BIOLOGY SYLLABUS

Pre-University

Higher 1 / 2 / 3

Syllabus 8876 / 9477 / 9816

Implementation starting with the 2025 Pre-U 1 cohort

Ministry of Education
SINGAPORE

CONTENTS

SECTION 1: INTRODUCTION

1. INTRODUCTION

1.1 Goals and Vision of Science Education

Our science students are diverse, with different needs, interests and aptitudes for science. Given the diversity of our science students and the needs of Singapore, the twin goals of science education are to:

a. Enthuse and nurture all students to be scientifically literate, so that they are able to make informed decisions and take responsible actions in their daily lives; and

b. Provide strong science fundamentals for students to innovate and pursue Science, Technology, Engineering, Math (STEM) for future learning and work.

The goals of science education, which serve the interwoven needs of the individual and society, can be unpacked into three dimensions: *personal/functional, cultural/civic* and *professional/economic*, as shown in **Figure 1.1**. *Science for Life and Society* is the tagline to capture the essence of these goals of science education, which can be achieved through developing strong fundamentals in scientific knowledge, practices and values.

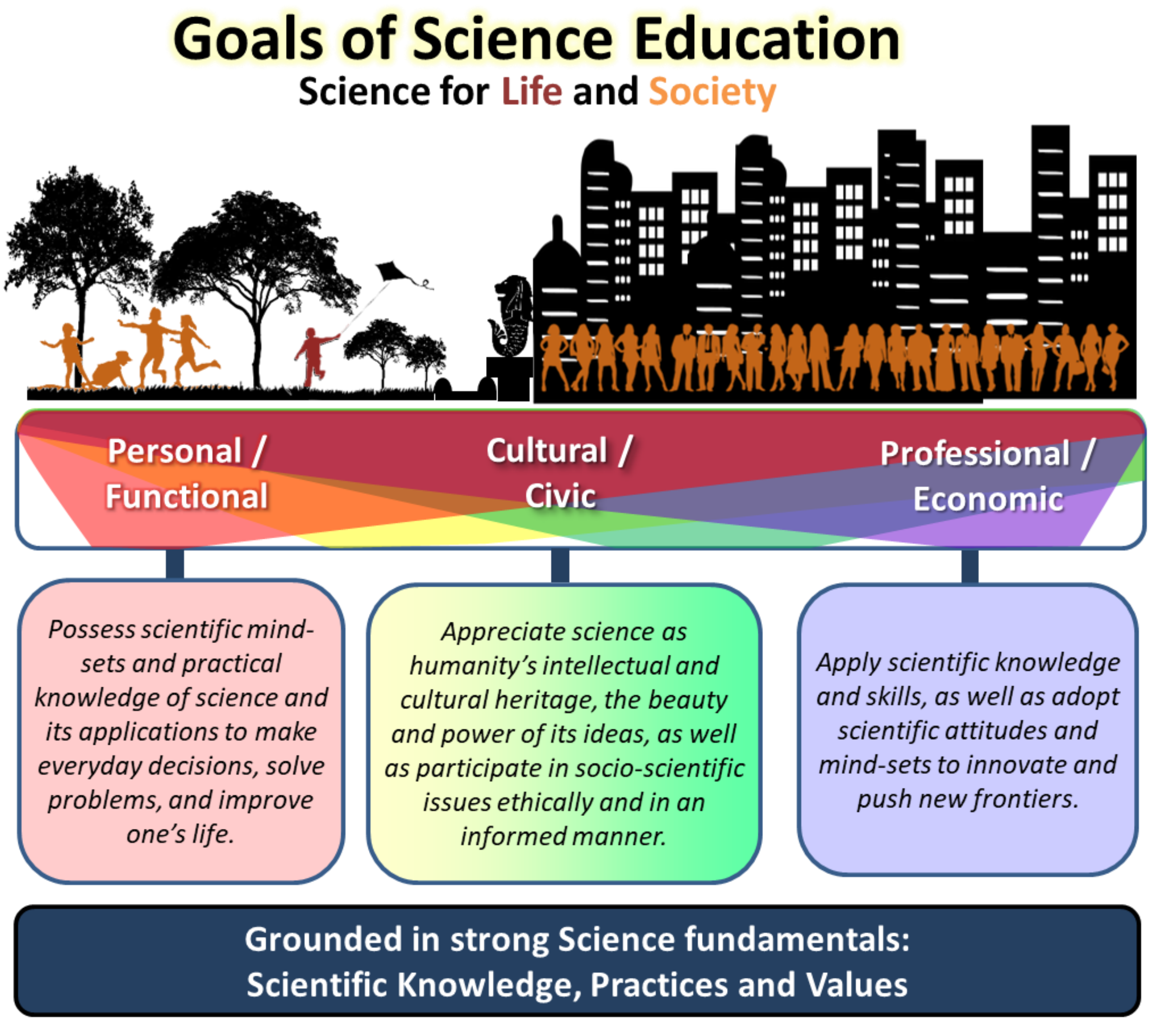


Figure 1.1: Overview of Goals of Science Education in Singapore

The *Science Curriculum Framework*, as shown in **Figure 1.2**, encapsulates the thrust of science education in Singapore to provide students with strong fundamentals in science for life, learning, citizenry and work.

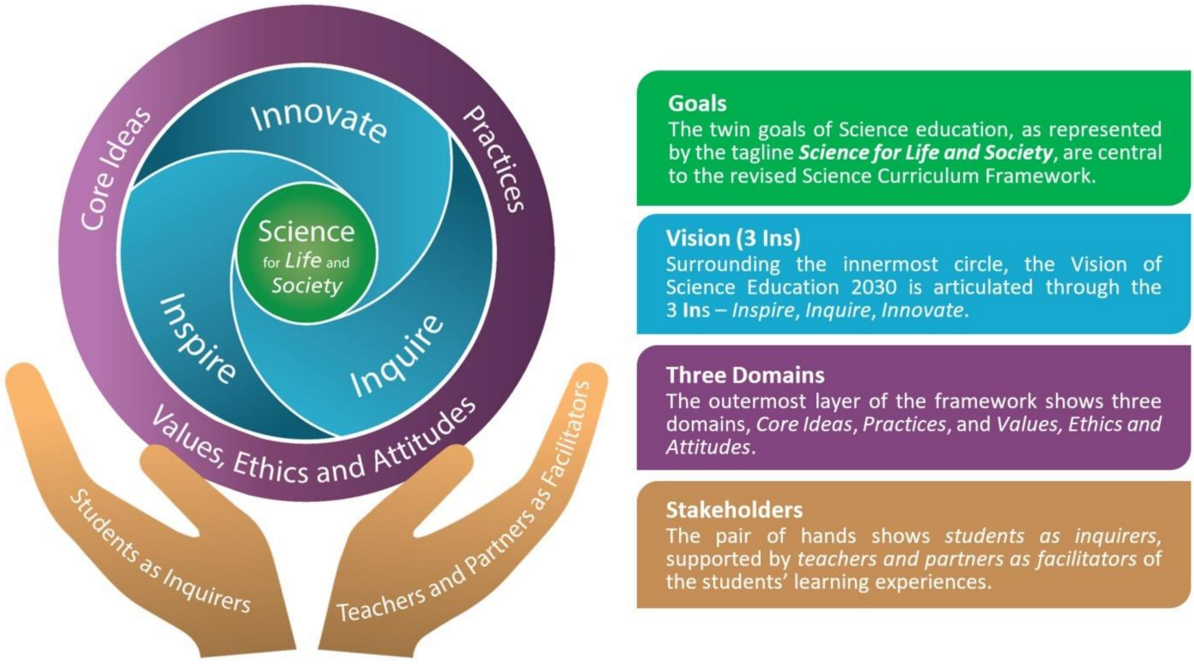


Figure 1.2: Science Curriculum Framework

The twin goals of science education, as represented by the tagline ***Science for Life and Society***, are central to the Science Curriculum Framework. Surrounding the innermost circle, the Vision of Science Education 2030 is articulated through the 3 **In**s – *Inspire*, *Inquire*, *Innovate*. The outermost layer of the framework shows three domains, *Core Ideas*, *Practices*, and *Values, Ethics and Attitudes*. The pair of hands shows *students as inquirers*, supported by *teachers and partners as facilitators* of the students' learning experiences.

The term *Core Ideas* refers to the fundamental ideas that are essential for the understanding of science. The term *Practices* signals the importance of "Ways of thinking and doing in science" and emphasises science as a human endeavour guided by *Values, Ethics and Attitudes* embedded within society. In addition, teaching and learning involves not just the students and teachers but other partners who can facilitate learning in various contexts to help students appreciate the application of science in their daily lives, society and the environment.

Our vision for science education, manifested through the three **In**-s, encapsulates the overall experience of our students in science education:

a. <u>Inspired by science</u>. Students enjoy learning science and are fascinated by how everyday phenomena have scientific connections and how science helps solve many of our global challenges. They regard science as relevant and meaningful, and appreciate how science and technology have transformed the world and improved our lives. Students are open to the possibility of pursuing science-related careers to serve the good of society.

b. <u>Inquire like scientists</u>. Students have strong fundamentals in science, and possess the spirit of scientific inquiry. They are able to engage confidently in the *Practices of Science* and are grounded in the knowledge, issues and questions that relate to the roles played by science in daily life, society and the environment. They can discern, weigh alternatives and evaluate claims and ideas critically, based on logical scientific evidence and arguments, while consciously suspending judgement where there is lack of evidence.

c. Innovate using science. Students apply science to generate creative solutions to solve real-world problems, ranging from those affecting everyday lives to complex problems affecting humanity. It is envisaged that there will be a strong pipeline of students who can contribute towards STEM research, innovation and enterprise.

The goals and vision of science education are aligned with the broader MOE framework of 21st Century Competencies (21CC). Inspired students, who inquire and innovate through the Practices of Science (POS), they develop future-ready competencies such as critical, adaptive and inventive thinking. The 21CC framework shown in **Figure 1.3** guides the purposive development, through the total curriculum, of key competencies and mindsets for students to be successful in the future.

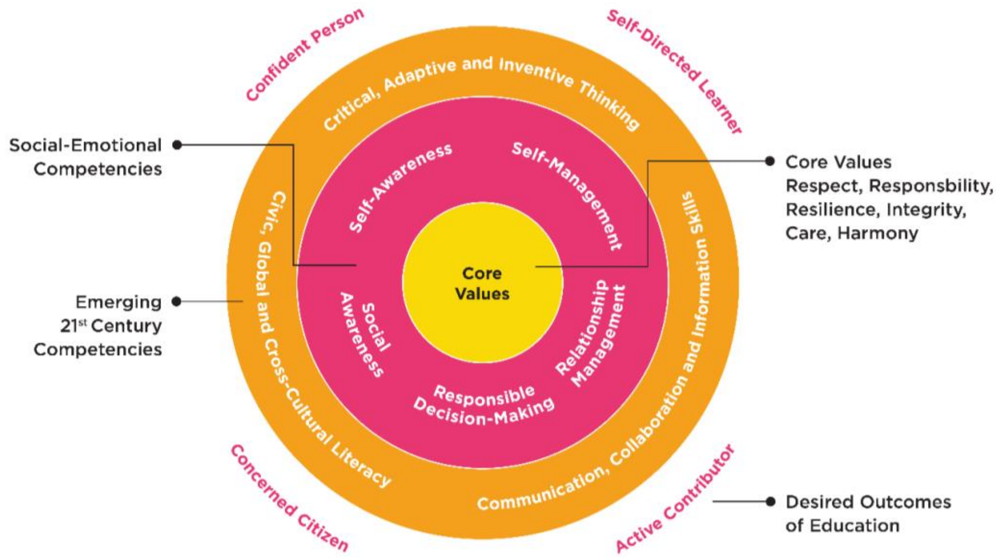


Figure 1.3: Framework for 21st Century Competencies and Student Outcomes

The teaching and learning of science naturally serve the larger goal of developing 21CC in students. The emerging 21CC domains that can be most naturally developed through the process of scientific inquiry, such as engaging in scientific investigation, reasoning, modelling and problem-solving, are **Critical, Adaptive and Inventive Thinking**, as well as **Communication**. The development of the other emerging 21CC domains (e.g. Collaboration, Information Skills, Civic and Global Literacy) depends on the context of the lesson. Intentional development of 21CC through science makes learning meaningful and facilitates the transfer of learning.

