applying the biological species concept to asexually reproducing species and to bacteria that have horizontal gene transfer The biological species concept does not work well with groups of organisms that do not breed sexually or where genes can be transferred from one species to another.	✓	
6	Topic Unity and diversity—Organisms—Classification and cladistics	✓	✓
6.1	General Outcome How do cladistic methods differ from traditional taxonomic methods?	✓	✓
6.1.1	Specific Outcome Clades as groups of organisms with common ancestry and shared characteristics The most objective evidence for placing organisms in the same clade comes from base sequences of genes or amino acid sequences of proteins. Morphological traits can be used to assign organisms to clades.	✓	✓
6.1.2	Specific Outcome Gradual accumulation of sequence differences as the basis for estimates of when clades diverged from a common ancestor This method of estimating times is known as the “molecular clock”. The molecular clock can only give estimates because mutation rates are affected by the length of the generation time, the size of a population, the intensity of selective pressure and other factors.	✓	✓
6.1.3	Specific Outcome Base sequences of genes or amino acid sequences of proteins as the basis for constructing cladograms Examples can be simple and based on sample data to illustrate the tool. *NOS:* Students should recognize that different criteria for judgement can lead to different hypotheses. Here, parsimony analysis is used to select the most probable cladogram, in which observed sequence variation between clades is accounted for with the smallest number of sequence changes.	✓	✓
6.1.4	Specific Outcome Analysing cladograms Students should be able to deduce evolutionary relationships, common ancestors and clades from a cladogram. They should understand the terms “root”, “node” and “terminal branch” and also that a node represents a hypothetical common ancestor.	✓	✓

Curriculum Elements		Biology (Higher) 25-3	Biology (Higher) 25-5
6.1.5	Specific Outcome Using cladistics to investigate whether the classification of groups corresponds to evolutionary relationships A case study of transfer of plant species between families could be used to develop understanding, for example the reclassification of the figwort family (Scrophulariaceae). However, students are not required to memorize the details of the case study. *NOS:* Students should appreciate that theories and other scientific knowledge claims may eventually be falsified. In this example, similarities in morphology due to convergent evolution rather than common ancestry suggested a classification that by cladistics has been shown to be false.	✓	✓
6.1.6	Specific Outcome Classification of all organisms into three domains using evidence from rRNA base sequences This is the revolutionary reclassification with an extra taxonomic level above kingdoms that was proposed in 1977.		✓
7	Topic Unity and diversity—Ecosystems—Evolution and speciation		✓
7.1	General Outcome What is the evidence for evolution? How do analogous and homologous structures exemplify commonality and diversity?		✓
7.1.1	Specific Outcome Evidence for evolution from base sequences in DNA or RNA and amino acid sequences in proteins Sequence data gives powerful evidence of common ancestry.		✓
7.1.2	Specific Outcome Evidence for evolution from selective breeding of domesticated animals and crop plants Variation between different domesticated animal breeds and varieties of crop plant, and between them and the original wild species, shows how rapidly evolutionary changes can occur.		✓
7.1.3	Specific Outcome Abrupt speciation in plants by hybridization and polyploidy Use knotweed or smartweed (genus Persicaria) as an example because it contains many species that have been formed by these processes.		✓
8	Topic Unity and diversity—Ecosystems—Conservation of biodiversity		✓
8.1	General Outcome What factors are causing the sixth mass extinction of species? How can conservationists minimize the loss of biodiversity?		✓

Curriculum Elements		Biology (Higher) 25-3	Biology (Higher) 25-5
8.1.1	Specific Outcome Causes of anthropogenic species extinction This should be a study of the causes of the current sixth mass extinction, rather than of non-anthropogenic causes of previous mass extinctions. To give a range of causes, carry out three or more brief case studies of species extinction: North Island giant moas (Dinornis novaezealandiae) as an example of the loss of terrestrial megafauna, Caribbean monk seals (Neomonachus tropicalis) as an example of the loss of a marine species, and one other species that has gone extinct from an area that is familiar to students.		✓
8.1.2	Specific Outcome Evidence for a biodiversity crisis Evidence can be drawn from Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services reports and other sources. Results from reliable surveys of biodiversity in a wide range of habitats around the world are required. Students should understand that surveys need to be repeated to provide evidence of change in species richness and evenness. Note that there are opportunities for contributions from both expert scientists and citizen scientists. *NOS:* To be verifiable, evidence usually has to come from a published source, which has been peer reviewed and allows methodology to be checked. Data recorded by citizens rather than scientists brings not only benefits but also unique methodological concerns.		✓
8.1.3	Specific Outcome Need for several approaches to conservation of biodiversity No single approach by itself is sufficient, and different species require different measures. Include in situ conservation of species in natural habitats, management of nature reserves, rewilding and reclamation of degraded ecosystems, ex situ conservation in zoos and botanic gardens and storage of germ plasm in seed or tissue banks.		✓
8.1.4	Specific Outcome Selection of evolutionarily distinct and globally endangered species for conservation prioritization in the EDGE of Existence programme Students should understand the rationale behind focusing conservation efforts on evolutionarily distinct and globally endangered species (EDGE). *NOS:* Issues such as which species should be prioritized for conservation efforts have complex ethical, environmental, political, social, cultural and economic implications and therefore need to be debated.		✓
9	Topic Form and Function—Molecules—Carbohydrates and lipids		✓
9.1	General Outcome In what ways do variations in form allow diversity of function in carbohydrates and lipids? How do carbohydrates and lipids compare as energy storage compounds?		✓
9.1.1	Specific Outcome Production of macromolecules by condensation reactions that link monomers to form a polymer Students should be familiar with examples of polysaccharides, polypeptides and nucleic acids.		✓

