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1. INTRODUCTION

1.1 BACKGROUND

Design of the A-Level science curriculum

As scientific and technological advances influence and impact how we live, communicate and interact with each other, it is important to offer a science education that develops in individuals knowledge of the core ideas in science and an understanding of the practices associated with scientific inquiry, which will enable them to make decisions on science-related issues and challenges brought about by these advances. To develop such individuals, research in science education has shown that there is a need to strike a balance between teaching the products of science (e.g. core ideas, theories, and models), the processes of science and the nature of science. These products, processes and nature of science have been articulated in the revised H2 science curriculum. The H1 science curriculum, which is designed as a subset of H2 science, will also incorporate these key features.

Purpose of H1 science curriculum

While H2 science develops in our students the disciplinary understanding, skills and attitudes necessary for further studies in the subject and related fields, H1 science is designed to broaden students’ learning and support the development of scientific literacy. The Practices of Science is a key feature in H1 science where greater emphasis would be placed on the development of those components that will enable students to become scientifically literate consumers and citizens. This is especially important for future citizens in an increasingly technologically-driven world. Leaders of the country should be equipped to make informed decisions based on sound scientific knowledge and principles about current and emerging science-related issues which are important to self, society and the world at large (for example, in appreciating the energy constraints faced by Singapore, or in understanding how epidemics can spread).

Key changes to H1 science curriculum

The key changes to the H1 science curriculum are in tandem with the changes in the H2 science curriculum. Namely, the use of Core Ideas to frame the teaching and learning of science, and the introduction of the Practices of Science to place emphasis on science as a way of knowing and doing, beyond viewing it as an acquisition of a body of knowledge. As in H2 science, H1 science also encourages the use of real-world contexts in teaching and learning, and in using a wider range of pedagogies through Learning Experiences.

Differences between H2 and H1 science curriculum

The Learning Experiences outlined in H2 science are largely relevant and applicable to H1 science. However, the actual choice of pedagogy and Learning Experiences would need to be carefully adapted and designed to suit the teaching for H1 science, especially in the area of science practical activities. There would be less emphasis on developing students’ proficiency in handling
equipment and in carrying out various laboratory tests and techniques. Instead, the focus of science practical experiences will be on developing students’ scientific knowledge and providing opportunities for students to understand the evidence-based nature of scientific knowledge.

1.2 **Purpose and Value of Biology**

In Singapore, biology education from the primary to the A-Level has been organised as a continuum in the following manner:

(a) From Primary 3 to 6, students learn about how life works at the systems level;
(b) From Lower Secondary science to O-Level Biology, students learn about how life works at the physiological level; and
(c) At the A-Level, students learn about how life works at the cellular and molecular level while understanding the implications on macro levels.

The Biology syllabus is developed as a seamless continuum from the O-Level to the A-Level, without the need for topics to be revisited at the A-Level. The O-Level syllabus is foundational and thus should provide the necessary background for study at the A-Level. Students who intend to offer H2 Biology will therefore be assumed to have knowledge and understanding of O-Level Biology, either as a single subject or as part of a balanced science course.

Many new and important fields of biology have emerged through recent advancements in life sciences. Vast amounts of knowledge have been generated as evident from the sprouting of scientific journals catering to niche areas of research. As such, this syllabus refines and updates the content knowledge of the previous syllabus (8875) so that students can keep themselves up to date with knowledge that is relevant for their participation in a technology-driven economy.

The value of learning H1 Biology ultimately hinges on the development of a scientific mind and disposition while addressing the broader questions of what life is and how life is sustained. The Science Curriculum Framework developed by MOE elaborates on the development of the scientific mind and disposition. Through the study of H1 Biology course, students should become scientifically literate citizens who are well prepared for the challenges of the 21st century.

1.3 **Aims**

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

1. provide students with an experience that develops their interest in biology and builds the knowledge, skills and attitudes necessary for them to become scientifically literate citizens who are well-prepared for the challenges of the 21st century;

2. develop in students the understanding, skills, ethics and attitudes relevant to the *Practices of Science*, including the following:
• understanding the nature of scientific knowledge
• demonstrating science inquiry skills
• relating science and society;

3. address the broader questions of what life is and how life is sustained, including:
• understanding life at the cellular and molecular levels, and making connections to how these micro-systems interact at the physiological and organismal levels
• recognising the evolving nature of biological knowledge
• stimulating interest in and demonstrating care for the local and global environment.