1.2 BACKGROUND ON THE 2025 A-LEVEL SCIENCE CURRICULUM

The A-Level science curriculum review ensures the continued relevance of the curriculum in laying a strong foundation of knowledge, skills and attitudes in order to prepare our students well for university, work and life in the future. The review is guided by internal and external scans, and also took into consideration broader MOE emphases on learning for life as well as the development of 21st Century Competencies (21CC) and digital literacy (DL) in our students.

The key curricular shifts are to:

1. Strengthen the POS[1], through enhancing digital literacy. The learning of science should reflect the evolving nature of the scientific disciplines as they are practised. Data collection, analysis, modelling, and interpreting data and evidence are important areas of the POS that can be strengthened and made more authentic with the use of information and communications technology. Digital literacy (DL)[2], including data competencies (DC) and computational thinking (CT), could also be naturally built up through the curriculum as students encounter opportunities to make use of a variety of hardware and software to investigate and model the world.

2. Maintain strong disciplinary fundamentals while layering in compelling real-world applications and interdisciplinary connections. Timely refreshing of the curricular content retains the focus on learning key concepts and core ideas in science, while embedding Science, Technology, Society and Environment (STSE) and Science, Technology, Engineering and Mathematics (STEM) contexts and applications more deliberately. This can help bring out the relevance and impact of science for more students.[3] To encourage debate and discussion, contexts could involve socio-scientific issues that prompt the exploration of values, ethics, and attitudes in science. Contexts related to sustainability will also feature to a greater extent across the science syllabuses in view of Singapore's commitment to the 2030 Agenda for Sustainable Development.[4]

3. Broaden practical work learning experiences beyond the confines of the laboratory and include more open-ended tasks to promote greater student agency, experimentation and authenticity. As pre-university students are building their "science identity", challenging them to take up an open-ended group investigative task can increase student agency and as form an important part of their overall learning experience in science. The task design should encourage curiosity, problem-posing and inventive thinking, thus providing opportunities for students to embrace uncertainty and ambiguity, and to learn through iteration and from failures. Such activities could include science investigations and/or engineering design challenges where students plan and carry out their own group investigative tasks and deepen their understanding of POS.

[1] The *Practices of Science* (POS) emphasises that science as a discipline is more than the acquisition of a body of knowledge (e.g. scientific facts, concepts, laws, and theories); it is also a way of knowing and doing.

[2] DC refers to the handling and analysis of data. CT can be taught in the context tackling complex problems in scientific domains, and comprises four elements: decomposition, pattern recognition, abstraction, and algorithmic thinking.

[3] Bennett, J., Lubben, F., & Hogarth, S. (2007). Bringing science to life: A synthesis of the research evidence on the effects of context-based and STS approaches to science teaching. *Sci. Ed.*, 91(3): 347–370.

[4] See report Towards a sustainable and resilient Singapore.

One of the strategic thrusts in the Educational Technology Masterplan (EdTech) 2030[5] is to strengthen the development of students' DL and technological skills. In curricular shift 1 above, the use of digital sensors for data collection and the use of spreadsheet to analyse and visualise larger authentic data sets in the revised H2 Biology Practical is well aligned to the "find", "think" and "create" components of the National Digital Literacy Programme (NDLP), as launched by MOE in 2020 (see **Figure 1.4**). Enhanced DL skills through the A-level science curriculum empowers students to become technologically-adept innovators who can "discover" needs and "develop" solutions to real-world problems.

Figure 1.4: MOE Framework for Strengthening Digital Literacy

[5] https://www.moe.gov.sg/education-in-sg/educational-technology-journey/edtech-masterplan

1.3 PURPOSE AND VALUE OF BIOLOGY EDUCATION AT PRE-UNIVERSITY

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 (9744) so that students acquire knowledge that is relevant for their participation in a technology-driven economy and as a global citizen cognisant of threats of emerging infectious diseases and the impacts of climate change.

The value of learning H2 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 the H2 Biology course, students should be prepared for life science-related courses at university and, consequently, careers that are related to this field.

The H1 Biology curriculum is designed as a subset of H2 Biology. While H2 Biology develops in our students the disciplinary understanding, skills and attitudes necessary for further studies in the subject and related fields, H1 Biology is designed to broaden students' learning that will support the development of scientific literacy. This is especially important for future citizens in an increasingly technologically-driven world to 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 the mechanisms involved in epidemics or pandemics).

The MOE-H3 Biology syllabus is designed to build on and extend the knowledge, understanding and skills acquired from the H2 Biology 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. 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. 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.

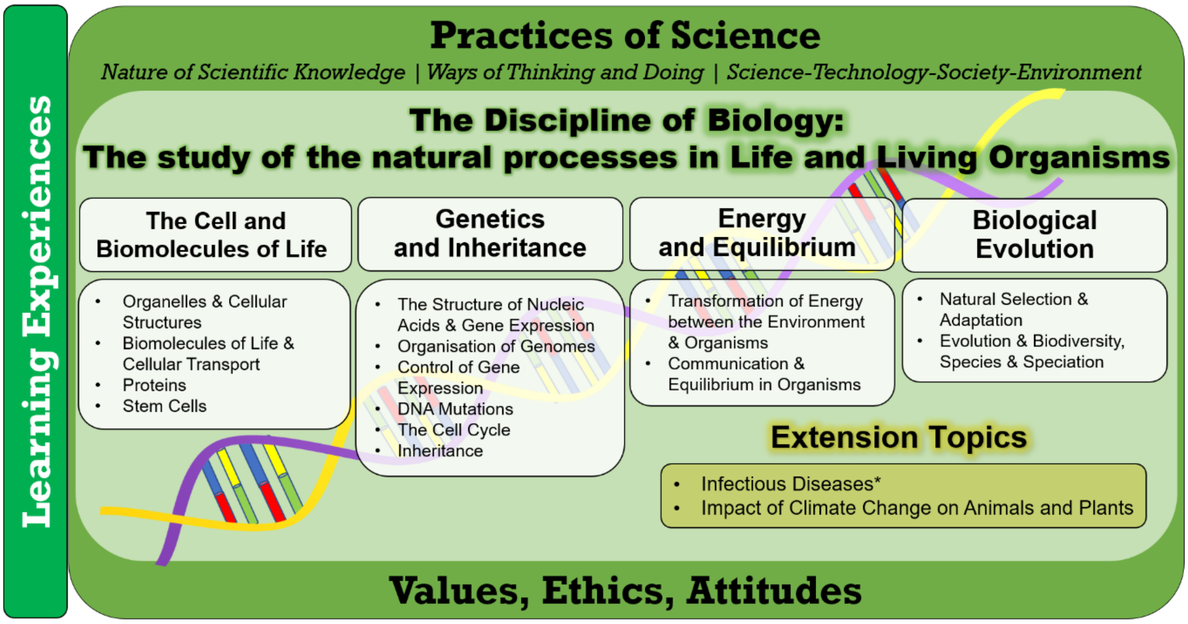
The aims of the H1, H2 and H3 Biology syllabuses are detailed in **Table 1.1**.

Table 1.1: Aims of A-Level Biology Syllabuses

<table>
<tr><th>Aims</th><th>H1</th><th>H2</th><th>H3</th></tr>
<tr><td>Twin Goals of Science Education</td><td>provide students with an experience that develops 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</td><td>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 and for further studies in related fields</td><td>provide students with an experience that deepens their knowledge and skills in biology, and fosters attitudes necessary for further studies in related fields</td></tr>
<tr><td>Practices of Science & Values, Ethics and Attitudes</td><td colspan="2">develop in students the understanding, skills, ethics and attitudes relevant to the Practices of Science, including the following:
Demonstrating Ways of Thinking and Doing (WOTD)
Understanding the Nature of Scientific Knowledge (NOS)
Relating Science-Technology-Society-Environment (STSE)</td><td>develop in students an appreciation of the practice, value and rigour of biology as a discipline</td></tr>
<tr><td rowspan="2">Disciplinary Ways of Thinking and Doings</td><td colspan="2">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</td><td>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</td></tr>
<tr><td></td><td colspan="2">develop in students the skills needed for effective communication to different audiences through a range of styles, modes and tools</td></tr>
</table>

1.4 A-Level Biology Curriculum Framework

The *Values, Ethics, Attitudes*, the *Practices of Science*, the *Disciplinary Content* and *Learning Experiences* are put together in a framework (see **Figure 1.5**) to guide the design and implementation of the A-level Biology curriculum.



*in H2 and H3 Biology only

Figure 1.5: A-Level Biology Curriculum Framework

The *Values, Ethics, Attitudes* (see Section 1.4.1) undergird the study of science and the use of related knowledge and skills to make a positive contribution to humanity.

The *Practices of Science* (see Section 1.4.3) 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 *Disciplinary Content* is the Biology syllabuses that are organised around four *Core Ideas* of Biology (see Section 1.4.2). For each Core Idea, pertinent and 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, the H2 and H3 Biology syllabuses features two *Extension Topics* (A) Infectious Diseases, and (B) Impact of Climate Change on Animals and Plants (H1 features only one *Extension Topic*). These are based on important emerging biological issues impacting both the local and global contexts. They require students to demonstrate assimilation of the Core Ideas and extend their knowledge and understanding to real-world challenges. Furthermore, extension topics will equip students with the necessary knowledge and process skills to make informed decisions about scientific issues. Both Extension Topics take up about 15 percent of the total Biology curriculum and are presented through the use of guiding questions, narratives, assessable learning outcomes and suggested learning experiences.

1.4.1 Values, Ethics, Attitudes

Although science uses objective methods to arrive at evidence-based conclusions, it is in fact a human enterprise conducted in particular social contexts, which thus involves consideration of values and ethics. The intent of fostering an awareness and appreciation of these values in the curriculum is to sensitise our students to the ethical implications of the application of science in society.

Humanity will face challenges in the upcoming centuries that require the development of scientific and technological solutions, alongside other approaches, but these solutions have complex outcomes and there is a need to consider their impact in terms of their benefits and drawbacks to humanity and the ethical issues involved. This is complicated by a myriad of beliefs and value systems. Thus, science education needs to equip students with attitudes (see **Table 1.2**) and the ability to articulate their ethical stance as they participate in discussions about socio-scientific issues[6] that involve ethical dilemmas, with no single right answers.