Curriculum Elements		Biology (Higher) 25-3	Biology (Higher) 25-5
9.1.2	**Specific Outcome** Digestion of polymers into monomers by hydrolysis reactions Water molecules are split to provide the -H and -OH groups that are incorporated to produce monomers, hence the name of this type of reaction.		✓
9.1.3	**Specific Outcome** Form and function of monosaccharides Students should be able to recognize pentoses and hexoses as monosaccharides from molecular diagrams showing them in the ring forms. Use glucose as an example of the link between the properties of a monosaccharide and how it is used, emphasizing solubility, transportability, chemical stability and the yield of energy from oxidation as properties.		✓
9.1.4	**Specific Outcome** Polysaccharides as energy storage compounds Include the compact nature of starch in plants and glycogen in animals due to coiling and branching during polymerization, the relative insolubility of these compounds due to large molecular size and the relative ease of adding or removing alpha-glucose monomers by condensation and hydrolysis to build or mobilize energy stores.		✓
9.1.5	**Specific Outcome** Structure of cellulose related to its function as a structural polysaccharide in plants Include the alternating orientation of beta-glucose monomers, giving straight chains that can be grouped in bundles and cross-linked with hydrogen bonds.		✓
9.1.6	**Specific Outcome** Formation of phospholipid bilayers as a consequence of the hydrophobic and hydrophilic regions Students should use and understand the term “amphipathic”.		✓
9.1.7	**Specific Outcome** Ability of non-polar steroids to pass through the phospholipid bilayer Include oestradiol and testosterone as examples. Students should be able to identify compounds as steroids from molecular diagrams.		✓
10	**Topic** Form and Function—Molecules—Proteins		✓
10.1	**General Outcome** What is the relationship between amino acid sequence and the diversity in form and function of proteins? How are protein molecules affected by their chemical and physical environments?		✓
10.1.1	**Specific Outcome** Generalized structure of an amino acid Students should be able to draw a diagram of a generalized amino acid showing the alpha carbon atom with amine group, carboxyl group, R-group and hydrogen attached.		✓

Curriculum Elements		Biology (Higher) 25-3	Biology (Higher) 25-5
10.1.2	**Specific Outcome** Chemical diversity in the R-groups of amino acids as a basis for the immense diversity in protein form and function Students are not required to give specific examples of R-groups. However, students should understand that R-groups determine the properties of assembled polypeptides. Students should appreciate that Rgroups are hydrophobic or hydrophilic and that hydrophilic R-groups are polar or charged, acidic or basic.		✓
10.1.3	**Specific Outcome** Dependence of tertiary structure on hydrogen bonds, ionic bonds, disulfide covalent bonds and hydrophobic interactions Students are not required to name examples of amino acids that participate in these types of bonding, apart from pairs of cysteines forming disulfide bonds. Students should understand that amine and carboxyl groups in R-groups can become positively or negatively charged by binding or dissociation of hydrogen ions and that they can then participate in ionic bonding.		✓
10.1.4	**Specific Outcome** Effect of polar and non-polar amino acids on tertiary structure of proteins In proteins that are soluble in water, hydrophobic amino acids are clustered in the core of globular proteins. Integral proteins have regions with hydrophobic amino acids, helping them to embed in membranes.		✓
10.1.5	**Specific Outcome** Quaternary structure of non-conjugated and conjugated proteins Include insulin and collagen as examples of non-conjugated proteins and haemoglobin as an example of a conjugated protein. *NOS:* Technology allows imaging of structures that would be impossible to observe with the unaided senses. For example, cryogenic electron microscopy has allowed imaging of single-protein molecules and their interactions with other molecules.		✓
10.1.6	**Specific Outcome** Relationship of form and function in globular and fibrous proteins Students should know the difference in shape between globular and fibrous proteins and understand that their shapes make them suitable for specific functions. Use insulin and collagen to exemplify how form and function are related.		✓
11	**Topic** Form and Function—Cells—Membranes and membrane transport	✓	✓
11.1	**General Outcome** What processes depend on active transport in biological systems?	✓	✓
11.1.1	**Specific Outcome** Relationships between fatty acid composition of lipid bilayers and their fluidity Unsaturated fatty acids in lipid bilayers have lower melting points, so membranes are fluid and therefore flexible at temperatures experienced by a cell. Saturated fatty acids have higher melting points and make membranes stronger at higher temperatures. Students should be familiar with an example of adaptations in membrane composition in relation to habitat.		✓

Curriculum Elements		Biology (Higher) 25-3	Biology (Higher) 25-5
11.1.2	Specific Outcome Gated ion channels in neurons Include nicotinic acetylcholine receptors as an example of a neurotransmitter-gated ion channel and sodium and potassium channels as examples of voltage-gated channels.		✓
11.1.3	Specific Outcome Adhesion of cells to form tissues Include the term "cell-adhesion molecules" (CAMs) and the understanding that different forms of CAM are used for different types of cell–cell junction. Students are not required to have detailed knowledge of the different CAMs or junctions.	✓	
12	Topic Form and Function—Cells—Organelles and compartmentalization	✓	✓
12.1	General Outcome How are organelles in cells adapted to their functions? What are the advantages of compartmentalization in cells?	✓	✓
12.1.1	Specific Outcome Advantage of the separation of the nucleus and cytoplasm into separate compartments Limit to separation of the activities of gene transcription and translation—post-transcriptional modification of mRNA can happen before the mRNA meets ribosomes in the cytoplasm. In prokaryotes this is not possible—mRNA may immediately meet ribosomes.		✓
12.1.2	Specific Outcome Functional benefits of the double membrane of the nucleus Include the need for pores in the nuclear membrane and for the nucleus to break into vesicles during mitosis and meiosis.	✓	✓
12.1.3	Specific Outcome Structure and function of vesicles in cells Include the role of clathrin in the formation of vesicles.	✓	✓
13	Topic Form and Function—Cells—Cell specialization		✓
13.1	General Outcome What are the roles of stem cells in multicellular organisms? How are differentiated cells adapted to their specialized functions?		✓
13.1.1	Specific Outcome Production of unspecialized cells following fertilization and their development into specialized cells by differentiation Students should understand the impact of gradients on gene expression within an early-stage embryo.		✓
13.1.2	Specific Outcome Properties of stem cells Limit to the capacity of cells to divide endlessly and differentiate along different pathways.		✓

