BIOLOGY SYLLABUS

Pre-University

Higher 3

Syllabus 9816

Implementation starting with
2021 Pre-University One Cohort

Ministry of Education
SINGAPORE

CONTENTS

Page

1. INTRODUCTION

1.1 Background

The MOE-H3 Biology (9816) syllabus is designed to build on and extend the knowledge, understanding and skills acquired from the H2 Biology (9744) syllabus. It caters to students of strong ability and keen interest in biology, and is designed with a strong emphasis on independent and self-directed learning. Students should simultaneously offer H2 Biology. The H3 Biology syllabus is meant to provide a comprehensive understanding of the subject through depth and rigour, not only for students pursuing further studies in the biology-related fields, but also for those who would find the knowledge and understanding useful in future.

1.2 Aims

The aims of a course based on this syllabus should be to:

1. provide students with an experience that deepens their knowledge and skills, and fosters attitudes necessary for further studies in related fields

2. develop in students an appreciation of the practice, value and rigour of biology as a discipline

3. develop in students the skills to think deeply, laterally and critically about biological issues, so that they can critically analyse what they have read and respond through writing well-structured arguments that integrate knowledge and skills acquired from different areas of biology

4. develop in students the skills needed for effective communication to different audiences through a range of styles, modes and tools.

1.3 Practices of Science

Science as a discipline is more than the acquisition of a body of knowledge (e.g. scientific facts, concepts, laws, and theories); it is a way of knowing and doing. It includes an understanding of the nature of scientific knowledge and how this knowledge is generated, established and communicated. Scientists rely on a set of established procedures and practices associated with scientific inquiry to gather evidence and test their ideas on how the natural world works. However, there is no single method and the real process of science is often complex and iterative, following many different paths. While science is powerful, generating knowledge that forms the basis for many technological feats and innovations, it has limitations.

Teaching students the nature of science helps them to develop an accurate understanding of what science is and how it is practised and applied in society. Students should be encouraged to consider relevant ethical issues, how scientific knowledge is developed, and the strengths and limitations of science. Teaching the nature of science also enhances the students' understanding of science content, increases their interest in science and helps show its human side. Science teaching should emphasise *how* we know as well as *what* we know.

Understanding the nature of scientific knowledge, demonstrating science inquiry skills and relating science and society are the three components that form our Practices of Science. Students' understanding of the nature and limitations of science and scientific inquiry are developed effectively when the practices are taught in the context of relevant science content. Attitudes relevant to science such as inquisitiveness, concern for accuracy and precision, objectivity, integrity and perseverance are emphasised.

The curriculum provides opportunities for students to reflect how the Practices of Science contribute to the accumulation of scientific knowledge. Students are encouraged to think about the 'whys' when planning and conducting investigations, developing models[1] or engaging in scientific arguments. Through such reflection, they can come to understand the importance of each practice and develop a nuanced appreciation of the nature of science.

[1] A model is a representation of an idea, an object, a process or a system that is used to describe and explain phenomena that may or may not be experienced directly. Models exist in different forms from the concrete, such as physical scale models, to abstract representations, such as diagrams or mathematical expressions. Students should appreciate that model development requires making decisions about what aspects of a specific situation are important for the model being used, and understand that all models contain approximations and assumptions that allow them to be used and deployed while potentially limiting their validity and predictive power.

The *Practices of Science* comprise three components:

A. Understanding the nature of scientific knowledge
B. Demonstrating science inquiry skills
C. Relating science and society

A. Understanding the Nature of Scientific Knowledge

- A1. Understand that science is an evidence-based, model-building enterprise concerned with the natural world
- A2. Understand that the use of both logic and creativity is required in the generation of scientific knowledge
- A3. Recognise that scientific knowledge is generated from consensus within the community of scientists through a process of critical debate and peer review
- A4. Understand that scientific knowledge is reliable and durable, yet subject to revision in the light of new evidence

B. Demonstrating Science Inquiry Skills

- B1. Identify scientific problems, observe phenomena and pose scientific questions/hypotheses
- B2. Plan and conduct investigations by selecting the appropriate experimental procedures, apparatus and materials with due regard for accuracy, precision and safety
- B3. Obtain, organise and represent data in an appropriate manner
- B4. Analyse and interpret data
- B5. Construct explanations based on evidence and justify these explanations through sound reasoning and logical argument
- B6. Use appropriate models to explain concepts, solve problems and make predictions
- B7. Make decisions based on evaluation of evidence, processes, claims and conclusions
- B8. Communicate scientific findings and information using appropriate language and terminology

C. Relating Science and Society

- C1. Recognise that the application of scientific knowledge to problem solving could be influenced by other considerations such as economic, social, environmental and ethical factors
- C2. Demonstrate an understanding of the benefits and risks associated with the application of science to society
- C3. Use scientific principles and reasoning to understand, analyse and evaluate real-world systems, as well as to generate solutions for problem solving

Developing 21st Century Competencies through the Learning of Science

To prepare our students for the future, a Framework for 21st Century Competencies (21CC) and Student Outcomes was developed by MOE (see **Figure 1.1**). This 21CC framework is meant to equip students with the key competencies and mindsets to be successful in the 21st century.