Table 1.2: Values, Ethics, Attitudes

Values, Ethics, and Attitudes	Brief Description
Curiosity	Desiring to explore the environment and question what is found.
Creativity	Seeking innovative and relevant ways to solve problems.
Integrity	Handling and communicating data and information with complete honesty.
Objectivity	Seeking data and information to validate observations and explanations without bias.
Open-mindedness	Accepting all knowledge as tentative and suspending judgment. Tolerance for ambiguity. Willingness to change views if the evidence is convincing.
Resilience	Not giving up on the pursuit for answers / solutions. Willingness to take risks and embrace failure as part of the learning process.
Responsibility	Showing care and concern for living things and awareness of our responsibility for the quality of the environment.
Healthy Scepticism	Questioning the observations, methods, processes and data, as well as trying to review one's own ideas.

[6] Examples of socio-scientific issues are genetic engineering (e.g. cloning and gene therapy), reproductive technology, climate change and the adoption of nuclear energy.

1.4.2 Core Ideas

Our science curriculum is organised around *Core Ideas*, which are distilled ideas central to the discipline of science. The selection of Core Ideas is guided by the two principles of

- **Centrality:** Ideas which are important to the understanding of the discipline, and are generative, with the potential to add breadth, depth and make connections; and
- **Coherence**: Ideas which are aligned to overall goals, developmentally appropriate, timely and timeless.

Core Ideas help students appreciate the connectedness and the conceptual links within and across the different sub-disciplines of science (i.e. biology, chemistry and physics). The **Unifying Ideas** across science (biology, chemistry and physics) are described in **Table 1.3**, and the **Disciplinary Ideas** within biology are listed in **Table 1.4**.

Table 1.3: Unifying Ideas across science subjects

Unifying Idea	Description
Pattern	A pattern is an observed sequence or repetition in nature. A way to make sense of the world around us is to organise its diversity through classification based on similarities and differences, and recognising deviations. Understanding patterns helps us to also predict events and processes that occur in the natural world
Diversity	Diversity refers to the variety of living and non-living things around us. Such diversity in the natural and man-made worlds helps to maintain a balance in the ecosystem and provide us with useful resources to develop solutions to real world problems. We have to use the resources in nature responsibly and sustainably.
System	A system comprises parts which interact with one another within a boundary. Interactions within and between systems can be explored at different scales. Studying systems allow us to understand how different parts with different functions, may work together for a common purpose.
Structure	Structure refers to the arrangement of and relations between parts of a system. Making sense of the structure of systems and their parts leads to a deeper understanding of their functions and properties, which allow us to make and test predictions of their behaviours.
Energy	Energy is required for things to work. The total amount of energy within a chosen system is always the same (i.e. conserved). While energy cannot be created or destroyed, it can be transferred from one energy store to another during an event or process. In these processes some energy may become less useful.
Matter	Matter is anything that has mass and occupies space. All matter in the Universe, living and non-living, is made up of very small particles called atoms. The behaviour and arrangement of the atoms explain the properties of different materials. We can better appreciate nature by understanding the structure and properties of matter.
Balance	Balance is achieved when opposing forces or influences act on a system to allow the system to be in equilibrium or in a steady state. Maintaining balance is important in living things and in ecosystems. We are able to design stable systems through understanding the mechanisms by which balance is achieved.

Unifying Idea	Description
Change	Change is caused by interactions within and across systems, which may involve forces or the flow of matter and energy. Different types of interactions allow us to understand the behaviour of systems and make predictions on how changes in one factor affects the other factors in a system.

Table 1.4: Disciplinary Ideas within Biology

Disciplinary Ideas
1. Diverse life forms are similar in that their basic unit are cells. 2. Structure and function of organisms from the molecular to the organ system levels are related to each other. 3. Biological systems interact among themselves and with the environment resulting in the flow of energy and nutrients. 4. To ensure survival, living organisms obtain, transform and utilise energy from the external world. 5. Living organisms 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 needed for sustaining life. 6. Genetic information is passed down from parents to offspring during reproduction to ensure the continuity of life. 7. The diversity of living organisms is achieved through a process of evolution, driven by mechanisms such as natural selection.

Core Ideas represent the enduring understanding that emerges from learning each science subject. These ideas cut across traditional content boundaries, providing a broader way of thinking about phenomena in the natural world. This shift is not without precedent – a number of the key external curricula and standards have recently re-organised and built the subject content and skills around core ideas, with the intention for the core ideas to shift the students' learning mentality from a compartmentalised view of scientific knowledge to a more coherent and integrated understanding of science. The use of core ideas in science to frame the curriculum can help to build deep conceptual understanding in students so that they can better apply these concepts to solve problems in novel situations and contexts.

The *Disciplinary Content* is the Biology syllabuses that are organised around four *Core Ideas* of Biology and they are as follows:

- Core Idea 1: The Cell and Biomolecules of Life
- Core Idea 2: Genetics and Inheritance
- Core Idea 3: Energy and Equilibrium
- Core Idea 4: Biological Evolution

1.4.3 Practices of Science (POS)

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.

Teaching students the nature of science (NOS) helps them 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 NOS 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* which are explicitly articulated in the syllabus to allow teachers to embed them as learning objectives in their lessons. The 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 should be emphasised in the teaching of these practices where appropriate.

Time should be set aside to allow students to reflect on how the POS contribute to the accumulation of scientific knowledge. This means, for example, that when students pose questions, plan and conduct investigations, develop models or engage in arguments, they should have opportunities to think about what they have done and why.

The use of technology and tools are essential to doing and learning science. Just as the slide rule has given way to pocket calculators, the use of computer software for data analysis and visualisation has become common practice today. Thus, the POS described here include the use of digital technology in teaching and learning science where appropriate.

See **Figure 1.6** for the components of POS, which will be discussed in **Table 1.5**.

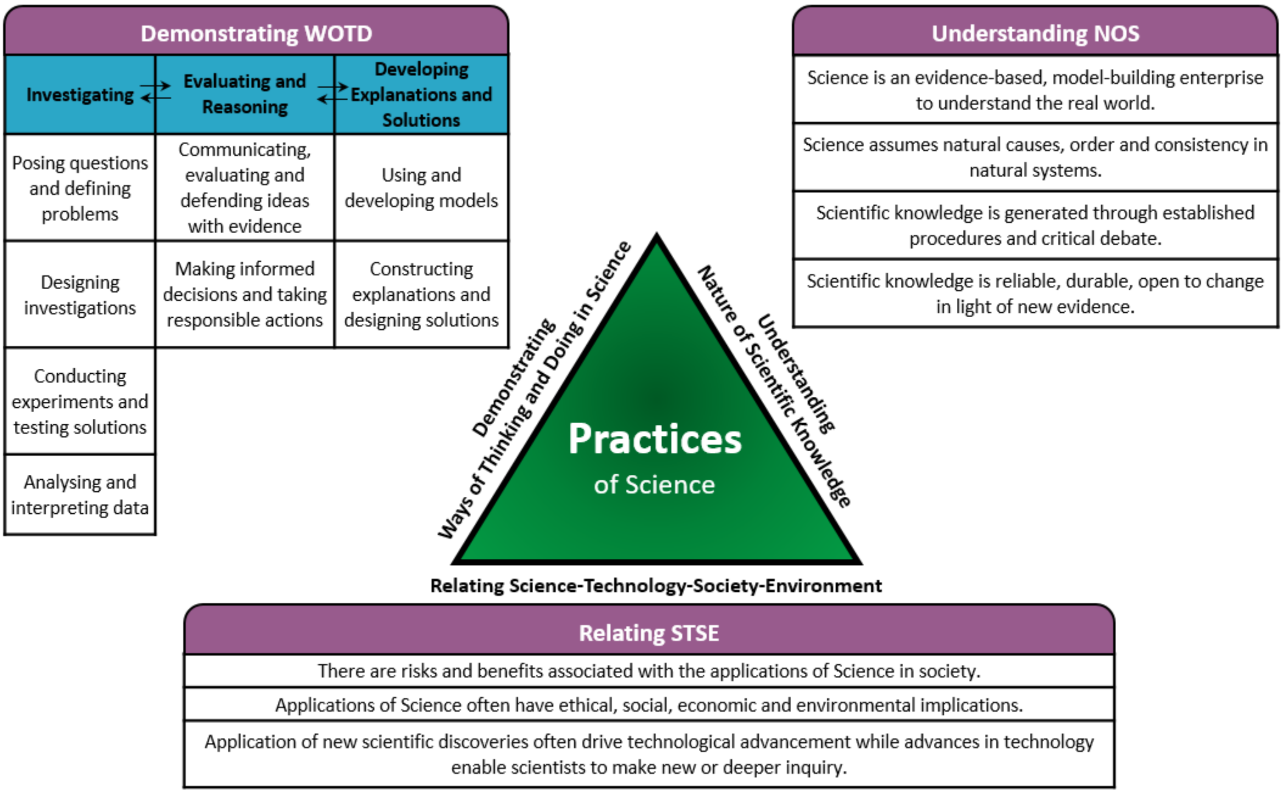


Figure 1.6: Practices of Science

Table 1.5 Components of POS

Demonstrating WOTD

WOTD in Science illustrates a set of established practices associated with scientific inquiry to gather evidence and test ideas on how the natural world works. The three broad, iterative domains of scientific activity are:

I. Investigating
Posing questions and defining problems. Scientific questions initiate the drive to find out more about the natural and man-made world(s), such as what is and how it works. The applications of Science are motivated by finding solutions to problems. This also involves asking questions and scoping the problem so that it may be solved through the application of science and technology. **Designing investigations.** Scientific investigations are often carried out as part of scientific inquiry into a phenomenon or testing of a theory or model that explains the world. In the applications of science, investigations are also conducted to identify the most appropriate solution or determine ways to improve on a technological system. Various criteria are considered in planning investigations, including the general approach, the apparatus and type of data needed. **Conducting experiments and testing solutions.** This involves the application of techniques, methods, understanding on a range of apparatus and equipment (including sensors and dataloggers) and/or apply methods. **Analysing and interpreting data.** Scientists are actively involved in organising and interpreting data to reveal any patterns and relationships that may serve as evidence for communicating to others. Students learning science should be introduced to the use of technology as an aid in practical work or as a tool for the interpretation of experimental and theoretical results. The use of digital tools can allow a great volume of data to be systematically and efficiently analysed, to decide on and/or predict the efficacy of a model.
II. Evaluating and Reasoning
Communicating, evaluating and defending ideas with evidence. Practices in Science and technology involve clear and persuasive communication of ideas in various forms (e.g. orally, written, visual) and media (e.g. journals, newspaper, news). In the process, reasoning, argumentation and critique of ideas are practiced, based on evidence, such that explanations and design solutions become acceptable within the scientific and technological communities. **Making informed decisions and taking responsible actions.** This involves identifying and analysing a situation competently and reflect upon the implication of decisions made based on various considerations (e.g. economic, social, environmental and ethical).
III. Developing Evaluations and Solutions
Using and developing models. Models are approximations of phenomena or systems that are based on evidence and hold potential for describing, explaining and predicting phenomena to aid scientific inquiry and/or analyse technological systems. **Constructing explanations and designing solutions.** Science strives to explain the causes of phenomena while scientific applications endeavour to solve problems. The process of constructive explanations and designing solutions are iterative and systematic.

Understanding NOS

Science is an epistemic endeavour to build a better understanding of reality. What kinds of knowledge can scientists build?

unique way of knowing which uses empirical standards, logical arguments, and sceptical reviews. It consists of both a body of knowledge of natural systems and the processes used to refine, elaborate, revise, and extend this knowledge.

Science assumes natural causes, order and consistency in natural systems. Scientists often use hypotheses to develop and test theories and explanations for physical phenomena. Science assumes that objects and events in natural systems occur in consistent patterns that are understandable through measurement and observation. Scientific knowledge is based on the assumption that natural laws operate today as they did in the past and they will continue to do so in the future[7]. Theories are validated by the scientific community before they are accepted.