Curriculum Elements		Biology (Higher) 25-3	Biology (Higher) 25-5
13.1.3	Specific Outcome Location and function of stem cell niches in adult humans Limit to two example locations and the understanding that the stem cell niche can maintain the cells or promote their proliferation and differentiation. Bone marrow and hair follicles are suitable examples.		✓
13.1.4	Specific Outcome Differences between totipotent, pluripotent and multipotent stem cells Students should appreciate that cells in early-stage animal embryos are totipotent but soon become pluripotent, whereas stem cells in adult tissue such as bone marrow are multipotent.		✓
13.1.5	Specific Outcome Adaptations to increase surface area-to-volume ratios of cells Include flattening of cells, microvilli and invagination. Use erythrocytes and proximal convoluted tubule cells in the nephron as examples.		✓
13.1.6	Specific Outcome Adaptations of type I and type II pneumocytes in alveoli Limit to extreme thinness to reduce distances for diffusion in type I pneumocytes and the presence of many secretory vesicles (lamellar bodies) in the cytoplasm that discharge surfactant to the alveolar lumen in type II pneumocytes. Alveolar epithelium is an example of a tissue where more than one cell type is present, because different adaptations are required for the overall function of the tissue.		✓
13.1.7	Specific Outcome Adaptations of cardiac muscle cells and striated muscle fibres Include the presence of contractile myofibrils in both muscle types and hypotheses for these differences: branching (branched or unbranched), and length and numbers of nuclei. Also include a discussion of whether a striated muscle fibre is a cell.		✓
14	Topic Form and Function—Organisms—Muscle and motility		✓
14.1	General Outcome How do muscles contract and cause movement? What are the benefits to animals of having muscle tissue?		✓
14.1.1	Specific Outcome Adaptations for movement as a universal feature of living organisms Students should explore the concept of movement by considering a range of organisms including one motile and one sessile species.		✓
14.1.2	Specific Outcome Sliding filament model of muscle contraction Students should understand how a sarcomere contracts by the sliding of actin and myosin filaments.		✓

Curriculum Elements		Biology (Higher) 25-3	Biology (Higher) 25-5
14.1.3	Specific Outcome Role of the protein titin and antagonistic muscles in muscle relaxation The immense protein titin helps sarcomeres to recoil after stretching and also prevents overstretching. Antagonistic muscles are needed because muscle tissue can only exert force when it contracts.		✓
14.1.4	Specific Outcome Structure and function of motor units in skeletal muscle Include the motor neuron, muscle fibres and the neuromuscular junctions that connect them.		✓
14.1.5	Specific Outcome Roles of skeletons as anchorage for muscles and as levers Students should appreciate that arthropods have exoskeletons and vertebrates have endoskeletons.		✓
14.1.6	Specific Outcome Movement at a synovial joint Include the roles of bones, cartilage, synovial fluid, ligaments, muscles and tendons. Use the human hip joint as an example. Students are not required to name muscles and ligaments, but they should be able to name the femur and pelvis.		✓
14.1.7	Specific Outcome Range of motion of a joint Application of skills: Students should compare the range of motion of a joint in a number of dimensions. Students should measure joint angles using computer analysis of images or a goniometer.		✓
14.1.8	Specific Outcome Internal and external intercostal muscles as an example of antagonistic muscle action to facilitate internal body movements Students should appreciate that the different orientations of muscle fibres in the internal and external layers of intercostal muscles mean that they move the ribcage in opposite directions and that, when one of these layers contracts, it stretches the other, storing potential energy in the sarcomere protein titin.		✓
14.1.9	Specific Outcome Adaptations for swimming in marine mammals Include streamlining, adaptation of limbs to form flippers and of the tail to form a fluke with up-and-down movement, and changes to the airways to allow periodic breathing between dives.		✓
15	Topic Interaction and interdependence—Molecules—Enzymes and metabolism		✓
15.1	General Outcome In what ways do enzymes interact with other molecules? What are the interdependent components of metabolism?		✓