1.4 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 models¹ 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 cannot 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. The use of models involves the understanding that all models contain approximations and assumptions limiting their validity and predictive power.
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.

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.
1.5 **H1 Biology Curriculum Framework**

The rapid progress in the field of life sciences poses a challenge for biology education, especially in terms of designing a framework that integrates fundamental knowledge, skills and attitudes. With this in mind, this syllabus has adopted a framework that will chart a new direction for biology education. Figure 1.2 below provides an overview of this framework.

![Figure 1.2. Overview of the H1 Biology Curriculum Framework](image)

The content in this H1 Biology teaching and learning syllabus is organised around four core ideas of biology. For each core idea, pertinent, open-ended guiding questions are listed to help students frame the concepts and promote inquiry, while narratives allow links between concepts – both within and between core ideas – to be made.

Besides the core ideas, this H1 Biology teaching and learning syllabus features an extension topic. The extension topic is based on important emerging biological issues impacting both the local and global contexts. It requires students to demonstrate assimilation of the core ideas and extend their knowledge and understanding to real-world challenges. Furthermore, the extension topic 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 the extension topic.
2. CONTENT

2.1 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 does it promote continuity of life?
- How is the basic unit crucial in understanding life?
- How are the structures of biomolecules related to their functions?
- How is the movement of substances into and out of cells regulated, 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?

Sub-cellular structures provide the means to drive cellular processes

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 other cellular structures (for example, the cytoskeleton) will help in understanding the concept of how structure relates to function.

There are significant differences between the cells of prokaryotes and eukaryotes. For example, in prokaryotes the main genetic material (nucleoid) is not enclosed by a membrane and plasmids may be present as extra-chromosomal DNA. Furthermore, membrane-bound organelles such as mitochondria and endoplasmic reticulum are absent. Prokaryotic ribosomes are also different from eukaryotic ribosomes and bacterial cell walls comprise peptidoglycan, which is not found in the cell walls of eukaryotes. Within the eukarya domain, there are important differences between the cells of plants and 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. Knowing how cellular structures facilitate specific cellular processes is fundamental to explaining how life ‘works’.

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, lipids, proteins and nucleic acids) function as molecular building blocks for macromolecules to be assembled. Nucleic acids, which include DNA and RNA, are made from monomers known as nucleotides. Proteins are made from polypeptide subunits that are themselves polymers of amino acids. Various sugar monomers such as glucose, fructose and galactose form polymers such as starch and cellulose.

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. Transport processes that move substances across membranes
include 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 contrast to eukaryotic and prokaryotic cells, viruses lack several of those cellular structures.
In this regard, viruses are considered obligate parasites and rely on the cellular machinery of
the eukaryotes or prokaryotes they infect to reproduce.

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

Proteins play a variety of roles in cells including transport and enzymatic functions. Protein
structure can be affected by temperature and pH. Enzymes are an important group of
proteins that control and regulate many biological processes and functions, such as
chemiosmosis, protein synthesis, cell and nuclear division, and gene expression. 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.
Organelles and Cellular Structures

This concept includes discussion of the typical cell model of prokaryotes and eukaryotes, including plants and animals. A strong understanding of the structure of the following organelles and cellular structures in relation to their function is necessary: rough and smooth endoplasmic reticulum, Golgi body, mitochondria, ribosomes, lysosomes, chloroplasts, cell surface membrane, nuclear envelope, centrioles, nucleus and nucleolus.