Scientific knowledge is generated through established procedures and critical debate. Collaboration by students in their science learning echoes the social NOS for practising scientists. By presenting their work and ideas to others as part of the scientific community, they develop multiple ways to observe and measure, suggest predictions and propose inferences.

Scientific knowledge is reliable, durable, open to change in light of new evidence. Scientific explanations are tentative and open to revision if sufficient evidence or arguments can be provided. Scientific knowledge advances as old ideas are replaced by better explanations.

Relating STSE

Science is not done completely independent of the other spheres of human activity. The relationships and connections to these areas are important as students learn science in context.

STSE 1. There are risks and benefits associated with the applications of science in society. Science and its applications have the potential to bring about both benefits and harm to society.

STSE 2. **Applications of science often have ethical, social, economic, and environmental implications.** It is useful to be able to predict some of these implications while appreciating the possibility of unintended consequences.

STSE 3. **Applications of new scientific discoveries often drive technological advancements while advances in technology enable scientists to make new or deeper inquiry.** Science and technology can exist in a virtuous cycle, with new science inspiring new technology, and advances in engineering allowing the successful execution of challenging experiments (e.g. achieving greater precision in measurements, carrying out complex investigations or analysis).

[7] Laws are regularities or descriptions of natural phenomena. A scientific theory is a substantiated explanation of an aspect of the natural world, based on a body of facts that has been repeatedly verified through observation and experiment.

SECTION 2: CONTENT

2. CONTENT

The content in the Biology syllabus is organised around four *Core Ideas* of Biology:

- *Core Idea* 1: The Cell and Biomolecules of Life
- *Core Idea* 2: Genetics and Inheritance
- *Core Idea* 3: Energy and Equilibrium
- *Core Idea* 4: Biological Evolution

For each *Core Idea*, pertinent and 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 H2 Biology syllabus features two examinable *Extension Topics*. These are based on important emerging biological issues impacting both the local and global contexts. They require students to demonstrate assimilation of the *Core Ideas* and extend their knowledge and understanding to real-world challenges. Furthermore, extension topics will equip students with the necessary knowledge and process skills to make informed decisions about scientific issues. In line with this, the two *Extension Topics* chosen are (A) Infectious Diseases, and (B) Impact of Climate Change on Animals and Plants. Both *Extension Topics* take up about 15 percent of the total H2 and H3 Biology curriculum and are presented through the use of guiding questions, narratives and assessable learning outcomes.

H2 and H3 Biology students are expected to study all four *Core Ideas* and both *Extension Topics*. Whereas H1 Biology students are expected to study all four *Core Ideas* and only the *Extension Topic* on Impact of Climate Change on Animals and Plants.

2.1 H1 BIOLOGY CONTENT

2.1.1 Core Idea 1: The Cell and Biomolecules of Life

This core idea entails the study of cells which are the basic units of life.

The following questions should help students frame their learning:

- Why is a cell the basic unit of life and how does it promote continuity of life?
- How is the knowledge of this 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 functions of such movements?
- How do cells of prokaryotes and eukaryotes, cells of plants and animals, and cells of unicellular and multicellular organisms differ?

A. Organelles and Cellular Structures

This topic discusses 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.

Learning Outcomes Students should be able to:
(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
(b) interpret and recognise drawings, photomicrographs and electron micrographs of the cytoplasm (cytosol) and cellulose cell wall, and 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
(c) outline the functions of the cell structures listed in (b)
(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)

B. 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.

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

C. Proteins

Proteins play a variety of roles in structural, transport, enzymatic and signalling functions. A protein's structure is related to its properties and functions. Changes in temperature and pH may denature proteins.

Learning Outcomes Students should be able to:
(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 on the rate 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)

D. Stem Cells

This concept highlights the diversity in cell type and the morphology in an organism. 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 differential gene expression. The same genome gives rise to a wide range of cells which further form tissues, organs and systems in an organism.

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. Blood stem cells are used in blood marrow transplants in cancer treatments. Skin stem cells are used to culture skin cells to treat patients with massive burns. -

Learning Outcomes Students should be able to:
(p) describe the unique features of stem cells, including zygotic stem cells, embryonic stem cells and blood stem cells, correctly using the terms: i. totipotency (e.g. zygotic stem cells) ii. pluripotency (e.g. embryonic stem cells) iii. multipotency (e.g. blood stem cells) (q) Explain the normal functions of stem cells in a living organism, including embryonic stem cells and blood stem cells.

2.1.2 Core Idea 2: Genetics and Inheritance

This core idea helps make sense of the transition from molecular to organismal levels. It 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 cellular organelles 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 some examples of genetic diseases.

The following questions should help students frame their learning:

- 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?

A. The Structure of Nucleic Acids and Gene Expression

The structure of DNA was proposed by James Watson and Francis Crick in 1953. Maurice Wilkins and Rosalind Franklin were two other scientists who also played crucial roles in the discovery of the DNA structure. 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. Besides the synthesis of mRNA, transcription may also result in the synthesis of tRNA or rRNA; tRNA is needed during translation 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.

Learning Outcomes Students should be able to:
(a) describe the structure and roles of DNA and RNA (tRNA, rRNA and mRNA) (knowledge of the structure and roles of mitochondrial DNA and chloroplast DNA is not required)
(b) describe the process of DNA replication
(c) describe how the information on DNA is used to synthesise polypeptides (description of the processes of transcription, formation of mRNA from pre-mRNA and translation is required.)

B. DNA Mutations

This concept illustrates how DNA mutations could have huge physiological impact on organisms. Changes in DNA sequence or number of chromosomes could result in genetic diseases such as sickle cell anaemia or Down syndrome in humans.

Understanding of the relationship between genes and diseases has led to the advancement of medical science. Genetic maternal screening allows for the early detection of DNA mutations in foetuses. This informs parents early of the possibility of their children having genetic diseases to facilitate their decision-making. However, it also raises complex ethical issues, such as the dilemma between respecting maternal autonomy and acting in the interest of the foetus.

Learning Outcomes Students should be able to:
(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 (e) explain how gene mutations can result in diseases (including sickle cell anaemia) (f) discuss the bioethics of genetic maternal screening for mutations, including trisomy–21

C. The Cell Cycle

There are two different types of cell cycles: mitotic and meiotic. Cell cycles are tightly regulated at various checkpoints. 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 through crossing over of homologous chromosomes and the independent assortment of bivalents.

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. Normally, two groups of genes are involved in regulating cell division: tumour suppressor genes and proto-oncogenes. Mutations in either or both of these groups of genes may lead to the development of cancer. Cancer has a much higher incidence in Singapore compared to other diseases and accounts about 30 percent 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. As such, an understanding of how cancer develops is important as this would set the platform for discussion of developing anti-cancer drugs.

Learning Outcomes Students should be able to:
(g) describe the events that occur during the mitotic cell cycle and the main stages of mitosis (including the behaviour of chromosomes, nuclear envelope, cell surface membrane and centrioles) (h) 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 details of the mechanism are not required) (i) identify the causative factors, including genetic, chemical carcinogens and ionising radiation, which may increase the chances of cancerous growth (j) describe the development of cancer as a multi-step process that includes accumulation of mutations (details of tumour suppressor genes and proto-oncogenes are not required), angiogenesis and metastasis (k) 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 surface membrane and centrioles is not required.)

D. 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.

Learning Outcomes Students should be able to:
(l) explain the terms: *locus, allele, dominant, recessive, codominant, incomplete dominance, homozygous, heterozygous, phenotype, genotype* and sex *linkage* (m) explain how genes are inherited from one generation to the next via the germ cells or gametes (n) explain how the environment may affect the phenotype, using examples including the effect of diet on differentiation of honeybees (o) use genetic diagrams to solve problems in dihybrid crosses, including those involving codominance, incomplete dominance, multiple alleles and sex linkage (p) use genetic diagrams to solve problems involving test crosses

2.1.3 Core Idea 3: Energy and Equilibrium

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

The following questions should help students frame their learning:

- How do organisms obtain and use energy for growth and survival?

A. 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. Carbon fixation occurs during the light-independent stage and 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 - metabolised 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, fermentation occurs with the release of fewer ATP molecules and the formation of either lactate or ethanol depending on the cell type.

Learning Outcomes Students should be able to:
(a) state that photosynthesis occurs in chloroplasts
(b) identify the initial reactants and final products of the light-dependent and light-independent stages (details of the intermediate molecules, enzymes, names of complexes in the ETC and detailed mechanism of action of ATP synthase are not required.)
(c) outline briefly that photosynthesis involves conversion of light energy to chemical energy and this energy is stored in the form of carbohydrates
(d) 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, enzymes, detailed mechanism of action of ATP synthase and calculation of total yield of ATP in each biochemical pathway are not needed.)
(e) state that glycolysis occurs in the cytoplasm and that the link reaction, Krebs cycle and oxidative phosphorylation occur in the mitochondria
(f) 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.)
(g) state that respiration under aerobic conditions releases more energy than respiration under anaerobic conditions

2.1.4 Core Idea 4: Biological Evolution

This core idea 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

The following questions should help students frame their learning:

- 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. Charles Darwin's theory of natural selection (and, in parallel, Alfred Wallace's similar observations and conclusions) states that inheritable variation occurs in individuals in a population.

Learning Outcomes Students should be able to:
(a) explain why variation (as a result of mutation, meiosis and sexual reproduction) is important in natural selection (b) explain, with examples, how environmental factors act as forces of natural selection (c) explain the role of natural selection in evolution (d) explain how genetic variation (including harmful recessive alleles) may be preserved in a natural population (e) explain the biological concept of the species

2.1.5 Extension Topic A: 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 water 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; the loss of mangrove and seagrass habitats, 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.

In a bid to curtail the increasing carbon emissions globally, nations have pledged to reduce greenhouse gas emissions at international summits such as the Paris Agreement. Under the Paris Agreement, Singapore targets to peak its emissions at 65 million tonnes by around 2030, reduce that amount by around 50% by 2050, and subsequently achieve net-zero emissions by 2100. It is therefore pivotal that nations, societies, companies and even individuals can be aware and mindful of the carbon footprints left behind by anthropogenic activities as well as take concerted effort to effectively reduce emissions.

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.

Mosquitoes kill more people through the life-threatening diseases they spread than any other predators. 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 will be important to Singapore.

There is a collective part that all of us can play as individuals to slow down the global effects of climate change. It is also pivotal to imbue in youths the importance of fighting climate change as they will continue to pass down the stewardship of this planet we call earth to the next generation and beyond. Hence, concerted effort through active citizenry and appropriate advocacy can bring about greater awareness of climate change and more importantly achieve realistic goals to slow down the rate of climate change.

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

1. The need for a safe and sustainable food supply;
2. The threat to natural ecosystems

The following questions should help students frame their learning:

- How can our actions ameliorate or contribute to climate change?
- Why is there an urgent need to ameliorate climate change through an understanding and application of the sciences?
- What are several active citizenry initiatives that I can propose and undertake to combat or ameliorate the effects of climate change?