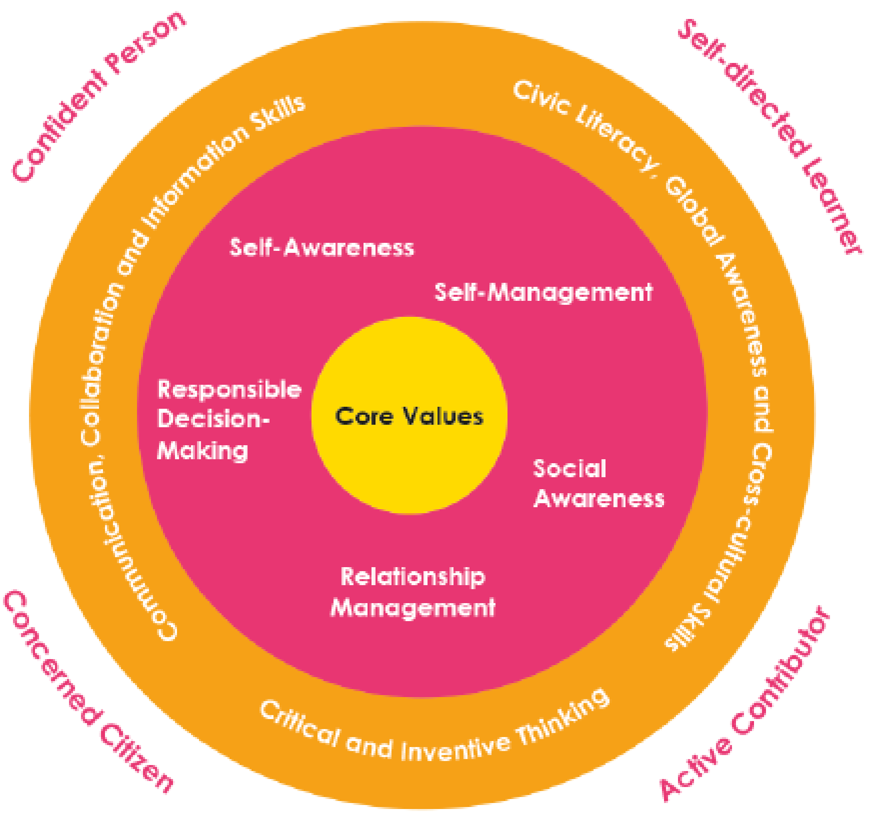

Figure 1.1: Framework for 21st Century Competencies and Student Outcomes

The features and intent of the Practices of Science are consistent with the emphasis on developing 21CC in our students.

The development of 21CC is not separate from the learning of science. The features of scientific inquiry, such as the processes of scientific investigation, reasoning, modelling and problem solving support a student's development of 21CC. The nature and limitations of science and scientific inquiry are developed effectively when scientific practices are learnt in the context of relevant science content. Deep disciplinary learning in science develops 21CC and promotes the process of learning for transfer to other areas of life.

1.4 H3 Biology Curriculum Framework

The MOE-H3 Biology Curriculum Framework (see **Figure 1.2**) encapsulates the key features of the curriculum in broad strokes. This framework is aligned to that of H2 Biology, anchored by the same Core Ideas. Throughout the study of additional H3 content, explicit links will be made to the Core Ideas, deepening students' understanding of these and allowing a more sophisticated exploration of the Practices of Science (POS). Appropriate Learning Experiences will also feature prominently in H3 Biology to enhance students' learning.

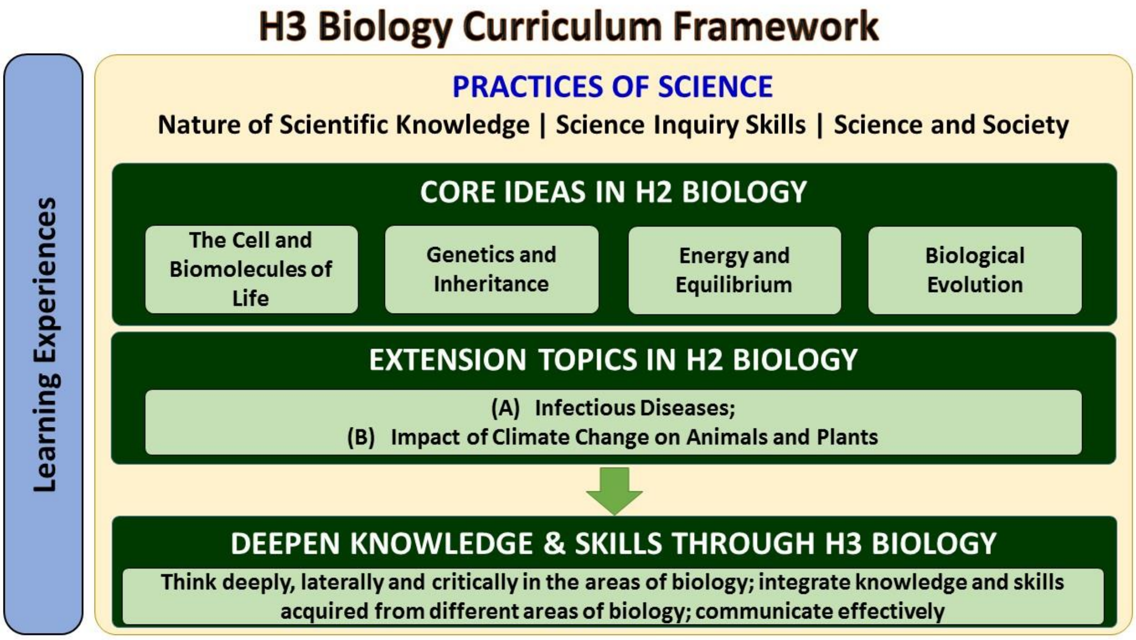

Figure 1.2: H3 Biology Curriculum Framework

The Practices of Science are common to the natural sciences of Physics, Chemistry and Biology. These practices highlight the ways of thinking and doing that are inherent in the scientific approach, with the aim of equipping students with the understanding, skills, and attitudes shared by the scientific disciplines, including an appropriate approach to ethical issues.

The content in this H3 Biology syllabus is organised around the four Core Ideas and two Extension Topics, which correspond to those in the syllabus for H2 Biology. The two Extension Topics are based on important emerging biological issues impacting both the local and global contexts. They require students to demonstrate the assimilation of the Core Ideas and extend their knowledge and understanding to real-world challenges. Furthermore, the Extension Topics will equip students with the necessary knowledge and process skills to make informed decisions about scientific issues.

Students are expected to study all four Core Ideas and both Extension Topics.

Through H3 Biology, students acquire the skills for thinking deeply, laterally and critically in the areas of biology; the ability to critically analyse what they have read and respond through writing well-structured arguments that integrate knowledge and skills acquired from different areas of biology; and the skills for effective communication to different audiences through a range of styles, modes and tools.

2. CONTENT

2.1 Additional Content

The additional content in the MOE-H3 Biology syllabus is organised into the four Core Ideas and two Extension Topics, which correspond to those in the syllabus for H2 Biology.

Within each of these Core Ideas or Extension Topics, information is organised into:

1. Narrative
2. Guiding Questions
3. Learning Outcomes

The Guiding Questions are open-ended, as they are meant to make connections between topics/concepts and reveal the underlying threads and unifying themes of the H2 content.

The Learning Outcomes list the specific content of the H3 syllabus. **H2 Learning Outcomes are not listed, but are all assessable as part of the H3 assessment**.

2.2 Core Idea 1: The Cell and Biomolecules of Life

Core Idea 1 – The Cell and Biomolecules of Life – entails the study of cells, which are the basic units of life.