Curriculum Elements		Biology (Higher) 25-3	Biology (Higher) 25-5
15.1.1	**Specific Outcome** Anabolic and catabolic reactions Examples of anabolism should include the formation of macromolecules from monomers by condensation reactions including protein synthesis, glycogen formation and photosynthesis. Examples of catabolism should include hydrolysis of macromolecules into monomers in digestion and oxidation of substrates in respiration.		✓
15.1.2	**Specific Outcome** Enzymes as globular proteins with an active site for catalysis Include that the active site is composed of a few amino acids only, but interactions between amino acids within the overall three-dimensional structure of the enzyme ensure that the active site has the necessary properties for catalysis.		✓
15.1.3	**Specific Outcome** Role of molecular motion and substrate-active site collisions in enzyme catalysis Movement is needed for a substrate molecule and an active site to come together. Sometimes large substrate molecules are immobilized while sometimes enzymes can be immobilized by being embedded in membranes.		✓
15.1.4	**Specific Outcome** Measurements in enzyme-catalysed reactions Application of skills: Students should determine reaction rates through experimentation and using secondary data.		✓
15.1.5	**Specific Outcome** Effect of enzymes on activation energy Application of skills: Students should appreciate that energy is required to break bonds within the substrate and that there is an energy yield when bonds are made to form the products of an enzyme-catalysed reaction. Students should be able to interpret graphs showing this effect.		✓
15.1.6	**Specific Outcome** Competitive inhibition as a consequence of an inhibitor binding reversibly to an active site Use statins as an example of competitive inhibitors. Include the difference between competitive and non-competitive inhibition in the interactions between substrate and inhibitor and therefore in the effect of substrate concentration.		✓
15.1.7	**Specific Outcome** Regulation of metabolic pathways by feedback inhibition Use the pathway that produces isoleucine as an example of an end product acting as an inhibitor.		✓
15.1.8	**Specific Outcome** Mechanism-based inhibition as a consequence of chemical changes to the active site caused by the irreversible binding of an inhibitor Use penicillin as an example. Include the change to transpeptidases that confers resistance to penicillin.		✓
16	**Topic** Interaction and interdependence—Molecules—Photosynthesis		✓

Curriculum Elements		Biology (Higher) 25-3	Biology (Higher) 25-5
16.1	General Outcome How is energy from sunlight absorbed and used in photosynthesis? How do abiotic factors interact with photosynthesis?		√
16.1.1	Specific Outcome Techniques for varying concentrations of carbon dioxide, light intensity or temperature experimentally to investigate the effects of limiting factors on the rate of photosynthesis Application of skills: Students should be able to suggest hypotheses for the effects of these limiting factors and explore protocols based upon their understanding of photosynthesis, and test these by experimentation. *NOS:* Hypotheses are provisional explanations that require repeated testing. During scientific research, hypotheses can either be based on theories and then tested in an experiment or be based on evidence from an experiment already carried out. Students can decide in this case whether to suggest hypotheses for the effects of limiting factors on photosynthesis before or after performing their experiments. Students should be able to identify the dependent and independent variable in an experiment.		√
16.1.2	Specific Outcome Carbon dioxide enrichment experiments as a means of predicting future rates of photosynthesis and plant growth Include enclosed greenhouse experiments and free-air carbon dioxide enrichment experiments (FACE). *NOS:* Finding methods for careful control of variables is part of experimental design. This may be easier in the laboratory but some experiments can only be done in the field. Field experiments include those performed in natural ecosystems. Students should be able to identify a controlled variable in an experiment.		√
16.1.3	Specific Outcome Advantages of the structured array of different types of pigment molecules in a photosystem Students should appreciate that a single molecule of chlorophyll or any other pigment would not be able to perform any part of photosynthesis.		√
16.1.4	Specific Outcome Generation of oxygen by the photolysis of water in photosystem II Emphasize that the protons and electrons generated by photolysis are used in photosynthesis but oxygen is a waste product. The advent of oxygen generation by photolysis had immense consequences for living organisms and geological processes on Earth.		√
16.1.5	Specific Outcome ATP production by chemiosmosis in thylakoids Include the proton gradient, ATP synthase, proton pumping by the chain of electron carriers and also the electrons sourced from photosystem I in cyclic photophosphorylation or photosystem II in non-cyclic photophosphorylation.		√
17	Topic Interaction and interdependence—Cells—Chemical signalling	√	√

Curriculum Elements		Biology (Higher) 25-3	Biology (Higher) 25-5
17.1	General Outcome How do cells distinguish between the many different signals that they receive? What interactions occur inside animal cells in response to chemical signals?	✓	✓
17.1.1	Specific Outcome Receptors as proteins with binding sites for specific signalling chemicals Students should use the term “ligand” for the signalling chemical.	✓	✓
17.1.2	Specific Outcome Cell signalling by bacteria in quorum sensing Include the example of bioluminescence in the marine bacterium Vibrio fischeri.	✓	✓
17.1.3	Specific Outcome Hormones, neurotransmitters, cytokines and calcium ions as examples of functional categories of signalling chemicals in animals Students should appreciate the differences between these categories.		✓
17.1.4	Specific Outcome Chemical diversity of hormones and neurotransmitters Consider reasons for a wide range of chemical substances being used as signalling chemicals. Include amines, proteins and steroids as chemical groups of hormones. A range of substances can serve as neurotransmitters including amino acids, peptides, amines and nitrous oxide.	✓	✓
17.1.5	Specific Outcome Localized and distant effects of signalling molecules Contrasts can be drawn between hormones transported by the blood system and neurotransmitters that diffuse across a synaptic gap.		✓
17.1.6	Specific Outcome Differences between transmembrane receptors in a plasma membrane and intracellular receptors in the cytoplasm or nucleus Include distribution of hydrophilic or hydrophobic amino acids in the receptor and whether the signalling chemical penetrates the cell or remains outside	✓	✓
17.1.7	Specific Outcome Initiation of signal transduction pathways by receptors Students should understand that the binding of a signalling chemical to a receptor sets off a sequence of responses within the cell.	✓	✓
17.1.8	Specific Outcome Transmembrane receptors that activate G protein Students should understand how G protein-coupled receptors convey a signal into cells. They should appreciate that there are many such receptors in humans.	✓	✓