Learning Outcomes Students should be able to:	
(a)	identify and explain the human activities over the last few centuries that have contributed to climate change through accumulation of greenhouse gases (limited to CO_2 and methane), including burning of fossil fuels linked to increasing energy usage, clearing of forests and food choices (increasing consumption of meat)
(b)	explain the effects of climate change as a result of greenhouse gas emissions, including melting of polar ice caps, rising sea levels, increase in frequency of extreme weather events, stress on fresh water supplies, migration of fishes and insects, stress to coral reef, seagrass and mangrove ecosystems, and release of greenhouse gases from frozen organic matter
(c)	explain how mangrove ecosystems help to mitigate the impacts of climate change
(d)	explain the relative differences between the carbon footprints of a range of anthropogenic activities, including deforestation, energy production (including fossil fuels, solar power, nuclear power and bioethanol) and food production (meat and plant-based)
(e)	discuss the consequences to the sustainable food supply of increased environmental stress resulting from climate change, including the effects on plants and animals of increased temperature and more extreme weather events
(f)	explain how temperature changes impact insects as a result of increased temperature leading to increased metabolism and the narrow temperature tolerance of insects, including how temperature affects the life cycle of *Aedes aegypti* as an example of a typical mosquito disease vector
(g)	explain how global warming affects the spread of mosquito-borne infectious diseases, including malaria and dengue, beyond the tropics

2.2 H2 BIOLOGY CONTENT

2.2.1 Core Idea 1: The Cell and Biomolecules of Life

This core idea entails the study of cells which are the basic units of life.

The following questions should help students frame their learning:

- Why is a cell the basic unit of life and how does it promote continuity of life?
- How is the knowledge of this 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 functions of such movements?
- How do cells of prokaryotes and eukaryotes, cells of plants and animals, and cells of unicellular and multicellular organisms differ?
- In what ways do viruses challenge the cell theory?

A. Organelles and Cellular Structures

This topic discusses 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.

Learning Outcomes Students should be able to:
(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 (b) interpret and recognise drawings, photomicrographs and electron micrographs of the cytoplasm (cytosol) and cellulose cell wall, and 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 (for practical assessment, candidates may be required to operate a light microscope, mount slides and use an eyepiece graticule and a stage micrometer) (c) outline the functions of the cell structures listed in (b) (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) (e) describe the structural components of viruses, including enveloped viruses and bacteriophages, and interpret drawings and photographs of them (f) discuss how viruses challenge the cell theory and concepts of what is considered living

B. 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. Regulating membrane transport is important for several biochemical processes to occur.

Learning Outcomes Students should be able to:
(g) describe the structure and properties of the following monomers: i. α-glucose and β-glucose (in carbohydrates) ii. glycerol and fatty acids (in lipids) iii. amino acids (in proteins) (knowledge of chemical formulae of specific R-groups of different amino acids is not required) (h) describe the formation and breakage of the following bonds: i. glycosidic bond ii. ester bond iii. peptide bond (i) describe the structures and properties of the following biomolecules and explain how these are related to their roles in living organisms: i. starch (including amylose and amylopectin) ii. cellulose iii. glycogen iv. triglyceride v. phospholipid (j) explain the fluid mosaic model and the roles of the constituent biomolecules (including phospholipids, proteins, glycolipids, glycoproteins and cholesterol) in cell membranes (k) outline the functions of membranes at the surface of cells and membranes within the cell (l) explain how and why different substances move across membranes through simple diffusion, osmosis, facilitated diffusion, active transport, endocytosis and exocytosis

C. Proteins

Proteins play a variety of roles in structural, transport, enzymatic and signalling functions. A protein's structure is related to its properties and functions. Changes in temperature and pH may denature proteins.

Learning Outcomes Students should be able to:
(m) 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) (n) explain the effects of temperature and pH on protein structure (o) describe the molecular structure of the following proteins and explain how the structure of each protein relates to the function it plays: i. haemoglobin (globular; transport) ii. collagen (fibrous; structural) (knowledge of details of the number of amino acids and types of secondary structures present is not required.) (p) 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 (q) investigate and explain the effects of temperature, pH, enzyme concentration and substrate concentration on the rate 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) (r) describe the structure of competitive and non-competitive inhibitors with reference to the binding sites of the inhibitor (s) explain the effects of competitive and non-competitive inhibitors (including allosteric inhibitors) on the rate of enzyme activity

D. Stem Cells

This concept highlights the diversity in cell type and the morphology in an organism. 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 differential gene expression. The same genome gives rise to a wide range of cells which further form tissues, organs and systems in an organism.

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. Blood stem cells are used in blood marrow transplants in cancer treatments. Skin stem cells are used to culture skin cells to treat patients with massive burns.

Learning Outcomes Students should be able to:
(t) describe the unique features of stem cells, including zygotic stem cells, embryonic stem cells and blood stem cells (lymphoid and myeloid), correctly using the terms: i. totipotency (e.g. zygotic stem cells) ii. pluripotency (e.g. embryonic stem cells) iii. multipotency (e.g. lymphoid and myeloid stem cells) (u) explain the normal functions of stem cells in a living organism, including embryonic stem cells and blood stem cells (lymphoid and myeloid)

2.2.2 Core Idea 2: Genetics and Inheritance

This core idea helps make sense of the transition from molecular to organismal levels. It 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 cellular organelles 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 certain types of cancer are some examples of genetic diseases.

The following questions should help students frame their learning:

- 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?

A. The Structure of Nucleic Acids and Gene Expression

The structure of DNA was proposed by James Watson and Francis Crick in 1953. Maurice Wilkins and Rosalind Franklin were two other scientists who also played crucial roles in the discovery of the DNA structure. 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. Besides the synthesis of mRNA, transcription may also result in the synthesis of tRNA or rRNA; tRNA is needed during translation 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.

Learning Outcomes Students should be able to:
(a) describe the structure and roles of DNA and RNA (tRNA, rRNA and mRNA) (knowledge of the structure and roles of mitochondrial DNA and chloroplast DNA is not required) (b) describe the process of DNA replication and how the end replication problem arises (c) describe how the information on DNA is used to synthesise polypeptides (description of the processes of transcription, formation of mRNA from pre-mRNA in eukaryotes and translation is required)

B. Organisation of Genomes

The nuclear genomes of eukaryotes differ greatly in size, number of genes and gene density from one another. The number of chromosomes differs between species and, in addition, certain eukaryotic organelles such as mitochondria and chloroplasts possess small amounts of their own DNA. Eukaryotic genomes generally have a higher proportion of non-coding DNA to coding DNA. In addition to a large, circular chromosome, bacteria also have several plasmids. Even though bacteria reproduce asexually, they exhibit a great deal of genetic diversity through mutation and genetic transfer. In contrast to eukaryotic and prokaryotic genomes, the viral genome varies according to the type of virus: the genome may be DNA or RNA in nature and single- or double-stranded. For RNA viruses, they may possess either positive-sense RNA (i.e. identical to viral mRNA and thus can be immediately translated) or negative-sense RNA (i.e. complementary to viral mRNA and thus must be used as a template for the synthesis of positive-sense RNA by RNA polymerase before translation).

Learning Outcomes Students should be able to:
(d) describe the structure and organisation of viral, prokaryotic and eukaryotic genomes (including DNA/RNA, single-/double-stranded, number of nucleotides, packing of DNA, linearity/circularity and presence/absence of introns)
(e) describe how the genomes of viruses are inherited through outlining the reproductive cycles of: i. bacteriophages that reproduce via lytic and lysogenic cycles, including lambda phage ii. enveloped viruses, including influenza iii. retroviruses, including HIV
(f) describe how variation in viral genomes arises, including antigenic shift and antigenic drift
(g) outline the mechanism of asexual reproduction by binary fission in a typical prokaryote and describe how transformation, transduction and conjugation (including the role of F plasmids but not Hfr) give rise to variation in prokaryotic genomes
(h) describe the structure and function of non-coding DNA in eukaryotes (i.e. portions that do not encode protein or RNA, including introns, centromeres, telomeres, promoters, enhancers and silencers) (knowledge of transposons, satellite DNA, pseudo-genes and duplication of segments is not required)

C. Control of Gene Expression

In eukaryotes, regulation of gene expression can occur at the chromatin level, transcriptional level, post-transcriptional level, translational level and/or even post-translational level. This allows differential gene expression in the same cell at different times (temporal) or in cells from different tissues at the same time (spatial). Basic molecular techniques allow scientists to study gene expression.

Learning Outcomes Students should be able to:
(i) explain how differential (i.e. spatial and temporal) gene expression in eukaryotes can be regulated at different levels: i. chromatin level (histone modification and DNA methylation) ii. transcriptional level (control elements, such as promoters, silencers and enhancers, and proteins, such as transcription factors, including activators and repressors) iii. post-transcriptional level (processing of pre-mRNA in terms of splicing, polyadenylation and 5' capping) iv. translational level (half-life of RNA and initiation of translation) v. post-translational level (biochemical modification and protein degradation) (j) describe the principles and procedures of these molecular techniques: i. polymerase chain reaction (including its advantages and limitations) ii. gel electrophoresis iii. southern blotting and nucleic acid hybridisation

D. DNA Mutations

This concept illustrates how DNA mutations could have huge physiological impact on organisms. Changes in DNA sequence or number of chromosomes could result in genetic diseases such as sickle cell anaemia or Down syndrome in humans.

Understanding of the relationship between genes and diseases has led to the advancement of medical science. Genetic maternal screening allows for the early detection of DNA mutations in foetuses. This informs parents early of the possibility of their children having genetic diseases to facilitate their decision-making. However, it also raises complex ethical issues, such as the dilemma between respecting maternal autonomy and acting in the interest of the foetus.

Learning Outcomes Students should be able to:
(k) 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 (l) explain how gene mutations can result in diseases (including sickle cell anaemia) (m) discuss the bioethics of genetic maternal screening for mutations, including trisomy–21

E. The Cell Cycle

There are two different types of cell cycles: mitotic and meiotic. Cell cycles are tightly regulated at various checkpoints. 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 through crossing over of homologous chromosomes and the independent assortment of bivalents.

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. Normally, two groups of genes are involved in regulating cell division: tumour suppressor genes and proto-oncogenes. Mutations in either or both of these groups of genes may lead to the development of cancer. Cancer has a much higher incidence in Singapore compared to other diseases and accounts for about 30 percent 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. As such, an understanding of how cancer develops is important as this would set the platform for discussion of developing anti-cancer drugs.

Learning Outcomes Students should be able to:
(n) describe the events that occur during the mitotic cell cycle and the main stages of mitosis (including the behaviour of chromosomes, nuclear envelope, cell surface membrane and centrioles)
(o) 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 details of the mechanism are not required)
(p) identify the causative factors, including genetic, chemical carcinogens, ionising radiation and loss of immunity, which may increase the chances of cancerous growth
(q) explain how the loss of function mutation of tumour suppressor genes, including *p53*, and gain in function mutation of proto-oncogenes, including *ras*, results in uncontrolled cell division
(r) describe the development of cancer as a multi-step process that includes accumulation of mutations, angiogenesis and metastasis
(s) describe the events that occur during the meiotic cell cycle and the main stages of meiosis (including the behaviour of chromosomes, nuclear envelope, cell surface membrane and centrioles) (names of the main stages are expected, but not the sub-divisions of prophase)

Learning Outcomes Students should be able to:	
(t)	explain the significance of the meiotic cell cycle (including how meiosis and random fertilisation can lead to variation)

F. 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. Statistical tests, such as the chi-squared test, allow scientists to test the significance of differences between observed and expected results of genetic crosses.