Students can frame their learning using the following questions:

- Why is a cell the basic unit of life and how do cells promote continuity of life?
- How is the basic unit crucial in understanding life?
- How are the structures of biomolecules related to their functions?
- How do cells regulate the movement of substances into and out of themselves, and what are the implications of such movements?
- What are the differences between cells of prokaryotes and eukaryotes, between cells of plants and animals, and between cells of unicellular and multicellular organisms?
- In what ways do viruses not fit the cell model?

Sub-cellular structures provide the means to drive cellular processes

Knowing how cellular structures facilitate specific cellular processes is fundamental to explaining how life works. The cell theory states that the cell is the smallest and most basic unit of life and that cells grow from existing cells. Understanding the role of cellular organelles (such as the nucleus, ribosome, chloroplast and mitochondrion) and cellular structures (for example, the cytoskeleton) will help in understanding the concept of how structure relates to function.

There are significant differences between cells of prokaryotes and eukaryotes. Using bacteria as a model, the nucleoid is not enclosed by any membrane. Plasmids may be present as extra-chromosomal DNA. Membrane-bound organelles, such as mitochondria and endoplasmic reticulum, are absent. Prokaryotic ribosomes are different from eukaryotic ribosomes. Some bacterial cells have cell walls that comprise peptidoglycan rather than cellulose. Within the eukarya domain, the cell model of plants is also different from that of animals. Unlike unicellular organisms which merely undergo cellular division, cells of multicellular organisms undergo division and differentiation to allow them to carry out their specific functions.

Biomolecules make up cells and cells regulate many cellular processes, including the movement of substances into and out of themselves, through membranes

The different classes of biomolecules (sugars, fatty acids, amino acids and nucleotides) function as molecular building blocks for macromolecules (polysaccharides, lipids, proteins and nucleic acids). Nucleic acids, which include DNA and RNA, are made from monomers known as nucleotides. Phospholipids, cholesterol, carbohydrates and proteins are important components in biological membranes.

Cells need to regulate the movement of substances into and out of themselves. Substances such as water, oxygen, glucose and minerals are important in the synthesis of new molecules and important cellular processes. According to the fluid mosaic model, cell membranes are selectively permeable due to the nature of the phospholipids and proteins from which they are made. The movement of different molecules depends on the nature of the substances through transport processes such as osmosis, diffusion and active transport. Membranes allow cells to create and maintain internal environments that are different from external environments.

Eukaryotic cells also contain internal membrane structures that partition the cell into specialised compartments so that cellular processes can occur with optimal activity e.g. chloroplasts and mitochondria. The endomembrane system, consisting of rough and smooth endoplasmic reticulum and Golgi apparatus, is responsible for protein processing and vesicular transport within the cell.

Prokaryotes generally lack such membrane-bound organelles and endomembrane systems; yet they survive and reproduce. In the endosymbiotic theory, organelles like mitochondria and chloroplasts represent formerly free-living prokaryotes that were taken inside another cell, and this could explain the link between the two domains in the tree of life.

In contrast to eukaryotic and prokaryotic cells, viruses lack several of those cellular structures. They rely on eukaryotes and prokaryotes to reproduce. In this regard, viruses are considered obligate parasites and there is debate as to whether viruses are living or non-living organisms.

Proteins, which are a class of biomolecules, play significant roles in cells

Proteins play a variety of roles in cells including structural, transport, enzymatic and signalling functions. They are essential for biological processes and functions, such as chemiosmosis, protein synthesis, cell signalling, immunology and blood glucose homeostasis. Protein structure can be affected by temperature and pH. Enzymes are an important group of proteins that control many biological reactions. The functions of these proteins will be revisited in the other Core Ideas.

Stem cells have the potential to divide and differentiate into different cell types

Following fertilisation, a single-cell zygote develops into a multicellular organism. The zygote can replicate its DNA, divide its nucleus and divide into two genetically-identical cells. Cell potency describes a cell's ability to differentiate into other cell types. The zygote and cells formed from the first few cell divisions during embryonic development (up to the eight-cell stage) produce totipotent cells. Beyond the eight-cell stage, one of the two daughter cells remains undifferentiated, retaining the ability to divide indefinitely as a stem cell, while the other daughter cell differentiates. After the eight-cell stage, the cells begin to specialise into pluripotent stem cells. Pluripotent stem cells undergo further specialisation into multipotent cells, which can further differentiate to become unipotent stem cells.

Environmental signals trigger the differentiation of a cell into a more specialised form. Cell differentiation involves changing or regulating the expression patterns of genes. Each specialised cell type in an organism expresses a subset of all the genes that constitute the genome and this expression is regulated by various mechanisms resulting in differential gene expression of the same genome.

It is important to recognise that a cell is dynamic in nature and not a static structure. At any point of time, numerous activities are occurring in the cell. In a plant cell, photosynthesis and respiration can be occurring simultaneously. This causes biochemical changes in the cytoplasm of the plant cell. If it is necessary to produce more chlorophyll pigments or increase the amount of cellulose, the rate of protein synthesis in those biochemical pathways will increase.

Core Idea 1: The Cell and Biomolecules of Life

<table>
<tr><th>GUIDING QUESTIONS</th><th>LEARNING OUTCOMES</th></tr>
<tr><td>How has the membrane theory developed to the current understanding?</td><td>(a) Describe how the fluid mosaic model of the cell membrane has developed to the current understanding.</td></tr>
<tr><td>How do the following challenge the cell theory - acellularity (prions and viruses), multinucleation (hyphae of some fungi) and the endosymbiotic theory?</td><td>(b) Describe the basic characteristics of
i. prions (including morphology and replication)
ii. Fungi (including the morphology and life-cycle of yeasts and filamentous fungi)
iii. Protoctista (including algae)
(c) Explain the following terms and discuss the extent to which each conforms to the cell theory:
i. acellularity (including prions and viruses),
ii. multinucleation (including hyphae of filamentous fungi)
iii. endosymbiosis (including endosymbiotic origin of eukaryotes)</td></tr>
<tr><td>Is it possible to have a multicellular organism without cellular differentiation?</td><td>(d) Justify the need for cell differentiation in multicellular organisms.</td></tr>
<tr><td rowspan="3">How does a complex network of protein interactions underlie cell function?</td><td>(e) Describe protein binding sites and protein subunits in producing large protein and glycoprotein molecules (including haemoglobin, immunoglobulin, prokaryotic RNA polymerase).</td></tr>
<tr><td>(f) Explain, with examples, how protein modification, (including cleavage, phosphorylation and glycosylation) confer new capabilities.</td></tr>
<tr><td>(g) Discuss and explain why proteins are able to recognise and bind to highly diverse molecules, with reference to the properties and shapes of their surfaces and clefts that allow highly complementary interactions.</td></tr>
<tr><td>How do so many enzymes work efficiently in ensuring that the cellular machinery operates efficiently?</td><td>(h) Discuss how a living eukaryotic cell regulates thousands of enzymes.</td></tr>
</table>

2.3 Core Idea 2: Genetics and Inheritance

An understanding of *Genetics and Inheritance* helps make sense of the transition from molecular to organismal levels. *Genetics and Inheritance* provides the molecular basis for understanding how variation in populations arises and this is important in the study of biological evolution. At the cellular level, expression of genes involves structures such as the nucleus, endoplasmic reticulum and ribosome. Many essential products of gene expression are enzymes involved in biochemical pathways that control physiological functions. As such, mutation of genes may give rise to dysfunctional proteins which, in turn, could result in diseases. Sickle cell anaemia and cancer are some examples of genetic diseases.