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<tbody>
<tr>
<td>(a) Outline the cell theory with the understanding that cells are the smallest unit of life, all cells come from pre-existing cells and living organisms are composed of cells.</td>
</tr>
<tr>
<td>(b) Interpret and recognise drawings, photomicrographs and electronmicrographs of the following membrane systems and organelles: rough and smooth endoplasmic reticulum, Golgi body, mitochondria, ribosomes, lysosomes, chloroplasts, cell surface membrane, nuclear envelope, centrioles, nucleus and nucleolus.</td>
</tr>
<tr>
<td>(c) Outline the functions of the membrane systems and organelles listed in (b).</td>
</tr>
<tr>
<td>(d) Describe the structure of a typical bacterial cell (small and unicellular, peptidoglycan cell wall, circular DNA, 70S ribosomes and lack of membrane-bound organelles).</td>
</tr>
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</table>
**Biomolecules of Life and Cellular Transport**

This concept focuses on how the structures of biomolecules give rise to properties that allow these biomolecules to carry out their functions. One of these functions involves regulating the transport of substances into and out of the cell. This regulation is afforded by the properties of the cell membrane which comprises phospholipids and proteins. Regulation of the movements is important for several biochemical processes to occur.

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<tr>
<td>(e) Describe the structure and properties of the following monomers:</td>
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<td>i. α-glucose and β-glucose (in carbohydrates)</td>
</tr>
<tr>
<td>ii. glycerol and fatty acids (in lipids)</td>
</tr>
<tr>
<td>iii. amino acids (in proteins) (Knowledge of chemical formulae of specific R-groups of different amino acids is not required)</td>
</tr>
<tr>
<td>(f) Describe the formation and breakage of the following bonds:</td>
</tr>
<tr>
<td>i. glycosidic bond</td>
</tr>
<tr>
<td>ii. ester bond</td>
</tr>
<tr>
<td>iii. peptide bond</td>
</tr>
<tr>
<td>(g) Describe the structures and properties of the following biomolecules and explain how these are related to their roles in living organisms:</td>
</tr>
<tr>
<td>i. starch (including amylose and amylopectin)</td>
</tr>
<tr>
<td>ii. cellulose</td>
</tr>
<tr>
<td>iii. triglyceride</td>
</tr>
<tr>
<td>iv. phospholipid</td>
</tr>
<tr>
<td>(h) Explain the fluid mosaic model and the roles of the constituent biomolecules (including phospholipids, proteins, glycolipids, glycoproteins and cholesterol) in cell membranes.</td>
</tr>
<tr>
<td>(i) Outline the functions of membranes at the surface of cells and membranes within the cell.</td>
</tr>
<tr>
<td>(j) Explain how and why different substances move across membranes through simple diffusion, osmosis, facilitated diffusion, active transport, endocytosis and exocytosis.</td>
</tr>
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Proteins

Proteins play a variety of roles in structural, transport, enzymatic and signalling functions. This concept focuses on the structure and properties of proteins and how temperature and pH may contribute to the denaturation of proteins. The structure of a protein is related to its function.

Learning Outcomes

(k) Explain primary structure, secondary structure, tertiary structure and quaternary structure of proteins, and describe the types of bonds that hold the molecule in shape (hydrogen, ionic, and disulfide bonds, and hydrophobic interactions).

(l) Explain the effects of temperature and pH on protein structure.

(m) Describe the molecular structure of the haemoglobin protein and explain how its structure relates to its function in transport. (Knowledge of details of the number of amino acids and types of secondary structures present is not required.)

(n) Explain the mode of action of enzymes in terms of an active site, enzyme-substrate complex, lowering of activation energy and enzyme specificity using the lock-and-key and induced-fit hypotheses.

(o) Investigate and explain the effects of temperature, pH, enzyme concentration and substrate concentration of an enzyme-catalysed reaction by measuring rates of formation of products (e.g. measuring gas produced using catalase) or rate of disappearance of substrate (e.g. using amylase, starch and iodine).
Stem Cells

This concept helps to explain the diversity in cell type and cell morphology within organisms. In an organism, all cells except the gametes are genetically identical. Yet, a liver cell, a rod cell in the eye and an epithelial cell in the ileum differ significantly in terms of morphology and function due to the expression of different sets of genes. The same genome gives rise to a wide range of cells which further form tissues, organs, and systems in an organism. This is achieved within cells by controlling which genes are switched on and which are switched off. By initiating transcription for a specific set of genes, the expression of the set of genes is switched on to produce proteins that will direct particular development of the cell.