Learning Outcomes Students should be able to:
(u) explain the terms: *locus, allele, dominant, recessive, codominant, homozygous, heterozygous, phenotype, genotype* and *linkage*
(v) explain how genes are inherited from one generation to the next via the germ cells or gametes
(w) explain how genotype is linked to phenotype
(x) use genetic diagrams to solve problems in dihybrid crosses, including those involving codominance, multiple alleles, sex linkage, autosomal linkage and epistasis
(y) use genetic diagrams to solve problems involving test crosses
(z) explain the meaning of the terms linkage and crossing-over and explain the effect of linkage and crossing-over on the phenotypic ratios from dihybrid crosses
(aa) describe the interaction between loci (epistasis) and predict phenotypic ratios in problems involving epistasis (knowledge of the expected ratio for various types of epistasis is not required; focus of this section is on problem solving)
(bb) explain how the environment may affect the phenotype, using examples including the effect of diet on differentiation of honeybees
(cc) explain the difference between genetic variation that is continuous (many, additive genes control a characteristic) and genetic variation that is discontinuous (one or a few genes control a characteristic)
(dd) use the chi-squared test to test the significance of differences between observed and expected results

2.2.3 Core Idea 3: Energy and Equilibrium

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

The following questions should help students frame their learning:

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

A. 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. Carbon fixation occurs during the light-independent stage and 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 - metabolised 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, fermentation occurs with the release of fewer ATP molecules and the formation of either lactate or ethanol depending on the cell type.

Learning Outcomes Students should be able to:	
(a)	identify components of chloroplasts and mitochondria in drawings, photomicrographs and electronmicrographs
(b)	explain the absorption and action spectra of photosynthetic pigments
(c)	with reference to the chloroplast structure, describe and explain how light energy is harnessed and converted into chemical energy during the light-dependent reactions of photosynthesis (names of complexes in the ETC and detailed mechanism of action of ATP synthase are not required)
(d)	outline the three phases of the Calvin cycle in the light-independent reactions of photosynthesis in C3 plants: (i) CO_2 fixation (ii) PGA reduction and (iii) ribulose bisphosphate (RuBP) regeneration, indicating the roles of rubisco, ATP and reduced NADP in these processes that ultimately allow synthesis of sugars (knowledge of details of the structure of intermediate compounds and the names of other enzymes is not required)
(e)	discuss limiting factors in photosynthesis and carry out investigations on the effect of limiting factors such as temperature, light intensity and carbon dioxide concentration on the rate of photosynthesis
(f)	outline the process of glycolysis, highlighting the location, raw materials used and products formed (knowledge of details of the intermediate compounds, names of enzymes and isomerisation is not required)
(g)	outline the processes of the link reaction and Krebs cycle, highlighting the location, raw materials used and products formed (in terms of dehydrogenation and decarboxylation)
(h)	outline the process of oxidative phosphorylation, including the roles of oxygen and the electron transport chain (ETC) in aerobic respiration (names of complexes in the ETC, detailed mechanism of action of ATP synthase and calculation of total yield of ATP from oxidative phosphorylation are not required)
(i)	explain the production of a small yield of ATP from respiration in anaerobic conditions in yeast and in mammalian muscle tissue
(j)	explain the significance of the formation of ethanol in yeast and lactate in mammals in the regeneration of NAD
(k)	investigate the effect of factors including substrate concentration, oxygen concentration and temperature on the rate of respiration
Learning Outcomes	

Students should be able to:	
(l)	outline chemiosmosis in photosynthesis and respiration (names of complexes in the ETC are not required)

B. Communication and Equilibrium in Organisms

The emphasis of this section is on how cell signalling processes can cause a physiological response in an organism. The circulatory system transports hormones from where they are secreted to the target cells. Hormones bind to specific binding sites – receptors found on the cell surface membrane or within the cell to initiate the process of cell signalling.

Cell signalling comprises the following stages: ligand-receptor interaction, signal transduction and amplification, and cellular response. Various molecules such as second messengers, kinases and transcription factors mediate the processes of converting information from the signal molecule (hormone) into a cellular response. Insulin and glucagon are examples of hormones that trigger cell signalling pathways to bring about responses to regulate blood glucose level.

It is important to appreciate the complexity and inter-connectedness of how the communication systems within and between cells interact to achieve the required response. The maintenance of blood glucose levels will be used to illustrate how physiological responses are regulated by controlling gene expression. Sufficient glucose in the blood is necessary to provide cells with respiratory substrates. The pancreas detects the level of blood glucose and secretes either insulin or glucagon to maintain a stable level of glucose in blood. These hormones trigger cellular responses in liver, muscle and adipose cells when the hormones bind to receptors. Signal transduction occurs through various proteins and molecules to amplify and transduce the signal and eventually, elicit a cellular response. Thus, cell signalling and communication result in a relatively stable internal environment for cells in an organism to function optimally. Diseases such as diabetes may result when such stable internal environment is not maintained.

Learning Outcomes Students should be able to:
(m) outline the main stages of cell signalling: i. ligand-receptor interaction ii. signal transduction (phosphorylation cascade and signal amplification) iii. cellular response (change in gene expression) (knowledge of intracellular receptors is not required) (n) explain the roles and nature of second messengers (including cyclic AMP) (o) explain the roles of kinases and phosphatases in signal amplification (p) outline how insulin and glucagon regulate the concentration of blood glucose through the respective tyrosine kinase receptor and G-protein linked receptor. (The outline should be limited to describing how the ligand induces a conformational change in a membrane-bound receptor to trigger downstream signalling pathways that elicit physiological changes in blood glucose concentration. Details of different second messengers and specific kinases activated in the pathway are not required)

2.2.4 Core Idea 4: Biological Evolution

This core idea 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).

The following questions should help students frame their learning:

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

A. Natural Selection and Adaptation

Natural selection occurs only if there is both variation in the genetic information between organisms in a population and 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 is 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 the organisms able to survive and reproduce better 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 evolution of the species is lost.

Learning Outcomes Students should be able to:
(a) explain why variation (as a result of mutation, meiosis and sexual reproduction) is important in natural selection (b) explain, with examples, how environmental factors act as forces of natural selection (c) explain the role of natural selection in evolution (d) Explain why the population is the smallest unit that can evolve (e) explain how genetic variation (including harmful recessive alleles) may be preserved in a natural population

B. Evolution and Biodiversity, Species and Speciation

Genetic information provides evidence of evolution. DNA sequences vary among species, but there are many overlaps; in fact, the ongoing branching that produces multiple lines of descent can be inferred by comparing the DNA sequences of different organisms. Such information is also derivable from the similarities and differences in amino acid sequences and anatomical structures.

Learning Outcomes Students should be able to:
(f) define biological evolution as descent with modification and explain the link between micro-evolution and macro-evolution (g) explain how evidence based on homologies identified in biochemical data (molecular homologies) and the fossil record (anatomical homologies), together with biogeography (supported by Wallace's findings), corroborate Darwin's theory of evolution (h) explain the biological concept of the species and its limitations (i) define biological classification as the organisation of species according to shared characteristics and describe how evolutionary relationship is established (j) explain how new species are formed with respect to geographical isolation (allopatric speciation) and behavioural or physiological isolation within the same geographical location (sympatric speciation) (k) define phylogeny as the organisation of species to show their evolutionary relationships (l) explain the importance of the use of genome sequences in reconstructing phylogenetic relationships and state the advantages of molecular methods, including multiple sequence alignment (nucleotide and amino acid), in classifying organisms (m) explain the Hardy–Weinberg model and the conditions/assumptions it operates in (n) calculate the frequencies of alleles, genotypes and phenotypes in a population for a gene with two alleles, using the Hardy–Weinberg equation

2.2.5 Extension Topic A: Infectious Diseases

Microorganisms, e.g. viruses and bacteria, cause diseases which disrupt the equilibrium of physiological systems in humans. This extension topic explores the diagnosis, treatment and public spread of some infectious diseases.

The following questions should help students frame their learning:

- What cause infectious diseases?
- How does the body respond during an infection?
- How can infectious diseases be prevented or diagnosed and treated?
- How do we describe and measure the spread of infectious diseases?

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 the use of 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. Certain viruses have also evolved to co-exist with their hosts so that they can continue to replicate in their hosts without killing them. 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.

In this topic, students are introduced to concepts in epidemiology, which is the branch of medicine that studies the incidence, distribution, and possible control of diseases. Equipping students with a common language to describe the spread of infectious diseases allows for the efficient understanding and communication of magnitude of diseases. By further unpacking the significance of the basic reproduction number (R_0) in predicting the progress of a disease outbreak, students could also gain some insight to the utility of mathematical models in informing public health policies and influencing strategies to mitigate further spread.

Learning Outcomes
Students should be able to:
(a) describe the specific (adaptive) immune system, including active, passive, naturally acquired and artificially acquired immunity, and the non-specific (innate) immune system (b) outline the roles of B lymphocytes, T lymphocytes, antigen-presenting cells and memory cells in specific primary and secondary immune responses (c) explain the relationship of the molecular structure of antibodies to their functions, using immunoglobulin G, IgG, as an example (d) explain how somatic recombination, hyper-mutation and class switching result in millions of different antibody molecules (e) discuss how vaccination can control disease (including the eradication of smallpox), limited to vaccination stimulates immunity without causing the disease and vaccination of a high enough proportion of the population can break the disease transmission cycle (f) discuss the benefits and risks of vaccination (g) explain how viruses, including influenza virus and HIV, cause diseases in humans through the disruption of host tissue and functions (including HIV and helper T cells, influenza virus and epithelial cells of the respiratory tract) (h) explain the modes of transmission and infection of bacterial pathogens, using *Mycobacterium tuberculosis* as an example (i) describe the modes of action of antibiotics, including penicillin, on bacteria (j) explain the meaning of the basic reproduction number, R_0, as an indicator of the transmissibility (contagiousness) of infectious agents, and how R_0 can be used to predict the progress of a disease outbreak (k) outline the terms (i) outbreak, (ii) epidemic, and (iii) pandemic, that are used to describe the spread of an infectious disease such as influenza

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

Climate change, which is mainly 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 water 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; the loss of mangrove and seagrass habitats, 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.

In a bid to curtail the increasing carbon emissions globally, nations have pledged to reduce greenhouse gas emissions at international summits such as the Paris Agreement. Under the Paris Agreement, Singapore targets to peak its emissions at 65 million tonnes by around 2030, reduce that amount by around 50% by 2050, and subsequently achieve net-zero emissions by 2100. It is therefore pivotal that nations, societies, companies and even individuals can be aware and mindful of the carbon footprints left behind by anthropogenic activities as well as take concerted effort to effectively reduce emissions.

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.

Mosquitoes kill more people through the life-threatening diseases they spread than any other predators. 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 will be important to Singapore.

There is a collective part that all of us can play as individuals to slow down the global effects of climate change. It is also pivotal to imbue in youths the importance of fighting climate change as they will continue to pass down the stewardship of this planet we call earth to the next generation and beyond. Hence, concerted effort through active citizenry and appropriate advocacy can bring about greater awareness of climate change and more importantly achieve realistic goals to slow down the rate of climate change.

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

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

The following questions should help students frame their learning:

- how can our actions ameliorate or contribute to climate change?
- Why is there an urgent need to ameliorate climate change through an understanding and application of the sciences?
- What are several active citizenry initiatives that I can propose and undertake to combat or ameliorate the effects of climate change?