Students can frame their learning using the following questions:

- How does the genetic make-up of an organism and the environment influence the organism's appearance, behaviour and survival?
- How does the inheritance of genetic information ensure the continuity of humans as a species?

Heritable information, in the form of DNA (and in some cases RNA), provides for continuity of life

Genetic information is stored in an organism's DNA; expression of genes results in the synthesis of functional products, such as rRNA, tRNA and proteins. These products play a role in intra- and extra-cellular biochemical pathways and influence the physiological processes in organisms.

Genomes contain heritable information necessary for continuity of life at all levels: cell, organism and system. This information is stored and passed on to subsequent generations via DNA. Reproduction can occur at the cellular or organismal level; each progeny needs to receive heritable genetic information from its parent(s).

An understanding of how eukaryotic, prokaryotic and viral genomes are organised has implications on how gene expression in organisms is controlled. The genome of prokaryotes typically comprises a large circular chromosome and smaller plasmids. Generally, structural genes, which code for proteins essential for bacterial survival, are found in the main chromosome while genes that confer advantages to bacterial survival in stressful environments are found in the plasmids. Prokaryotes reproduce by binary fission. In addition, genetic material can be transferred between bacteria through transformation, transduction and/or conjugation. This transfer of genetic material gives rise to genetic variation within a bacteria population.

In contrast, eukaryotic genomes are organised in a more complex manner. DNA is wrapped around histone proteins and compacted to form linear chromosomes; the number of chromosomes varies between eukaryotic species. Structurally, linear chromosomes have centromeres and telomeres, and their DNA consists of coding and non-coding sequences with the latter being in larger proportions. Coding DNA is expressed to give functional products (e.g. proteins, rRNA, tRNA) while non-coding DNA, e.g. control elements and centromeres, are involved in regulation of gene expression and nuclear division respectively.

Unlike prokaryotes and eukaryotes, the genome of viruses varies greatly; they can be DNA or RNA in nature and single or double-stranded, depending on the type of virus. Viruses undergo different reproductive cycles: some bacteriophages like the T4 phage reproduce via the lytic cycle while others like the lambda phage, reproduce via the lytic and/or lysogenic cycles; animal viruses, such as influenza virus and HIV, reproduce through other mechanisms. Again, unlike their prokaryotic or eukaryotic counterparts, viruses do not photosynthesise or respire, and they require host cells (bacteria, plants or animals) to reproduce. As such, there is much debate as to whether viruses are considered to be living or non-living organisms.

Expression of genetic information involves molecular mechanisms and gene regulation results in differential gene expression

In a single organism, the genes contained in all the nuclei of somatic cells are exactly the same, but the cell types differ morphologically and functionally. The differences between cell types are not due to different genes being present, but due to differential gene expression, i.e. the expression of different sets of genes by cells with the same genome.

Regulation of gene expression gives a cell control over its structure and function. It allows cell differentiation to occur. It may be controlled by the way DNA is packed in chromatin and at the various steps of protein synthesis, i.e. from transcription to post-translational modification of a protein. It is the basis for cellular differentiation and morphogenesis which gives an organism versatility and adaptability. Gene expression can be studied using fundamental techniques of molecular biology such as the polymerase chain reaction (PCR), gel electrophoresis, Southern blotting and nucleic acid hybridisation.

The cell cycle is tightly regulated

The cell cycle comprises interphase, nuclear division and cytokinesis. There are two types of nuclear division: mitosis and meiosis. A cell cycle that involves mitosis will give rise to genetically identical cells and this is important for growth, repair and the asexual reproduction of organisms. This cycle is coupled intricately with another important process of the living cell: DNA replication, which occurs during the synthesis phase of interphase. The mitotic cell cycle is tightly regulated at various checkpoints that control the rate of cell division; uncontrolled cell division could result in cancer.

A cell cycle that involves meiosis occurs in the reproductive organs of organisms and is important for sexual reproduction. Meiosis results in gametes having half the amount of genetic material present in somatic cells. The crossing-over of non-sister chromatids and the independent assortment of bivalents in meiosis, together with the random fertilisation of male and female gametes, contribute to genetic variation in populations. Genetic variation is essential for natural selection to occur. Homogeneity of a population can result in the entire population being wiped out by diseases or climatic change.

Mutation arises from imperfect replication of genetic information; together with other biological processes, such mutations increase genetic variation

Based on the central dogma, a change in the sequence of the DNA nucleotide, i.e. gene mutation, may affect the amino acid sequence in the polypeptide and hence the phenotype of the organism. Many mutations are detrimental to the individual since they affect the normal functioning of the gene product, e.g. genetic diseases such as sickle cell anaemia. Others are neutral, often because they have no effect on the phenotype, e.g. a change in a DNA triplet which still codes for the same amino acid. Occasionally, mutations may be beneficial. For example, individuals that are heterozygous for a mutated haemoglobin gene that causes sickle cell anaemia have a selective advantage in areas where malaria is common. Besides mutation of genes, chromosomal aberration and changes in chromosome number may also occur. Down syndrome arises due to the presence of an additional copy of chromosome 21.

Mutation, meiosis and sexual reproduction give rise to genetic variation within a population. There are two kinds of genetic variation: continuous variation involves many genes, which have an additive effect in controlling a characteristic; and discontinuous variation, which involves one or just a few genes in controlling a characteristic. Besides these, environmental factors are known to influence the phenotype of organisms.

The expression of genes gives rise to functional products that affect the biochemical reactions and physiological functions of organisms. This demonstrates how the genotype and phenotype of an organism are related. Besides its genotype, the environment also plays a role in determining the phenotype of an organism and this is related to the field of epigenetics. Some examples of environmental factors include the availability of nutrients and changes in temperature.