Curriculum Elements		Biology (Higher) 25-3	Biology (Higher) 25-5
17.1.9	Specific Outcome Mechanism of action of epinephrine (adrenaline) receptors Include the roles of a G protein and cyclic AMP (cAMP) as the second messenger. *NOS:* Students should be aware that naming conventions are an example of international cooperation in science for mutual benefit. Both “adrenaline” and “epinephrine” were coined by researchers and are based on production of the hormone by the adrenal gland, which is above (“epi-”) the kidney (nephrons). Unusually, these two terms persist in common use in different parts of the world.	✓	✓
17.1.10	Specific Outcome Transmembrane receptors with tyrosine kinase activity Use the protein hormone insulin as an example. Limit this to binding of insulin to a receptor in the plasma membrane, causing phosphorylation of tyrosine inside a cell. This leads to a sequence of reactions ending with movement of vesicles containing glucose transporters to the plasma membrane.	✓	✓
18	Topic Interaction and interdependence—Organisms—Integration of body systems	✓	✓
18.1	General Outcome What are the roles of hormones in integration of plant systems?	✓	✓
18.1.1	Specific Outcome Phytohormones as signalling chemicals controlling growth, development and response to stimuli in plants Students should appreciate that a variety of chemicals are used as phytohormones in plants.	✓	
18.1.2	Specific Outcome Auxin efflux carriers as an example of maintaining concentration gradients of phytohormones Auxin can diffuse freely into plant cells but not out of them. Auxin efflux carriers can be positioned in a cell membrane on one side of the cell. If all cells coordinate to concentrate these carriers on the same side, auxin is actively transported from cell to cell through the plant tissue and becomes concentrated in part of the plant.	✓	✓
18.1.3	Specific Outcome Promotion of cell growth by auxin Include auxin’s promotion of hydrogen ion secretion into the apoplast, acidifying the cell wall and thus loosening cross links between cellulose molecules and facilitating cell elongation. Concentration gradients of auxin cause the differences in growth rate needed for phototropism.	✓	✓
18.1.4	Specific Outcome Interactions between auxin and cytokinin as a means of regulating root and shoot growth Students should understand that root tips produce cytokinin, which is transported to shoots, and shoot tips produce auxin, which is transported to roots. Interactions between these phytohormones help to ensure that root and shoot growth are integrated.	✓	✓

Curriculum Elements		Biology (Higher) 25-3	Biology (Higher) 25-5
18.1.5	Specific Outcome Positive feedback in fruit ripening and ethylene production Ethylene (IUPAC name: ethene) stimulates the changes in fruits that occur during ripening, and ripening also stimulates increased production of ethylene. Students should understand the benefit of this positive feedback mechanism in ensuring that fruit ripening is rapid and synchronized.	✓	✓
19	Topic Interaction and interdependence—Organisms—Defence against disease	✓	✓
19.1	General Outcome What factors influence the incidence of disease in populations?	✓	✓
19.1.1	Specific Outcome Transmission of HIV in body fluids Include examples of the means and implications of HIV (human immunodeficiency virus) transmission.	✓	
19.1.2	Specific Outcome Infection of lymphocytes by HIV with AIDS as a consequence Students should understand that only certain types of lymphocyte are infected and killed, but that a reduction in these lymphocytes limits the ability to produce antibodies and fight opportunistic infections.	✓	
19.1.3	Specific Outcome Evolution of resistance to several antibiotics in strains of pathogenic bacteria Students should understand that careful use of antibiotics is necessary to slow the emergence of multiresistant bacteria. *NOS:* Students should recognize that the development of new techniques can lead to new avenues of research; for example, the recent technique of searching chemical libraries is yielding new antibiotics.	✓	✓
19.1.4	Specific Outcome Zoonoses as infectious diseases that can transfer from other species to humans Illustrate the prevalence of zoonoses as infectious diseases in humans and their varied modes of infection with several examples including tuberculosis, rabies and Japanese encephalitis. Include COVID-19 infection as a disease that has recently transferred from another species, with profound consequences for humans.	✓	✓
19.1.5	Specific Outcome Vaccines and immunization Students should understand that vaccines contain antigens, or nucleic acids (DNA or RNA) with sequences that code for antigens, and that they stimulate the development of immunity to a specific pathogen without causing the disease.		✓

Curriculum Elements		Biology (Higher) 25-3	Biology (Higher) 25-5
19.1.6	**Specific Outcome** Herd immunity and the prevention of epidemics Students should understand how members of a population are interdependent in building herd immunity. If a sufficient percentage of a population is immune to a disease, transmission is greatly impeded. *NOS:* Scientists publish their research so that other scientists can evaluate it. The media often report on the research while evaluation is still happening, and consumers need to be aware of this. Vaccines are tested rigorously and the risks of side effects are minimal but not nil. The distinction between pragmatic truths and certainty is poorly understood.	✓	✓
19.1.7	**Specific Outcome** Evaluation of data related to the COVID-19 pandemic Application of skills: Students should have the opportunity to calculate both percentage difference and percentage change.	✓	✓
20	**Topic** Interaction and interdependence—Ecosystems—Populations and communities	✓	✓
20.1	**General Outcome** How do interactions between organisms regulate sizes of component populations in a community? What interactions within a community make its populations interdependent?	✓	✓
20.1.1	**Specific Outcome** Random quadrat sampling to estimate population size for sessile organisms Both sessile animals and plants, where the numbers of individuals can be counted, are suitable. Application of skills: Students should understand what is indicated by the standard deviation of a mean. Students do not need to memorize the formula used to calculate this. In this example, the standard deviation of the mean number of individuals per quadrat could be determined using a calculator to give a measure of the variation and how evenly the population is spread.		✓
20.1.2	**Specific Outcome** Capture–mark–release–recapture and the Lincoln index to estimate population size for motile organisms Application of skills: Students should use the Lincoln index to estimate population size. Population size estimate = $M \times N/R$, where M is the number of individuals caught and marked initially, N is the total number of individuals recaptured and R is the number of marked individuals recaptured. Students should understand the assumptions made when using this method.		✓
20.1.3	**Specific Outcome** Population growth curves Students should study at least one case study in an ecosystem. A lag phase is not expected as a part of sigmoid population growth. Students should understand reasons for exponential growth in the initial phases. *NOS:* The curve represents an idealized graphical model. Students should recognize that models are often simplifications of complex systems. Application of skills: Students should test the growth of a population against the model of exponential growth using a graph with a logarithmic scale for size of population on the vertical axis and a non-logarithmic scale for time on the horizontal axis.		✓