The ability of stem cells to divide and their potential for self-renewal allows for growth. Stem cells replace cells that die or are damaged. During embryogenesis, cell division and differentiation allow the development of an entire organism in utero from a single-cell zygote.

Stem cells hold great potential as medical treatments. Haematopoietic stem cells are used in bone marrow transplants in cancer treatments. Skin stem cells are used to culture skin cells to treat patients with massive burns. Ethical debates over the use of stem cells are primarily concerned with the use of embryonic stem cells. The use of adult stem cells faces fewer such ethical issues.

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<tr>
<td>(p) Describe the unique features of zygotic stem cells, embryonic stem cells, and blood stem cells, correctly using the terms totipotency (zygotic stem cells which have the ability to differentiate into any cell type to form whole organisms and so are also pluripotent and multipotent), pluripotency (embryonic stem cells which have the ability to differentiate into almost any cell type to form any organ and so are not totipotent but are multipotent) and multipotency (blood stem cells which have the ability to differentiate into a limited range of cell types and so are not pluripotent or totipotent).</td>
</tr>
<tr>
<td>(q) Explain the normal functions of stem cells in a living organism, including embryonic stem cells and blood stem cells.</td>
</tr>
<tr>
<td>(r) Discuss the ethical implications of the application of stem cells in research and medical applications and how human induced pluripotent stem cells (iPSCs) overcome some of these issues. (Procedural details of how iPSCs are formed are not required.)</td>
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2.2 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 to the understanding of 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 which 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 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 contribute to 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).

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. Processes 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 may not change the amino acid inserted into a polypeptide. 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 mutation 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. 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 did not yet exist. 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, some genes are found on sex chromosomes while others involve multiple alleles. Alleles of some genes exhibit codominance or incomplete dominance.
The Structure of Nucleic Acids and Gene Expression

The structure of DNA was proposed by Watson and Crick in 1953. With an understanding of DNA structure, experimental evidence supported the proposal that DNA replicates in a semi-conservative manner. The central dogma states that genetic information is encoded in the DNA and transferred to the mRNA during transcription. In addition to mRNA transcription, tRNA and rRNA are transcribed; tRNA contains an anti-codon which is complementary to the codon on the mRNA while rRNA is a component of ribosomes. In eukaryotic transcription, pre-mRNA is synthesised and then processed to produce mature mRNA. Subsequently, through translation, the information on the mRNA is used to synthesise polypeptides, which are folded into functional proteins.

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<tbody>
<tr>
<td>(a) Describe the structure and roles of DNA and RNA (tRNA, rRNA and mRNA) (Knowledge of mitochondrial DNA is not required).</td>
</tr>
<tr>
<td>(b) Describe the process of DNA replication.</td>
</tr>
<tr>
<td>(c) Describe how the information on DNA is used to synthesise polypeptides in prokaryotes and eukaryotes. (Description of the processes of transcription, formation of mRNA from pre-mRNA and translation is required.)</td>
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</table>
DNA Mutations

Changes to the DNA sequence or amount could have huge physiological impact on organisms. This concept illustrates how DNA mutations could result in sickle cell anaemia and Down syndrome in humans.

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<tr>
<td>(d) Explain what is meant by the terms gene mutation and chromosomal aberration. For gene mutation, knowledge of how substitution, addition and deletion could change the amino acid sequence (including frameshift) is required. For chromosomal aberration, knowledge of numerical aberration (including aneuploidy, as in the case of trisomy 21 i.e. Down syndrome) and structural aberration (including translocation, duplication, inversion and deletion) is required.</td>
</tr>
<tr>
<td>(e) Explain how gene mutations can result in diseases (including sickle cell anaemia).</td>
</tr>
</tbody>
</table>
The Cell Cycle

There are two different types of cell cycles: mitotic and meiotic. The mitotic cell cycle is necessary for growth and repair while the meiotic cell cycle is necessary to generate gametes. Meiosis gives rise to genetic variation between gametes.