The chromosomal basis of inheritance sheds light on the pattern of transmitting genes from parent to offspring

When Gregor Mendel first started his investigations into inheritance, the concept of genes had not existed yet. He used the term ‘traits’ in place of genes. By using genetic diagrams, the phenotypic and genotypic ratios of filial generations can be predicted for crosses involving monohybrid or dihybrid inheritance. In line with Mendelian genetics, pedigree diagrams can be used to predict the probability of inheriting genetic diseases such as haemophilia and Huntington’s disease.

Non-Mendelian inheritance involves more complex traits. For example, alleles of some genes exhibit co-dominance or incomplete dominance and some genes have multiple alleles or are found on the sex chromosomes. Furthermore, phenotype may depend on interactions between two or more genes, e.g. epistasis. In addition, the inheritance of linked genes does not follow Mendelian laws; in predicting the phenotypic and genotypic ratios of filial generations for linked genes, the occurrence and frequency of crossing over has to be considered.

Core Idea 2: Genetics and Inheritance

GUIDING QUESTIONS	LEARNING OUTCOMES
Consider the work of Sir Ian Wilmut's Dolly the sheep (on somatic cell nuclear transfer), Sir John Gurdon, Shinya Yamanaka (on re-programming mature cells by introducing a few genes to immature cells) and plant tissue culture work of returning mature cells to a stem cell state. How have these scientific endeavours challenged the thinking that specialised cells are irreversible?	(a) Discuss how mature cells can be returned to a stem cell state
What is the significance of genetic engineering?	(b) Explain that genetic engineering involves the insertion of a gene, obtained either by synthesis or by extraction from an organism, into another organism (of the same or different species), such that the receiving organism expresses the gene product. (c) Explain the roles of restriction endonucleases, reverse transcriptase and ligases in genetic engineering. (d) Outline the procedures for cloning a eukaryotic gene in a bacterial plasmid and describe the properties of plasmids that allow them to be used as DNA cloning vectors. (e) Explain how eukaryotic genes are cloned using *E. coli* cells to produce eukaryotic proteins. (f) Explain the structure and roles of ribozymes and their potential role in genetic engineering (including novel peptide synthesis and modifications). (g) Evaluate the significance of genetic engineering to the world and humanity (including food sustainability for a rapidly growing population, disease treatment and drug design).
How has epigenetics contributed to the study of genetics?	(h) Explain that epigenetics (including DNA methylation, histone modification and chromatin remodelling) is a process that affects the expression of specific genes, without involving a change in DNA sequence.
	(i) Discuss how epigenetics has contributed to the study of genetics and heredity.

2.4 Core Idea 3: Energy and Equilibrium

This core idea describes how energy is obtained, transformed and utilised in biological systems.

Students can frame their learning using the following questions:

- How do organisms obtain and use energy for growth and survival?
- How do organisms respond to internal and external changes?

Energy is needed to drive biochemical processes in organisms

To maintain life-sustaining processes, organisms require materials and energy from their environment. Nearly all energy that sustains life ultimately comes from the sun. Plants and other photosynthetic organisms make use of sunlight to synthesise carbohydrates from carbon dioxide and water during the process of photosynthesis. Light energy from the sun is converted into chemical energy in the form of carbohydrates. This chemical energy may be used to form plant matter or subsequently released to fuel activities within the plants.

All other organisms depend on autotrophs for energy, either directly, by feeding on autotrophs such as plants; or indirectly, as energy is passed along food chains from one organism to the next. Food provides a source of carbohydrates which are broken down to release energy to phosphorylate ADP to ATP during aerobic respiration. Anaerobic respiration follows a different and less efficient chemical pathway to provide ATP. ATP obtained from respiration is used to drive various essential cellular processes.

In eukaryotes, photosynthesis and respiration occur in membrane-bound organelles. Many steps in photosynthesis and respiration are controlled by enzymes sequestered in these organelles and therefore are also limited by similar factors that will affect enzymatic reactions.

Communication is needed for organisms to respond to the environment and maintain equilibrium

Organisms should be able to detect changes both from the surrounding environment and within themselves so that they are able to respond to these changes to maintain a constant internal environment. This ability to respond to changes is made possible due to coordination across the various biological systems as well as communication between cells.

Communication between cells can take the form of electrical or chemical transmission via the nervous or endocrine system respectively. The endocrine system facilitates communication between different cells through the release of hormones into the bloodstream. Binding of hormones to receptors on or within target cells initiates signal transduction and eventually results in a change in gene expression to bring about certain physiological changes. Defects in any part of the signalling pathway often lead to detrimental conditions such as metabolic diseases and cancer.

Core Idea 3: Energy and Equilibrium

GUIDING QUESTIONS	LEARNING OUTCOMES
How does carbon fixation in different types of photosynthesis mitigate global warming?	(a) Explain how the anatomy and physiology of the leaves of C4 plants, such as maize and sorghum, are adapted to minimise photorespiration and to allow high rates of carbon fixation at high temperatures in terms of: i. the spatial separation of initial carbon fixation from the light-dependent stage (biochemical details of the C4 pathway are required in outline only) ii. the high optimum temperatures of the enzymes involved.
	(b) Discuss and compare the importance in mitigating global warming of photosynthetic carbon fixation by C3 plants, C4 plants, CAM plants and algae, including those in reef-building corals. (c) Explain how the physiology of the leaves of CAM plants is adapted to minimise photorespiration and to allow photosynthesis while minimising water loss by transpiration, in terms of: i. the temporal separation of initial carbon fixation from the light-dependent stage (biochemical details of the CAM pathway are required in outline only) ii. stomatal opening during the night.
What was the role of oxygen during the early days of life on earth (oxygen was toxic to organisms) in the adaptation and diversification of organisms?	(d) Explain, with reference to a range of well-supported hypotheses, the changes in atmospheric oxygen concentration during the evolution of life on Earth and evaluate the importance of these changes to evolution.
How and why do cells and organisms communicate?	(e) Describe and explain the transmission of an action potential along a myelinated neurone (the importance of Na^+ and K^+ ions in the impulse transmission should be emphasised). (f) Describe the structure of a cholinergic synapse and explain how it functions, including the role of Ca^{2+} ions. (g) Explain that quorum sensing is a system of signalling processes that respond to changes in population density in bacteria (gram-positive and gram-negative). (h) Explain the need for control in organised systems and explain the principles of homeostasis in terms of receptors, effectors and negative feedback. (i) Explain the need for different communication systems within organisms.