Curriculum Elements		Biology (Higher) 25-3	Biology (Higher) 25-5
20.1.4	Specific Outcome Modelling of the sigmoid population growth curve Application of skills: Students should collect data regarding population growth. Yeast and duckweed are recommended but other organisms that proliferate under experimental conditions could be used.	✓	✓
20.1.5	Specific Outcome Resource competition between endemic and invasive species Choose one local example to illustrate competitive advantage over endemic species in resource acquisition as the basis for an introduced species becoming invasive.		✓
20.1.6	Specific Outcome Tests for interspecific competition Interspecific competition is indicated but not proven if one species is more successful in the absence of another. Students should appreciate the range of possible approaches to research: laboratory experiments, field observations by random sampling and field manipulation by removal of one species. *NOS:* Students should recognize that hypotheses can be tested by both experiments and observations and should understand the difference between them.		✓
20.1.7	Specific Outcome Use of the chi-squared test for association between two species Application of skills: Students should be able to apply chi-squared tests on the presence/absence of two species in several sampling sites, exploring the differences or similarities in distribution. This may provide evidence for interspecific competition.		✓
20.1.8	Specific Outcome Allelopathy and secretion of antibiotics These two processes are similar in that a chemical substance is released into the environment to deter potential competitors. Include one specific example of each—where possible, choose a local example.	✓	
21	Topic Continuity and change—Molecules—DNA replication		✓
21.1	General Outcome How is new DNA produced? How has knowledge of DNA replication enabled applications in biotechnology?		✓
21.1.1	Specific Outcome Directionality of transcription and translation Students should understand what is meant by 5' to 3' transcription and 5' to 3' translation.		✓
21.1.2	Specific Outcome Initiation of transcription at the promoter Consider transcription factors that bind to the promoter as an example. However, students are not required to name other types.		✓

Curriculum Elements		Biology (Higher) 25-3	Biology (Higher) 25-5
21.1.3	Specific Outcome Non-coding sequences in DNA do not code for polypeptides Limit examples to regulators of gene expression, introns, telomeres and genes for rRNAs and tRNAs in eukaryotes.		✓
21.1.4	Specific Outcome Post-transcriptional modification in eukaryotic cells Include removal of introns and splicing together of exons to form mature mRNA and also the addition of 5' caps and 3' polyA tails to stabilize mRNA transcripts.		✓
21.1.5	Specific Outcome Alternative splicing of exons to produce variants of a protein from a single gene Use alternative splicing of transcripts of the troponin T gene in foetal and adult heart muscle as an example.		✓
21.1.6	Specific Outcome Initiation of translation Include attachment of the small ribosome subunit to the 5' terminal of mRNA, movement to the start codon, attachment of the large subunit, the initiator tRNA and another tRNA. Students should understand the roles of the three binding sites for tRNA on the ribosome (A, P and E) during elongation.		✓
21.1.7	Specific Outcome Modification of polypeptides into their functional state Students should appreciate that many polypeptides must be modified before they can function. The examples chosen should include the two-stage modification of pre-proinsulin to insulin.		✓
21.1.8	Specific Outcome Recycling of amino acids by proteasomes Limit to the understanding that sustaining a functional proteome requires constant protein breakdown and synthesis.		✓
22	Topic Continuity and change—Molecules—Mutation and gene editing	✓	✓
22.1	General Outcome How do gene mutations occur? How can natural selection lead to both a reduction in variation and an increase in biological diversity?	✓	✓
22.1.1	Specific Outcome Gene mutations as structural changes to genes at the molecular level Distinguish between substitutions, insertions and deletions.		✓
22.1.2	Specific Outcome Consequences of base substitutions Students should understand that single-nucleotide polymorphisms (SNPs) are the result of base substitution mutations and that because of the degeneracy of the genetic code they may or may not change a single amino acid in a polypeptide.		✓

Curriculum Elements		Biology (Higher) 25-3	Biology (Higher) 25-5
22.1.3	**Specific Outcome** Consequences of insertions and deletions Include the likelihood of polypeptides ceasing to function, either through frameshift changes or through major insertions or deletions. Use trinucleotide repeats of the gene HTT as an example of insertion and the delta 32 mutation of the CCR5 gene as an example of deletion.		✓
22.1.4	**Specific Outcome** Gene knockout as a technique for investigating the function of a gene by changing it to make it inoperative Students are not required to know details of techniques. Students should appreciate that a library of knockout organisms is available for some species used as models in research.		✓
22.1.5	**Specific Outcome** Use of the CRISPR sequences and the enzyme Cas9 in gene editing Students are not required to know the role of the CRISPR–Cas system in prokaryotes. However, students should be familiar with an example of the successful use of this technology. *NOS:* Certain potential uses of CRISPR raise ethical issues that must be addressed before implementation. Students should understand that scientists across the world are subject to different regulatory systems. For this reason, there is an international effort to harmonize regulation of the application of genome editing technologies such as CRISPR.		✓
22.1.6	**Specific Outcome** Hypotheses to account for conserved or highly conserved sequences in genes Conserved sequences are identical or similar across a species or a group of species; highly conserved sequences are identical or similar over long periods of evolution. Two hypotheses for the mechanism are functional requirements for the gene products and slower rates of mutation.	✓	✓
23	**Topic** Continuity and change—Cells—Gene expression		✓
23.1	**General Outcome** How is gene expression changed in a cell? How can patterns of gene expression be conserved through inheritance?		✓
23.1.1	**Specific Outcome** Control of the degradation of mRNA as a means of regulating translation In human cells, mRNA may persist for time periods from minutes up to days, before being broken down by nucleases.		✓
23.1.2	**Specific Outcome** Epigenesis as the development of patterns of differentiation in the cells of a multicellular organism Emphasize that DNA base sequences are not altered by epigenetic changes, so phenotype but not genotype is altered.		✓
23.1.3	**Specific Outcome** Differences between the genome, transcriptome and proteome of individual cells No cell expresses all of its genes. The pattern of gene expression in a cell determines how it differentiates.		✓