Cell cycles are tightly regulated at various checkpoints. The development of cancer is a multi-step process that comprises gene mutations caused by environmental factors, biological agents or hereditary predispositions. These mutations might cause cells to bypass cell cycle checkpoints. Cancer has a much higher incidence in Singapore compared to other diseases and accounts for as much as 30 per cent of the deaths in this country. The recorded incidence of cancer is on the rise and this could be due to the accumulation of mutations from one generation to the next, although other reasons have also been proposed: increased exposure to carcinogens and increased detection rates as a result of effective cancer screening programmes.

Learning Outcomes

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<tbody>
<tr>
<td>(f)</td>
<td>Describe the events that occur during the mitotic cell cycle and the main stages of mitosis (including the behaviour of chromosomes, nuclear envelope, cell membrane and centrioles).</td>
</tr>
<tr>
<td>(g)</td>
<td>Explain the significance of the mitotic cell cycle (including growth, repair and asexual reproduction) and the need to regulate it tightly. (Knowledge that dysregulation of checkpoints of cell division can result in uncontrolled cell division and cancer is required, but detail of the mechanism is not required.)</td>
</tr>
<tr>
<td>(h)</td>
<td>Identify the causative factors, including genetic, chemical carcinogens and ionising radiation, which may increase the chances of cancerous growth.</td>
</tr>
<tr>
<td>(i)</td>
<td>Describe the development of cancer as a multi-step process that includes accumulation of mutations that affect the cell cycle (details of tumour suppressor genes and proto-oncogenes are not required), angiogenesis and metastasis.</td>
</tr>
<tr>
<td>(j)</td>
<td>Explain the significance of the meiotic cell cycle (reduction division prior to fertilisation and cells not genetically identical) and that meiosis and random fertilisation can lead to variation. (Detailed description of the behaviour of chromosomes during meiosis is not required. Information about the stages and associated behaviour of the nuclear envelope, cell membrane and centrioles is not required.)</td>
</tr>
</tbody>
</table>
Inheritance

This concept includes both Mendelian and non-Mendelian inheritance. Besides genetics, the environment also plays a role in determining the phenotype of an organism.

<table>
<thead>
<tr>
<th>Learning Outcomes</th>
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</thead>
<tbody>
<tr>
<td>(k) Explain the terms: locus, allele, dominant, recessive, codominant, incomplete dominance, homozygous, heterozygous, phenotype, genotype and sex linkage.</td>
</tr>
<tr>
<td>(l) Explain how genes are inherited from one generation to the next via the germ cells or gametes.</td>
</tr>
<tr>
<td>(m) Explain, with examples, how the environment may affect the phenotype (including how temperature affects fur colour of Himalayan rabbits).</td>
</tr>
<tr>
<td>(n) Use genetic diagrams to solve problems in dihybrid crosses, including those involving codominance, incomplete dominance, multiple alleles and sex linkage.</td>
</tr>
<tr>
<td>(o) Use genetic diagrams to solve problems involving test crosses.</td>
</tr>
</tbody>
</table>
2.3 Core Idea 3: Energetics

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?

**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. Autotrophs, including 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 is released subsequently 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 the energy is passed along food chains from one organism to the next. These provide a source of carbohydrate which is 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.

**Transformation of Energy between the Environment and Organisms**

Plants and other photosynthetic organisms use sunlight to synthesise carbohydrates from carbon dioxide and water during the process of photosynthesis. The light-dependent (cyclic and non-cyclic photophosphorylation) and light-independent stages of photosynthesis facilitate the conversion of light energy to chemical energy in the form of carbohydrates. Carbohydrates produced from photosynthesis can be assembled into macromolecules or broken down subsequently to fuel activities within the plants. The Calvin cycle ultimately results in the synthesis of sugars in plants.