2.5 Core Idea 4: Biological Evolution

Core Idea 4 – Biological Evolution – helps students make sense of biology and the biodiversity of life on earth. Three important concepts within evolutionary biology are the:

1. definition of evolution and descent with modification;
2. processes of evolutionary change, natural selection and genetic drift; and
3. patterns of evolutionary relationships (depicted as phylogenetic trees or cladograms).

Students can frame their learning using the following questions:

- Why are there so many similarities among organisms yet so many different plants, animals and microorganisms?
- Why does biodiversity matter?

Natural selection is the major driving mechanism of evolution

The essential features of natural selection contribute to the change in the genetic makeup of a population over time. Darwin's theory of natural selection (and, in parallel, Wallace's similar observations and conclusions) states that inheritable variation occurs in individuals in a population.

Due to competition for resources that are often limited, individuals with more favourable variations or phenotypes are more likely to survive and produce more offspring, thus passing on the alleles that code for those traits to subsequent generations. Fitness is a measure of evolutionary success as indicated by the number of surviving offspring left to produce the next generation. It is worth noting that individual organisms do not evolve; rather, it is populations that evolve.

As the environment is always changing, a diverse gene pool is important for the long-term survival of a species. Genetic variation within a population contributes to the diversity of the gene pool. Changes in genetic information may be silent (with no observable phenotypic effects) or result in a new phenotype, which can be favourable, detrimental or neutral to the organism. The interaction of the environment and the phenotype determines the fitness of the phenotype; thus, the environment does not direct the changes in DNA, but acts upon phenotypes that occur through random changes in DNA. These changes can involve alterations in DNA sequences, changes in gene combinations and/or the formation of new gene combinations. Note that there is no perfect genome for organisms.

Although natural selection is usually the major mechanism for evolution, genetic change in populations can occur through other processes, including mutation, genetic drift, sexual selection and artificial selection. Inbreeding, small population size, non-random mating, absence of migration and a net lack of mutations can lead to a loss of genetic diversity.

Evidence of evolution by natural selection is derived from a wide range of studies, e.g. in biochemistry, morphology, genetic information from existing and extinct organisms, geology and physical science. Phylogenetic trees serve as dynamic models that show common ancestry while geographical distribution and the fossil record provide the evolutionary link between ancestral and present-day organisms.

The process of evolution explains the diversity of life

Changes in the gene pools of populations can occur as a result of environmental changes (including those caused by human activities) or major natural catastrophes. A diverse gene pool is vital for the survival of species when such changes occur. Small populations are especially sensitive to these forces. Mutations in DNA and recombination during meiosis are sources of variation; new genes and combinations of alleles may confer new phenotypes.

Speciation and extinction have occurred throughout Earth's history and life continues to evolve within a changing environment, thus explaining the diversity of life. New species arise when two populations diverge from a common ancestor and become reproductively isolated. Common core biological processes e.g. metabolic pathways like photosynthesis and respiration and the universal genetic code support the idea of common ancestry. Phylogenetic trees are used to model evolutionary relationships and descent with modification.

Core Idea 4: Biological Evolution

GUIDING QUESTIONS	LEARNING OUTCOMES
Why evolution is seen as the greatest show on earth?	(a) Explain, with examples, sexual selection and its significance for evolution.
	(b) Explain, with examples, the evolutionary concepts of adaptive radiation and ring species. (c) Discuss the contributions of polyploidy, hybridisation and introgression in evolution and their implications for reconstructing phylogenies.
To what extent can various biomolecules and processes (as found in the H2 syllabus) also be considered at the same level as the DNA in the understanding of evolution?	(d) Explain the significance of biomolecules, and the biochemical processes through which they are synthesised, to the understanding of evolution (biomolecules to include carbohydrates, lipids, proteins and nucleic acids).
What is the rationale behind the use of mitochondrial DNA and the y-chromosomal Adam (the Genographic Project) in tracing the ancestry and diaspora of humans?	(e) Discuss the contributions of mitochondrial DNA and the Y-chromosomal Adam (the Genographic Project) to trace and support the ancestry and diaspora of humans.

2.6 Extension Topic A: Infectious Diseases

Micro-organisms, e.g. viruses and bacteria, cause diseases which disrupt the equilibrium of physiological systems in humans. This extension topic explores how some infectious diseases are diagnosed and treated.

Students can frame their learning using the following questions:

- What cause infectious diseases?
- How does the body respond during an infection?
- How can infectious diseases be prevented or diagnosed and treated?

With an understanding of how the human immune system functions, students explore the development of vaccines and how vaccines are used to eradicate infectious diseases like smallpox. Yet, not all viruses can be eliminated by vaccines. The HIV and influenza viruses infect humans. While vaccinations and treatment through anti-viral drugs are available, the viruses are still present in the population due to their high mutation rate which could give rise to drug-resistant strains. Besides viral infections, diseases can also be caused by bacterial infections. Tuberculosis is caused by the bacterium *Mycobacterium tuberculosis*. Although successful vaccination programmes in Singapore have kept the infection under control, there have been new cases appearing in the population and it remains a fatal disease in developing countries.

Extension Topic A: Infectious Disease

GUIDING QUESTIONS	LEARNING OUTCOMES
Is the immune system necessary to ensure the survival of all organisms?	(a) Explain why specific (adaptive) and non-specific (innate) immunity can be both mutually exclusive and interdependent in the protection against pathogens. (b) Explain how immunological self-tolerance ensures that B lymphocytes and T lymphocytes do not normally attack host cells that are functioning correctly. (c) Explain why the human microbiota is important for our health.
Why do most of the current epidemics not develop into pandemics and hence, evaluate the possibility of a future pandemic.	(d) Explain the factors affecting the probability that a pandemic will occur, including sanitation, water supply, food, climate, large-scale movements of people, evolution of new strains of virulent pathogens and development of drug resistance.

2.7 Extension Topic B: Impact of Climate Change On Animals and Plants

Climate change, which is attributed to an increase in the emission of greenhouse gases, has great impact on the human population. By the year 2050, climate change is expected to cause the extinction of approximately at least one quarter of all species on land. In the oceans, species such as corals, which are sensitive to warming temperatures, are also at great risk. Many species have evolved to survive within specific temperature ranges and cannot adapt to the new temperatures. In addition, the survival of a species is threatened when the species it depends on for food cannot adapt. The Intergovernmental Panel on Climate Change (IPCC) has predicted that by 2100, the Earth's surface will rise by up to 6°C on average. The effects of this temperature rise on species and ecosystems will be catastrophic. Currently, the following effects of global warming are evident: the melting of glaciers; the bleaching and dying of coral reefs; extreme storms, droughts, and heat waves; and major shifts in the timing of organisms' biological cycles.