Curriculum Elements		Biology (Higher) 25-3	Biology (Higher) 25-5
23.1.4	Specific Outcome Methylation of the promoter and histones in nucleosomes as examples of epigenetic tags Methylation of cytosine in the DNA of a promoter represses transcription and therefore expression of the gene downstream. Methylation of amino acids in histones can cause transcription to be repressed or activated. Students are not required to know details of how this is achieved.		✓
23.1.5	Specific Outcome Epigenetic inheritance through heritable changes to gene expression Limit to the possibility of phenotypic changes in a cell or organism being passed on to daughter cells or offspring without changes in the nucleotide sequence of DNA. This can happen if epigenetic tags, such as DNA methylation or histone modification, remain in place during mitosis or meiosis.		✓
23.1.6	Specific Outcome Examples of environmental effects on gene expression in cells and organisms Include alteration of methyl tags on DNA in response to air pollution as an example.		✓
23.1.7	Specific Outcome Consequences of removal of most but not all epigenetic tags from the human ovum and sperm Students can show this by outlining the epigenetic origins of phenotypic differences in tigons and ligers (lion–tiger hybrids).		✓
23.1.8	Specific Outcome Monozygotic twin studies Limit to investigating the effects of the environment on gene expression.		✓
23.1.9	Specific Outcome External factors impacting the pattern of gene expression Limit to one example of a hormone and one example of a biochemical such as lactose or tryptophan in bacteria.		✓
24	Topic Continuity and change—Cells—Water potential	✓	
24.1	General Outcome How does water potential influence movement of water into and out of cells?	✓	
24.1.1	Specific Outcome Water potential as the potential energy of water per unit volume Students should understand that it is impossible to measure the absolute quantity of the potential energy of water, so values relative to pure water at atmospheric pressure and 20°C are used. The units are usually kilopascals (kPa).	✓	
24.1.2	Specific Outcome Movement of water from higher to lower water potential Students should appreciate the reasons for this movement in terms of potential energy.	✓	

Curriculum Elements		Biology (Higher) 25-3	Biology (Higher) 25-5
24.1.3	Specific Outcome Contributions of solute potential and pressure potential to the water potential of cells with walls Use the equation ψw = ψs = ψ p. Students should appreciate that solute potentials can range from zero downwards and that pressure potentials are generally positive inside cells, although negative pressure potentials occur in xylem vessels where sap is being transported under tension.	✓	
24.1.4	Specific Outcome Water potential and water movements in plant tissue Students should be able to explain in terms of solute and pressure potentials the changes that occur when plant tissue is bathed in either a hypotonic or hypertonic solution.	✓	
25	Topic Continuity and change—Organisms—Reproduction	✓	✓
25.1	General Outcome How does sexual reproduction in plants exemplify themes of change or continuity? What changes within organisms are required for reproduction?	✓	✓
25.1.1	Specific Outcome Sexual reproduction in flowering plants Include production of gametes inside ovules and pollen grains, pollination, pollen development and fertilization to produce an embryo. Students should understand that reproduction in flowering plants is sexual, even if a plant species is hermaphroditic.	✓	✓
25.1.2	Specific Outcome Features of an insect-pollinated flower Students should draw diagrams annotated with names of structures and their functions.	✓	✓
25.1.3	Specific Outcome Methods of promoting cross-pollination Include different maturation times for pollen and stigma, separate male and female flowers or male and female plants. Also include the role of animals or wind in transferring pollen between plants.	✓	✓
25.1.4	Specific Outcome Self-incompatibility mechanisms to increase genetic variation within a species Students should understand that self-pollination leads to inbreeding, which decreases genetic diversity and vigour. They should also understand that genetic mechanisms in many plant species ensure male and female gametes fusing during fertilization are from different plants.	✓	✓
25.1.5	Specific Outcome Dispersal and germination of seeds Distinguish seed dispersal from pollination. Include the growth and development of the embryo and the mobilization of food reserves.	✓	✓
26	Topic Continuity and change—Organisms—Inheritance	✓	✓
26.1	General Outcome What patterns of inheritance exist in plants and animals? What is the molecular basis of inheritance patterns?	✓	✓