Learning Outcomes Students should be able to:
(a) identify and explain the human activities over the last few centuries that have contributed to climate change through accumulation of greenhouse gases (limited to CO_2 and methane), including burning of fossil fuels linked to increasing energy usage, clearing of forests and food choices (increasing consumption of meat) (b) explain the effects of climate change as a result of greenhouse gas emissions, including melting of polar ice caps, rising sea levels, increase in frequency of extreme weather events, stress on fresh water supplies, migration of fishes and insects, stress to coral reef, seagrass and mangrove ecosystems, and release of greenhouse gases from frozen organic matter (c) explain how mangrove ecosystems help to mitigate the impacts of climate change (d) explain the relative differences between the carbon footprints of a range of anthropogenic activities, including deforestation, energy production (including fossil fuels, hydroelectric power, nuclear power, solar power, wind power and bioethanol) and food production (animal- and plant-based) (e) discuss the consequences to the sustainable food supply of increased environmental stress resulting from climate change, including the effects on plants and animals of increased temperature and more extreme weather events (f) discuss the effects of increased environmental stress (including increased temperatures and more extreme weather events) as a result of global climate change, on habitats, organisms, food chains and niche occupation (g) discuss how climate change affects the rich biodiversity of the tropics including the potential loss of this rich reservoir for biomedicines and genetic diversity for food (h) explain how temperature changes impact insects as a result of increased temperature leading to increased metabolism and the narrow temperature tolerance of insects, including how temperature affects the life cycle of *Aedes aegypti* as an example of a typical mosquito disease vector (i) explain how global warming affects the spread of mosquito-borne infectious diseases, including malaria and dengue, beyond the tropics

2.3 H3 BIOLOGY CONTENT

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. Guiding Questions
2. 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**.

2.3.1 Core Idea 1: The Cell and Biomolecules of Life

Guiding Questions	Learning Outcomes Students should be able to:
How has the membrane theory developed to the current understanding?	(a) describe how the fluid mosaic model of the cell membrane has developed to the current understanding
How do the following challenge the cell theory - acellularity (prions and viruses), multinucleation (hyphae of some fungi) and the endosymbiotic theory?	(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)
Is it possible to have a multicellular organism without cellular differentiation?	(d) justify the need for cell differentiation in multicellular organisms
How does a complex network of protein interactions underlie cell function?	(e) describe protein binding sites and protein subunits in producing large protein and glycoprotein molecules (including haemoglobin, immunoglobulin and prokaryotic RNA polymerase)
	(f) explain, with examples, how protein modification, (including cleavage, phosphorylation and glycosylation) confer new capabilities
	(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
How do so many enzymes work efficiently in ensuring that the cellular machinery operates efficiently?	(h) discuss how a living eukaryotic cell regulates thousands of enzymes

2.3.2 Core Idea 2: Genetics and Inheritance

Guiding Questions	Learning Outcomes Students should be able to:
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

2.3.3 Core Idea 3: Energy and Equilibrium

Guiding Questions	Learning Outcomes Students should be able to:
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 the need for control in organised systems and explain the principles of homeostasis in terms of receptors, effectors and negative feedback

	(h) explain the need for different communication systems within organisms

2.3.4 Core Idea 4: Biological Evolution

Guiding Questions	Learning Outcomes Students should be able to:
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)

2.3.5 Extension Topic A: Infectious Diseases

Guiding Questions	Learning Outcomes Students should be able to:
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.

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

Guiding Questions	Learning Outcomes Students should be able to:
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
	(c) discuss the impact of humans on the environment since the start of the Holocene and how this impact may be measured, including the concepts of biocapacity and ecological footprint.

SECTION 3: PEDAGOGY

3. PEDAGOGY

3.1 Inspiring Students Through Pedagogical Practices

Pedagogy is the intentional practice of teaching informed by educational theories, research and practice. They refer to classroom strategies, teaching actions and teacher-student interactions to help students learn and achieve the outcomes of the curriculum. It is guided by our core beliefs about teaching and learning as articulated in the Singapore Curriculum Philosophy.

Teachers are key in facilitating a variety of learning experiences, drawing on the *Knowledge Bases* and adopting the *Pedagogical Practices*, as described in the *Singapore Teaching Practice* (*STP*). Apt use of pedagogies considering student profile and the nature of the lesson can help our students develop 21CC and work towards the realisation of MOE's Desired Outcomes of Education (DOEs).

Through appropriate LEs and pedagogies, students acquire an understanding of the scientific enterprise, its methods, limitations, benefits and pitfalls, and develop into scientifically literate citizens. Specific to science learning, we unpack four pedagogies as shown in **Figure 3.1** (see blue box).

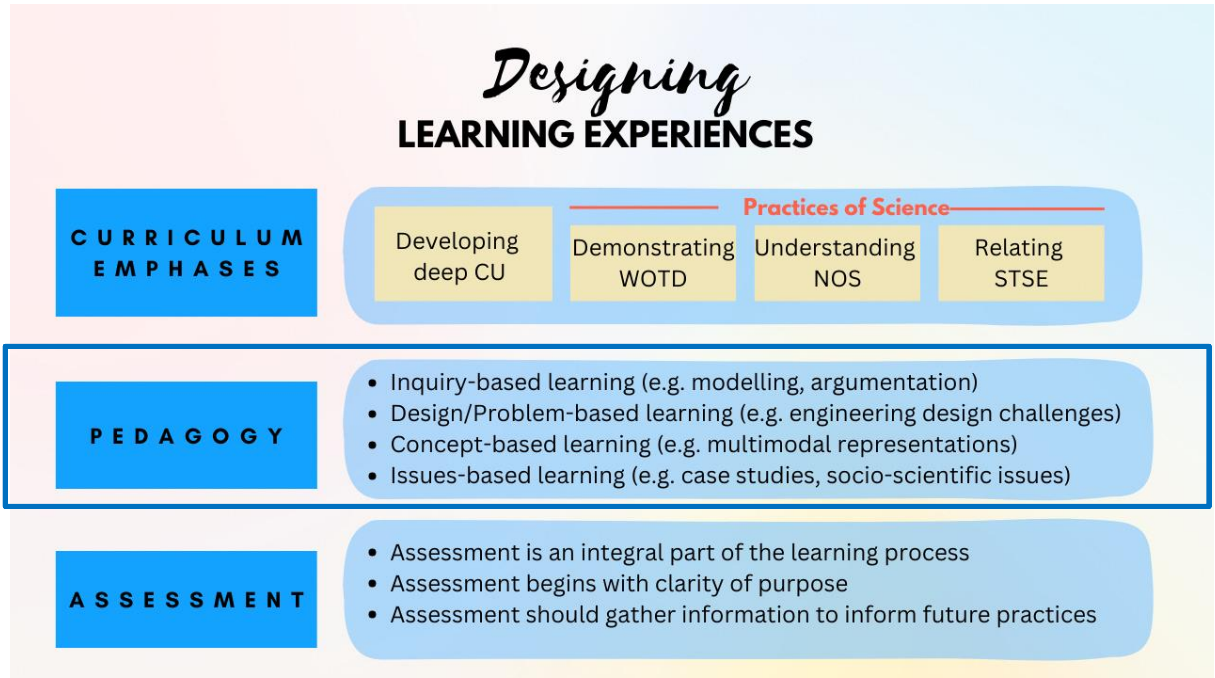


Figure 3.1: Pedagogical Approaches when designing LEs

3.2 Practical Work as an Integral Part of Science Learning

The excitement of scientific investigation brings to life the theory and underpinning knowledge of many fundamental scientific concepts[8], as they link the domain of observables and objects to the domain of scientific ideas (see **Table 3.1**)[9].

Table 3.1: Linking the domains of "observables" & "scientific ideas" through practical work

N	Type of Practical	A	P	Main Learning Objective
1	**Modelling** experiment (Model Development)	I	✓	Modelling a physical phenomenon
2	**Planning** (and doing) experiment	I	-	Planning (and conducting) an investigation
3	**Design Challenge** (Model Deployment)	D	-	Solving a problem or challenge given a physical setup
4	**Confirmatory** Experiment	D	✓	Practicing procedures & Confirming theory

A: Approach; P: Procedure; I: Inductive; D: Deductive

Depending on students' readiness and learning objectives, the level of inquiry in a science practical lesson can vary in terms of degree of complexity (see **Table 3.2**). An activity can be inquiry-based when students conduct the analysis and draw their own conclusions or design their own solutions. Scaffolding for students is instrumental in helping them advance their competencies in scientific inquiry, e.g., they could start from structured inquiry before progressing to higher levels of inquiry, such as open-ended investigations. In such cases, students are required to design all or part of the experimental procedures, decide on what data to record, analyse and interpret the data on their own. This encourages greater autonomy and deeper practices of science in students.

[8] Holman, J. (2009). Good Practical Science. Gatsby Foundation.
[9] Millar, R., & Abrahams, I. (2009). Practical work: making it more effective. *School Science Review, 91(334)*, 59

Table 3.2: Continuum of strategies in terms of amount of information given to the student[10]

Degree of complexity	How much information is given to the student?		
	Question?	Methods?	Solution?
Level 4 Open Inquiry *(Student formulates questions and designs experimental procedures)*	×	×	×
Level 3 Guided Inquiry *(Student designs or selects the experimental procedures)*	✓	×	×
Level 2 Structured Inquiry *(Teachers prescribed the experimental procedures)*	✓	✓	×
Level 1 Confirmation *(Results are known in advance)*	✓	✓	✓

In practical work, students learn to address challenges inherent in observing the physical world, including troubleshooting equipment used to make observations. The use of graphing software (e.g. Excel spreadsheets) allows convenient visualisation and analysis of data. Planning and conducting their mini-investigative projects individually or in small groups also provide many opportunities for students to harness digital tools in the process of recording data, analysing results, and presenting their findings.

[10] Adapted from Bell, R. L., Smetana, L., & Binns, I. (2005). Simplifying inquiry instruction. *The Science Teacher*, 72(2), 30–33

3.3 Science Learning Beyond the Boundaries through STEM LEs

Given how scientists work in areas where subject boundaries are becoming more blurred and interdisciplinary work is increasing important, it would be helpful to teach and learn science that allow students to apply science in real-world contexts and to make connections to other subjects. The design of STEM Les could be unpacked at two levels along a continuum: 1) level of application and 2) level of integration (see **Figure 3.2**). While the extent of curriculum integration could vary, an example of an interdisciplinary curriculum is one where there is a common theme, cross-cutting concept, project or unit across several subjects. Teachers could also make use of real-world contexts to illustrate concepts and applications, and expose students to problems that involve multiple solutions.

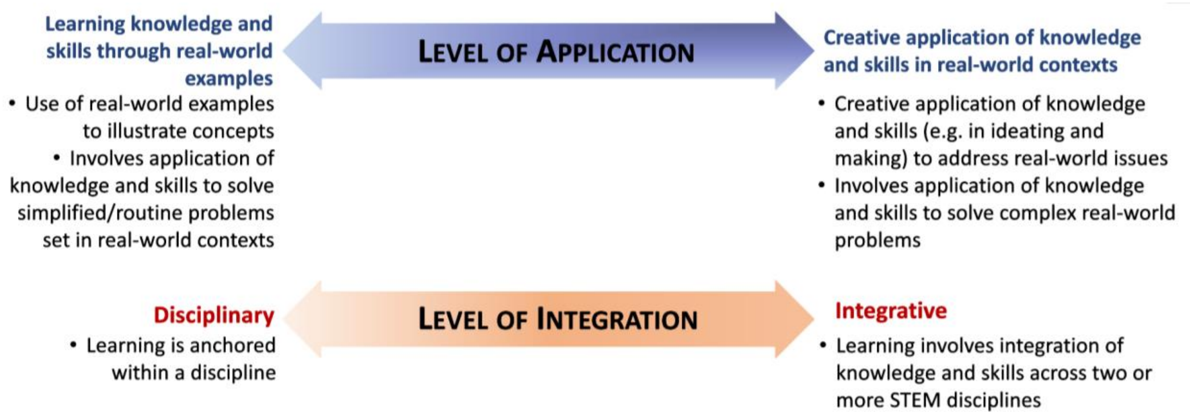


Figure 3.2: Two design considerations for STEM LE

To help students become future-ready, a range of STEM LEs can be adopted. These LEs should provide opportunities to:

a. **make learning relevant** for students by selecting suitable real-world contexts to illustrate knowledge, skills and practices within a discipline;
b. encourage **creative application** by allowing students to apply their knowledge skills and practices within a discipline to work collaboratively in solving problems set in real-world contexts;
c. **enhance students' understanding** to provide students a more coherent and complete understanding of what they are learning by making connections with what is learnt in other STEM disciplines; and/or
d. engage students in **managing complexity** through solving of real-world problems which require them to work collaboratively and apply their knowledge, skills and practices across the STEM disciplines.