Climate change is affecting the global ecology and ecosystem, e.g. loss of biodiversity and impact on food webs. The study of biological processes is important in understanding and taking appropriate action, e.g. the observation that many species are becoming smaller in size can be explained by fundamental ecological and metabolic principles. There are also consequences for both crop plants and protein sources, e.g. fish that are important for human nutrition.

As a small, low-lying city-state with one of the world's most open economies, Singapore is vulnerable to the harmful effects of climate change, such as rising sea levels and the increased frequency of rainfall.

Trends in our local weather records are consistent with the global observations of climate change. The weather has become increasingly hot. Since the 1970s, Singapore has experienced an average warming rate of 0.25°C per decade. The sea level has also risen. Tide gauge data in the Singapore Straits shows that the mean sea level has increased by about 3 mm per year over the last 15 years. More instances of short, intense rainfall have also been recorded within the last few years.

Extreme weather events can lead to changes in rainfall patterns, resulting in more intense rainfall or drier periods. Flood, haze and water management will be of greater importance to Singapore. In addition, an increase in the frequency of extreme weather events may lead to unstable global food prices and disruptions to business supply chains, which will affect our food imports and business activities in Singapore.

Disruption of ecosystems and loss of biodiversity have major impacts on the emergence, transmission, and spread of many human infectious diseases. For example, deforestation reduces the diversity of forest mosquitoes, which are the vectors for dengue. The species that survive and become dominant, for reasons that are not well understood, almost always transmit dengue better than the species that had been most abundant in the intact forests. Deforestation can also result in loss of habitat and food for species that serve as reservoirs for human disease. The resultant disturbance can bring the reservoir species into closer contact with humans, facilitating the spread of the disease to humans. An example is the original outbreak of Nipah virus infections in Malaysia.

Mosquitoes kill more people through the life-threatening diseases they spread than any other predators. Furthermore, mosquito-borne infectious diseases affect millions of people and debilitated people cannot work or support themselves. Climate change has influenced how mosquito-borne diseases have spread in the world through the effects on the diseases' vectors. Being in a region where two of the main mosquito-borne diseases (dengue and malaria) are endemic, an understanding of the intertwined processes of how vectors respond to climate change and how climate change affects the spread of these diseases are important to Singapore.

This topic explores the impact of climate change and three main areas of concern:

1. The need for a safe and sufficient food supply;
2. The threat of how infectious diseases are changing; and
3. The maintenance of ecosystems as reservoirs for bio-resources like medicine and food.

Students can frame their learning using the following questions:

- How can our way of life influence climate change?
- Why is there an urgent need to ameliorate climate change through an understanding and application of the sciences?

Extension Topic B: Impact of Climate Change on Animals and Plants

GUIDING QUESTIONS	LEARNING OUTCOMES
Is the pessimistic outcome of global warming inevitable, and is a pessimistic outcome of global warming inevitable, and how could this be humankind's greatest scientific challenge and endeavour?	(a) Discuss how humans are responding to mitigate climate change, including biological measures (such as tree planting and developing drought resistant varieties of crops) and lifestyle changes (such as reducing use of cars and consumption of meat).
To what extent does a sixth mass extinction looms in the near future in view of anthropogenic climatic change?	(b) Discuss, with examples, how animal and plant species can adjust and adapt to climate change, and the possible consequences of climate change for ecosystems and the organisms within them in the longer term.

3. PEDAGOGY

To achieve the aims of the MOE-H3 Biology syllabus, the Learning Experiences of the students should be one where the students are:

a. provided with a solid foundation in the subject such that the breadth and depth are carefully balanced to allow opportunities for the exploration of topics in greater detail while retaining a broad view of biology;
b. kept up-to-date through reading books and articles about cutting-edge science in fields such as molecular genetics, infectious diseases, and immunology, reflecting the subject's exciting and rapid rate of development in the last 20 years;
c. given ample time to work independently and discuss collaboratively to solve non-routine problems; critique different sources of information and data; and write coherent arguments to justify their claims; and
d. given opportunities to participate in either face-to-face or online talks, lectures, seminars and discussion forums, as well as to attend learning journeys and symposiums related to the subject.

The pedagogy and assessment should support this approach to learning. Formative assessment, in particular, should focus on the process of critiquing and reasoning, with feedback on the strategies used and how the arguments can be improved, beyond just a focus on the correctness of the solutions.

Learning science is more than acquiring the facts and the outcomes of scientific investigations as a body of knowledge. Science is also a way of knowing and doing. Through the Practices of Science, students should acquire an appreciation of the nature of scientific knowledge, the scientific enterprise as well as an understanding of the skills and processes in scientific inquiry:

- **Nature of scientific knowledge:** Students understand the nature of scientific knowledge implicitly through the process of 'doing science'. To complement this, an explicit approach may be used. This approach utilises elements from the history of science or the processes in science to improve students' views of the nature of scientific knowledge.

- **Science as an inquiry:** Broadly, scientific inquiry refers to the different approaches by which scientists study and develop an understanding of the natural and physical world around us. Inquiry-based instruction could be used to develop the different aspects of the Practices of Science together with the understanding of science concepts as well as the dispositions and attitudes associated with science. Strategies that could be used to support inquiry-based learning in science include questioning, demonstrations, use of technology, as well as models and modelling.

- **Relating science and society:** Students should appreciate how science and technology are used in daily life. Learning science in a real-life context accessible to students can increase their interest and enhance their awareness of the interconnections among science, technology, society and the environment.

Science practical work supports the teaching and learning of science through developing the Practices of Science*,* experimental techniques, practical manipulative skills and conceptual understanding. It also cultivates interest in science and in learning science. In addition, attitudes like objectivity and integrity, which are important in the learning of the discipline of science, are reinforced.

Through critical reading and scientific argumentation, scientific articles and journals could provide students with both up-to-date advances in science and authentic problems encountered by scientists. Peer discussion sessions could provide a platform for students to analyse the situation and share their thoughts. In particular, students are encouraged to read beyond the required learning outcomes, and be kept up-to-date through reading books and articles about cutting-edge science in fields such as molecular genetics, infectious diseases, and immunology, reflecting the subject's exciting and rapid rate of development.

Through partnership with Institutes of Higher Learning (IHLs), research institutes and industries, students are encouraged to participate in science fairs, learning journeys, workshops, seminars and dialogues with scientists. These varied experiences aim to give students an authentic taste of how science features in society, and would greatly enrich students' learning and inspire them to take up science as a career.