As heterotrophs consume plant matter, energy from the plants is transferred to them. Chemical processes occur during aerobic respiration whereby carbohydrates are broken down to release energy to phosphorylate ADP to ATP during aerobic respiration. The energy is transferred between interacting molecules through the four stages of aerobic respiration when oxygen is present. In the absence of oxygen, anaerobic respiration occurs with the release of fewer ATP molecules and the formation of either lactate or ethanol depending on the cell type.
<table>
<thead>
<tr>
<th>Learning Outcomes</th>
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</thead>
<tbody>
<tr>
<td>(a) Identify the initial reactants and final products for each of the main stages of respiration under aerobic conditions (glycolysis, link reaction, Krebs cycle and oxidative phosphorylation). (Details of the intermediate molecules and enzymes in each biochemical pathway are not needed.)</td>
</tr>
<tr>
<td>(b) State that glycolysis occurs in the cytoplasm and that the link reaction, Krebs cycle and oxidative phosphorylation occur in the mitochondria</td>
</tr>
<tr>
<td>(c) Identify the initial reactants and final products for respiration under anaerobic conditions in yeast and mammalian muscle tissue. (Details of the intermediate molecules and enzymes in each biochemical pathway are not needed.)</td>
</tr>
<tr>
<td>(d) State that respiration under aerobic conditions releases more energy than respiration under anaerobic conditions</td>
</tr>
<tr>
<td>(e) State that photosynthesis occurs in chloroplasts.</td>
</tr>
<tr>
<td>(f) Identify the initial reactants and final products of the light-dependent and light-independent stages (Details of the intermediate molecules and enzymes are not required.)</td>
</tr>
<tr>
<td>(g) Outline briefly that photosynthesis involves conversion of light energy to chemical energy and this energy is stored in the form of sugars.</td>
</tr>
</tbody>
</table>
2.4 **Core Idea 4: Biological Evolution**

Within this Core Idea, students will develop an understanding of the key idea of Biological Evolution that helps them make sense of biology. Important concepts within evolutionary biology are this level are:

1. definition of evolution and descent with modification;
2. processes of evolutionary change, natural selection and genetic drift; and

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?

**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. Of note is that individuals do not evolve but rather populations 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.

**Natural Selection and Adaptation**

Natural selection occurs only if there is both (1) variation in the genetic information between organisms in a population and (2) variation in the expression of that genetic information, i.e. trait variation leads to differences in performance among individuals. The traits that positively affect survival are more likely to be reproduced and thus are more common in the population.

The interaction of four factors are considered in evolution: (1) the potential for a species to increase in number, (2) the genetic variation of individuals in a species due to mutation and sexual reproduction, (3) the competition for an environment’s limited supply of the resources that individuals need in order to survive and reproduce, and (4) the ensuing proliferation of those organisms that are better able to survive and reproduce in that environment.
Adaptation results from the accumulation of favourable genetic changes through natural selection, since organisms that are anatomically, behaviourally and physiologically well suited to a specific environment are more likely to survive and reproduce. This differential survival and reproduction of organisms in a population that have an advantageous, heritable trait leads to an increase in the proportion of individuals in future generations that have the favourable trait and to a decrease in the proportion of individuals that do not.

Adaptation also means that the distribution of traits in a population can change when conditions change. Changes in the physical environment, whether naturally occurring or human induced, have thus contributed to the expansion of some species, the emergence of new distinct species as populations diverge under different conditions, and the decline (and sometimes the extinction) of some species.

Species become extinct because they can no longer survive and reproduce in their altered environment. If members cannot adjust to change that is too fast or drastic, the opportunity for the species’ evolution is lost.

<table>
<thead>
<tr>
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</thead>
<tbody>
<tr>
<td>(a)   Explain why variation (as a result of mutation, meiosis and sexual reproduction) is important in natural selection.</td>
</tr>
<tr>
<td>(b)   Explain, with examples, how environmental factors act as forces of natural selection.</td>
</tr>
<tr>
<td>(c)   Explain the role of natural selection in evolution.</td>
</tr>
<tr>
<td>(d)   Explain why the population is the smallest unit that can evolve.</td>
</tr>
<tr>
<td>(e)   Explain how genetic variation (including harmful recessive alleles) may be preserved in a natural population.</td>
</tr>
</tbody>
</table>
2.5 **Extension Topic: Impact of Climate Change**

Climate change, which is attributed to an increase in the emission of greenhouse gases, has great impacts on the human population. By the year 2050, climate change is expected to have caused 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 one 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 on average by up to 60°C. 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.