Curriculum Elements		Biology (Higher) 25-3	Biology (Higher) 25-5
26.1.1	Specific Outcome Box-and-whisker plots to represent data for a continuous variable such as student height Application of skills: Students should use a box-and-whisker plot to display six aspects of data: outliers, minimum, first quartile, median, third quartile and maximum. A data point is categorized as an outlier if it is more than 1.5 × IQR (interquartile range) above the third quartile or below the first quartile.	✓	✓
26.1.2	Specific Outcome Use of a chi-squared test on data from dihybrid crosses Students should understand the concept of statistical significance, the p= 0.05level, null/alternative hypothesis and the idea of observed versus expected results. *NOS:* Students should recognize that statistical testing often involves using a sample to represent a population. In this case the sample is the F2 generation. In many experiments the sample is the replicated or repeated measurements.		✓
27	Topic Continuity and change—Ecosystems—Stability and change	✓	✓
27.1	General Outcome What features of ecosystems allow stability over unlimited time periods? What changes caused by humans threaten the sustainability of ecosystems?	✓	✓
27.1.1	Specific Outcome Sustainability as a property of natural ecosystems Illustrate ecosystem sustainability with evidence of forest, desert or other ecosystems that have shown continuity over long periods. There is evidence for some ecosystems persisting for millions of years.	✓	✓
27.1.2	Specific Outcome Requirements for sustainability in ecosystems Include supply of energy, recycling of nutrients, genetic diversity and climatic variables remaining within tolerance levels.	✓	✓
27.1.3	Specific Outcome Deforestation of Amazon rainforest as an example of a possible tipping point in ecosystem sustainability Include the need for a large area of rainforest for the generation of atmospheric water vapour by transpiration, with consequent cooling, air flows and rainfall. Include uncertainty over the minimum area of rainforest that is sufficient to maintain these processes. Application of skills: Students should be able to calculate percentage change. In this case the extent of deforestation can be assessed by calculating the percentage change from the original area of forest.	✓	✓
27.1.4	Specific Outcome Use of a model to investigate the effect of variables on ecosystem sustainability Mesocosms can be set up in open tanks but sealed glass vessels are preferable because entry and exit of matter can be prevented but energy transfer is still possible. Aquatic or microbial ecosystems are likely to be more successful than terrestrial ones. *NOS:* Care and maintenance of the mesocosms should follow IB ethical experiment guidelines.	✓	✓

Curriculum Elements		Biology (Higher) 25-3	Biology (Higher) 25-5
27.1.5	Specific Outcome Eutrophication of aquatic and marine ecosystems due to leaching Students should understand the effects of eutrophication resulting from leaching of nitrogen and phosphate fertilizers, including increased biochemical oxygen demand (BOD).		✓
27.1.6	Specific Outcome Effects of microplastic and macroplastic pollution of the oceans Students should understand that plastics are persistent in the natural environment due to non-biodegradability. Include examples of the effects of plastic pollution on marine life. NOS: Scientists can influence the actions of citizens if they provide clear information about their research findings. Popular media coverage of the effects of plastic pollution on marine life changed public perception globally, which has driven measures to address this problem.		✓
27.1.7	Specific Outcome Restoration of natural processes in ecosystems by rewilding Methods should include reintroduction of apex predators and other keystone species, re-establishment of connectivity of habitats over large areas, cessation of agriculture and resource harvesting and minimization of human influences including by ecological management. Include the example of Hinewai Reserve in New Zealand.		✓
28	Topic Continuity and change—Ecosystems—Climate change	✓	✓
28.1	General Outcome What are the impacts of climate change on ecosystems?	✓	✓
28.1.1	Specific Outcome Poleward and upslope range shifts of temperate species As evidence-based examples, include upslope range shifts for temperate-zone montane bird species in New Guinea and range contraction and northward spread in North American tree species.		✓
28.1.2	Specific Outcome Threats to coral reefs as an example of potential ecosystem collapse Increased carbon dioxide concentrations are the cause of ocean acidification and suppression of calcification in corals. Increases in water temperature are a cause of coral bleaching. Loss of corals causes the collapse of reef ecosystems.		✓
28.1.3	Specific Outcome Afforestation, forest regeneration and restoration of peat-forming wetlands as approaches to carbon sequestration *NOS:* There is active scientific debate over whether plantations of non-native tree species or rewilding with native species offer the best approach to carbon sequestration. Peat formation naturally occurs in waterlogged soils in temperate and boreal zones and also very rapidly in some tropical ecosystems.		✓

Curriculum Elements		Biology (Higher) 25-3	Biology (Higher) 25-5
28.1.4	**Specific Outcome** Regeneration rates of natural ecosystems Include Hinewai Reserve in New Zealand as one example of rapid regeneration of natural ecosystems after a period of ecological degradation. Also include a local example of regeneration.	✓	✓
28.1.5	**Specific Outcome** Phenology as research into the timing of biological events Students should be aware that photoperiod and temperature patterns are examples of variables that influence the timing of biological events such as flowering, budburst and bud set in deciduous trees, bird migration and nesting.	✓	✓
28.1.6	**Specific Outcome** Disruption to the synchrony of phenological events by climate change Students should recognize that within an ecosystem temperature may act as the cue in one population and photoperiod may be the cue in another. Include spring growth of the Arctic mouse-ear (Cerastium arcticum) and arrival of migrating reindeer (Rangifer tarandus) as one example. Also include a suitable local example or use the breeding of the great tit (Parus major) and peak biomass of caterpillars in north European forests as another.	✓	✓
28.1.7	**Specific Outcome** Increases to the number of insect life cycles within a year due to climate change Use the spruce bark beetle (Ips typographus or Dendroctonus micans) as an example.	✓	✓

Statement of Overlap with Existing Programs

Similar / Overlapping Courses	**Description of Similarity / Overlap - Rationale**
Biology 20	There are some similarities in several areas of study.
	Although there is some content in Biology (Higher) that could potentially be taught as 'extensions' in Biology 20, there is no significant overlap in the learning outcomes of the two courses.
Biology 30	There are some similarities in several areas of study.
	Although there is some content in Biology (Higher) that could potentially be taught as 'extensions' in Biology 30, there is no significant overlap in the learning outcomes of the two courses.
Science 10	There are some similarities in several areas of study.
	Although there is some content in Biology (Higher) that could potentially be taught as 'extensions' in Science 10, there is no significant overlap in the learning outcomes of the two courses.