4. ASSESSMENT

Assessment is the process of gathering and analysing evidence about student learning. This information is used to make decisions about students, curricula and programmes. Assessment for Learning (AfL) is assessment conducted constantly during classroom instruction to support teaching and learning. With the feedback about the state of students' learning, teachers then adapt their teaching strategies and pace based on the students' needs. Assessment of Learning (AoL) aims to summarize how much or how well students have achieved at the end of a course of study over an extended period of time. The A-level examination is an example of AoL.

The syllabus has been arranged in the form of Core and Extension content to be studied by all candidates. The syllabus places emphasis on the applications of biology and the impact of recent developments on the needs of contemporary society.

4.1 Assessment Objectives

The assessment objectives listed below reflect those parts of the Aims and Practices of Science which will be assessed.

A Knowledge with understanding

Candidates should be able to demonstrate knowledge with understanding in relation to:

1. scientific phenomena, facts, laws, definitions, concepts and theories
2. scientific vocabulary, terminology and conventions (including symbols, quantities and units)
3. scientific instruments and apparatus, including techniques of operation and aspects of safety
4. scientific quantities and their determination
5. scientific and technological applications with their social, economic and environmental implications.

The syllabus content defines the factual materials that candidates need to recall and explain. Questions testing the objectives above will often begin with one of the following words: *define*, *state*, *name*, *describe*, *explain* or *outline*.

B Handling, applying and evaluating information

Candidates should be able (in words or by using symbolic, graphical and numerical forms of presentation) to:

1. locate, select, organise, interpret and present information from a variety of sources
2. handle information, distinguishing the relevant from the extraneous
3. manipulate numerical and other data and translate information from one form to another
4. present reasoned explanations for phenomena, patterns, trends and relationships
5. make comparisons that may include the identification of similarities and differences
6. analyse and evaluate information to identify patterns, report trends, draw inferences, report conclusions and construct arguments
7. justify decisions, make predictions and propose hypotheses
8. apply knowledge, including principles, to novel situations
9. use skills, knowledge and understanding from different areas of Biology to solve problems
10. organise and present information, ideas and arguments clearly and coherently, using appropriate language

These assessment objectives above cannot be precisely specified in the syllabus content because questions testing such skills are often based on information which is unfamiliar to the candidate. In answering such questions, candidates are required to use principles and concepts that are within the syllabus and apply them in a logical, reasoned or deductive manner to a novel situation. Questions testing these objectives may begin with one of the following words: *discuss*, *predict*, *suggest*, *calculate* or *determine*.

4.2 Scheme of Assessment

Paper 1 (2 h 30 min, 75 marks)

This paper will consist of two sections, as follows:

Section A (50 marks) will comprise **one** compulsory stimulus-based question (25 marks) that may consist of a variable number of structured subparts, including data-based items; and **one** compulsory free-response question (25 marks) with no subparts. For the free-response question, the quality of scientific argumentation and written communication will be given a percentage of the marks available.

Section B (25 marks) will comprise two free-response questions, from which candidates will choose **one**. The quality of scientific argumentation and written communication will be given a percentage of the marks available.

Questions in both sections may be set on any area of the H3 and H2 syllabuses, and may require candidates to use material from different areas of the syllabuses within a single answer. Marks will also be available for evidence shown for relevant reading around the subject.

Weighting of Assessment Objectives

Assessment Objectives		Weighting (%)
A	**Knowledge with understanding**	25
B	**Handling, applying and evaluating information**	75

4.3 Additional Information

Required Subject Combination:
Candidates should simultaneously offer H2 Biology.

For more information on assessment, please refer to the Singapore Examinations and Assessment Board *http://www.seab.gov.sg/*.

5. RESOURCES AND REFERENCES

Textbooks and References

1. Blum, D; Knudson, M and Henig, R M (2005) *A Field Guide for Science Writers: The Official Guide of the National Association of Science Writers* (Oxford University Press)
2. Bonita, R; Beaglehole, R and Kjellstrom, T (2006) *Basic Epidemiology* (WHO Press)
3. Boohan, R and Needham, R (2016) *The Language of Mathematics in Science: A Guide for Teachers of 11–16 Science* (Association for Science Education) www.ase.org.uk/mathsinscience
4. Carson, R (1962) *Silent Spring* (Houghton Mifflin)
5. Dawkins, R (2008) *The Oxford Book of Modern Science Writing* (Oxford University Press)
6. Dawkins, R (2010) *The Greatest Show on Earth: The Evidence for Evolution* (Transworld Publishers)
7. Hvistendahl, M (2012) *Unnatural Selection: Choosing Boys Over Girls, and the Consequences of a World Full of Men* (PublicAffairs)
8. Jones, S (2003) Y: *The Descent of Men* (Abacus)
9. Kolbert, E (2014) *The Sixth Extinction: An Unnatural History* (Bloomsbury Publishing)
10. Mukherjee, Siddhartha (2011). *The Emperor of All Maladies: A Biography of Cancer* (Scribner)
11. O'Brien, S J (2005) *Tears of the Cheetah: The Genetic Secrets of Our Animal Ancestors* (St. Martin's Griffin)
12. Pinker, S (2014) The Sense of Style: T*he Thinking Person’s Guide to Writing in the 21st Century* (Penguin)
13. Raup, D M and Sepkoski, J J (1982) *Mass Extinctions in the Marine Fossil Record Science* 215 (4539): 1501–1503
14. Ridley, M (2000) *Genome: The Autobiography of a Species in 23 Chapters* (Fourth Estate)
15. Ridley, M (2004) *Nature via Nurture: Genes, Experience and What Makes Us Human* (HarperCollins)
16. Skloot, R (2011) *The Immortal Life of Henrietta Lacks* (Pan Macmillan)
17. *Weiner*, J (1995) *The Beak Of The Finch* (Vintage Publishing)
18. Weiner, J (2005) *His Brother's Keeper: A Story from the Edge of Medicine* (Harper Perennial)
19. Wells, S (2004) *The Journey of Man: A Genetic Odyssey* (Random House Trade Paperbacks)
20. Zimmer, C (2009) *The Tangled Bank: An Introduction to Evolution* (Roberts and Company Publishers)
21. *The Best American Science and Nature Writing* (published yearly)

Online Resources

A wide range of online resources are available to schools on the Student Learning Space (SLS) and One Portal All Learners (OPAL) 2.0. Specific links and suggestions have been provided in the Teaching and Learning Guide.