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 to 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 in Singapore. In addition, an increase in 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.

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 vector. 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, will be important to Singapore.

In this topic, the impact of climate change will be studied. The area of concern is the threat of how infectious diseases are changing.

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?

<table>
<thead>
<tr>
<th>Learning Outcomes</th>
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</thead>
<tbody>
<tr>
<td>(a) Identify and explain the human activities over the last few centuries that have contributed to climate change through increased emission of greenhouse gases (limited to CO₂ and methane) including burning of fossil fuels linked to increasing energy usage, clearing of forests and food choices (increasing consumption of meat).</td>
</tr>
<tr>
<td>(b) Explain the effects of climate change as a result of greenhouse gas emissions, including the melting of polar ice caps, rising sea levels, stress on fresh water supplies, heat waves, heavy rains, death of coral reefs, migration of fishes and insects and release of greenhouse gases in frozen organic matter.</td>
</tr>
<tr>
<td>(c) Explain how temperature changes impact insects, including increased temperature leading to increased metabolism and the narrow temperature tolerance of insects.</td>
</tr>
<tr>
<td>(d) Outline the life-cycle of <em>Aedes aegypti</em> as an example of a typical mosquito vector.</td>
</tr>
<tr>
<td>(e) Outline the development of viral dengue disease in humans, including host-pathogen interactions, human susceptibility to the virus; pathogen virulence, transmission and drug resistance.</td>
</tr>
<tr>
<td>(f) Explain how global warming affects the spread of mosquito-borne infectious diseases, including malaria and dengue, beyond the tropics.</td>
</tr>
</tbody>
</table>
3. PEDAGOGY

Teaching science involves tapping on the learner’s innate curiosity and desire to answer a question or solve a problem relating to science. Besides developing a strong conceptual understanding of scientific models and theories, students are given opportunities to use scientific inquiry and cultivate the ability to think and act in ways associated with scientific inquiry. This includes students asking questions about knowledge and issues that they can relate to in their daily lives, society and the environment; collecting and using evidence; and formulating and communicating explanations based on scientific knowledge.

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.
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 that will be assessed.

A Knowledge with understanding

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

1. scientific phenomena, facts, laws, definitions, concepts and theories
2. scientific vocabulary, terminology, 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

All candidates are required to enter for Papers 1, 2, 3 and 4.

<table>
<thead>
<tr>
<th>Paper</th>
<th>Type of Paper</th>
<th>Duration</th>
<th>Weighting (%)</th>
<th>Marks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Multiple Choice</td>
<td>1 h</td>
<td>33</td>
<td>30</td>
</tr>
<tr>
<td>2</td>
<td>Structured and Free-response Questions</td>
<td>2 h</td>
<td>67</td>
<td>60</td>
</tr>
</tbody>
</table>

**Paper 1 (1 h, 30 marks)**

This paper will consist of 30 compulsory multiple choice questions. All questions will be of the direct choice type with 4 options.

**Paper 2 (2 h, 60 marks)**

This paper will comprise two sections. Paper 2 will include questions that assess the higher-order skills of analysing, making conclusions and evaluating information and require candidates to integrate knowledge and understanding from different areas of the syllabus.

Section A (45 marks) will consist of a variable number of structured questions, all compulsory, including at least one data-based or comprehension-type question. The data-based question(s) will constitute 10-15 marks of the paper.

Section B (15 marks) will consist of 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.

**Weighting of Assessment Objectives**

<table>
<thead>
<tr>
<th>Assessment Objective</th>
<th>Weighting (%)</th>
<th>Assessment Components</th>
</tr>
</thead>
<tbody>
<tr>
<td>A Knowledge with understanding</td>
<td>40</td>
<td>Papers 1 and 2</td>
</tr>
<tr>
<td>B Handling, applying and evaluating</td>
<td>60</td>
<td>Papers 1 and 2</td>
</tr>
<tr>
<td>information</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

5. TEXTBOOKS AND REFERENCES

Students may find the following references helpful.


Dobzhansky, T (March 1973) Nothing in Biology Makes Sense Except in the Light of Evolution, American Biology Teacher vol. 35 (3)