SECTION 4: ASSESSMENT

4. ASSESSMENT

4.1 What is Assessment?

Assessment is the process of gathering and analysing evidence about student learning. This information is used to make decisions about students, curriculum and programmes. Assessments designed with a clarity of purpose and the provision of timely and targeted feedback can facilitate meaningful development of students' 21CC and scientific knowledge and skills.

4.2 MOE Assessment Philosophy and Three Key Messages

Creating Learner-centred and balanced assessments that develops students' metacognition can improve engagement levels and inspire self-directed learning.

a. Assessment is an integral to the teaching and learning process. Assessment is a part of teaching and learning, and must be closely aligned with curriculum objectives, content and pedagogy. In a classroom where assessment is used to support learning, there is no divide between teaching and assessment. Everything that happens in the classroom, and everything that students do (e.g., questions they ask, responses to learning activities), become sources of information that help teachers assess what students know and can do. The teacher will analyse these sources of information to make teaching decisions which enhance the quality of learning and address learning gaps. Hence, assessment becomes an ongoing, cyclical process that is woven into the minute-to-minute and day-to-day life in the classroom.

b. Assessment begins with clarity of purpose. Assessment tasks should be fit for purpose and based on sound educational principles. Summative assessment serves to provide information on students' mastery of content knowledge and skills, while formative assessment is carried out for the purpose of enhancing teaching and learning. A balanced assessment system should comprise both summative assessment and formative assessment. Whether implemented as formal examinations or infused in classroom learning activities, assessment should support meaningful learning. Decisions on 'what' to assess and 'how' to assess should be based on a clear purpose, in relation to the learning outcomes.

c. Assessment provides feedback to move learning forward and improve teaching practices. Assessment information should allow both teachers and students to make continuous improvement to teaching and learning. In addition to interpreting assessment information and adapting instructional practices accordingly to address learning gaps, teachers also need to guide students to understand and use assessment information to improve their learning. This will help engender ownership of learning to students and boost their motivation to learn. As students learn to self-assess and self-regulate, they will be equipped to become self-directed learners who are able to learn for life. Assessment information should produce both quantitative and qualitative descriptions of learners' performance to be useful to teachers and students.

4.3 A-Level Examination

Candidates will be assumed to have knowledge and understanding of biology at the O-Level, as a single subject or as part of a balanced science course.

This syllabus is designed to place less emphasis on factual material and greater emphasis on the applications of biology and the impact of recent developments on the needs of contemporary society. This approach has been adopted in recognition of the need for candidates to develop lifelong skills (e.g. critical and inventive thinking) in an increasingly technological world rather than focusing on large quantities of factual material which may have only short-term relevance.

Experimental work is an important component and should underpin the teaching and learning of biology.

4.3.1 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, 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 (**4.4.8 Glossary of Terms**).

B Handling, applying and evaluating information

Candidates should be able to (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 (**4.4.8 Glossary of Terms**).

C Experimental skills and investigations

Candidates should be able to:
1. follow a detailed sequence of instructions or apply standard techniques
2. devise and plan investigations which may include constructing and/or testing a hypothesis and select techniques, apparatus and materials
3. use techniques, apparatus and materials safely and effectively
4. make and record observations, measurements and estimates
5. interpret and evaluate observations and experimental data
6. evaluate methods and techniques, and suggest possible improvements.

4.3.2 Assessment for H1 Biology

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

Paper	Type of Paper	Duration	Weighting (%)	Marks
1	Multiple Choice	1 h	33	30
2	Structured and Free-response Questions	2 h	67	60

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

Assessment Objective		Weighting (%)	Assessment Components
A	Knowledge with understanding	45	Papers 1 and 2
B	Handling, applying and evaluating information	55	Papers 1 and 2

4.3.3 Assessment for H2 Biology

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

Paper	Type of Paper	Duration	Weighting (%)	Marks
1	**Multiple Choice**	1 h	15	30
2	**Structured Questions**	2 h	30	90
3	**Long Structured and Free-response Questions**	2 h	35	75
4	**Practical**	2 h 30 min	20	50

Paper 1 (1 h, 30 marks)

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

Paper 2 (2 h, 90 marks)

This paper consists of a variable number of structured questions, all compulsory, including data-based or comprehension-type questions. These include questions which require candidates to integrate knowledge and understanding from different areas of the syllabus.

Paper 3 (2 h, 75 marks)

This paper consists of a variable number of long structured questions, all compulsory, including data-based or comprehension-type questions and one free-response question of 20 marks. These include questions which require candidates to integrate knowledge and understanding from different areas of the syllabus.

Section A (55 marks) comprises two or more compulsory long structured questions. There will be one or more stimulus materials which may be taken or adapted from a source such as a scientific journal or book which may not necessarily relate directly to the content of the syllabus. Questions may require candidates to explain terms used in the passage, analyse data, justify decisions, perform calculations and draw conclusions based on information in the stimulus material.

Section B (20 marks) comprises 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.

Paper 4 (2 h 30 min, 50 marks)

This paper will assess appropriate aspects of objectives WOTD 1 to 8 in the following skill areas:

- Planning (P)
- Manipulation, measurement and observation (MMO)
- Presentation of data and observations (PDO)
- Analysis, conclusions and evaluation (ACE)

The assessment of skill area P will have a weighting of about 4%, and the skill areas MMO, PDO and ACE will have a weighting of 16%. Candidates will require access to apparatus, as stated in the Confidential Instructions. For some questions, candidates may be allocated a specific time for access to the apparatus. Paper 4 may include data handling/interpretation questions that do not require apparatus, in order to test the skill areas of PDO and ACE.

Candidates are **NOT** allowed to refer to note books, textbooks or any other information in the practical paper.

Weighting of Assessment Objectives

Assessment Objective		Weighting (%)	Assessment Components
A	**Knowledge with understanding**	36	Papers 1, 2, 3
B	**Handling, applying and evaluating information**	44	Papers 1, 2, 3
C	**Experimental skills and investigations**	20	Paper 4

4.3.4 Assessment for H3 Biology

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

4.3.5 Additional Information

Modern biological sciences draw extensively on concepts from the physical sciences. It is desirable therefore that, by the end of the course, candidates should have knowledge of the following topics, sufficient to aid understanding of biological systems. No questions will be set directly on them except where relevant to the assessment of a Learning Outcome.

- The electromagnetic spectrum
- Energy changes (potential energy, activation energy, chemical bond energy)
- Molecules, atoms, ions, electrons
- Acids, bases, pH, buffers
- Isotopes, including radioactive isotopes
- Oxidation and reduction
- Hydrolysis, condensation

Nomenclature

Candidates will be expected to be familiar with the nomenclature used in the syllabus. The proposals in 'Signs, Symbols and Systematics' (The Association for Science Education Companion to 16–19 Science, 2000) and the recommendations on terms, units and symbols in 'Biological Nomenclature' (2009) published by the Institute of Biology (now Society of Biology), in conjunction with the ASE, will generally be adopted although the traditional names sulfate, sulfite, nitrate, nitrite, sulfurous acid and nitrous acid will be used in question papers. Sulfur (and all compounds of sulfur) will be spelt with 'f' (not with 'ph') in question papers. However, candidates can use either spelling in their answers.

Disallowed Subject Combinations

Candidates may not simultaneously offer Biology at H1 and H2 levels.

Units and Significant Figures

Candidates should be aware that misuse of units and/or significant figures, i.e. failure to quote units where necessary, the inclusion of units in quantities defined as ratios or quoting answers to an inappropriate number of significant figures, is liable to be penalised.

4.3.6 **Practical Assessment** (only for H2 Biology)

Scientific subjects are, by their nature, experimental. It is therefore important that, wherever possible, the candidates carry out appropriate practical work to support the learning of this subject and to develop the expected practical skills.

Paper 4 Practical (only for H2 Biology)

This paper is designed to assess candidates' competence in those practical skills which can realistically be assessed within the context of a formal practical assessment.

Candidates will be assessed in the following skill areas:

(a) Planning (P)

Candidates should be able to

- define question/problem using appropriate knowledge and understanding
- give a clear logical account of the experimental procedure to be followed
- describe how the data should be used in order to reach a conclusion
- assess the risks of the experiment and describe precautions that should be taken to keep risks to a minimum.

(b) Manipulation, measurement and observation (MMO)

Candidates should be able to

- demonstrate a high level of manipulative skills in all aspects of practical activity
- make and record accurate observations with good details and measurements to an appropriate degree of precision
- make appropriate decisions about measurements or observations
- recognise anomalous observations and/or measurements (where appropriate) with reasons indicated.

(c) Presentation of data and observations (PDO)

Candidates should be able to

- present all information in an appropriate form
- manipulate measurements effectively in order to identify trends/patterns
- present all quantitative data to an appropriate number of decimal places/ significant figures.

(d) Analysis, conclusions and evaluation (ACE)

Candidates should be able to

- analyse and interpret data or observations appropriately in relation to the task
- draw conclusion(s) from the interpretation of experimental data or observations and underlying principles
- make predictions based on their data and conclusions
- identify significant sources of errors, limitations of measurements and/or

experimental procedures used, and explain how they affect the final result(s)

- state and explain how significant errors/limitations may be overcome/reduced, as appropriate, including how experimental procedures may be improved.

One or more of the questions may incorporate some assessment of Skill P, set in the context of the syllabus content, requiring candidates to apply and integrate knowledge and understanding from different sections of the syllabus. These questions may also require the treatment of given experimental data to draw a relevant conclusion and analyse the proposed plan.

The assessment of skills MMO, PDO and ACE will also be set mainly in the context of the syllabus content and will require access to apparatus, as stated in the Confidential Instructions. For some questions, candidates may be allocated a specific time for access to the apparatus. The assessment of PDO and ACE may also include questions on data-analysis which do not require practical equipment and apparatus.

Within the Scheme of Assessment, Paper 4 is weighted to 20% of the Higher 2 assessment. It is therefore recommended that the schemes of work include learning opportunities that apportion a commensurate amount of time for the development and acquisition of practical skills. The guidance for practical work, which is published separately, will provide examples of practical activities.

Mapping Science Practical Skills to Practices of Science

The development of science practical skills (P, MMO, PDO, and ACE) aids the development of certain science inquiry skills in the students. See **Table 4.3** for alignment between the science practical skills and WOTD.

Table 4.3: Mapping of Science Practical Skills to the WOTD

Practices of Science: Demonstrating Science Inquiry Skills		P	MMO	PDO	ACE
WOTD	Designing investigations	✓			
	Posing questions and defining problems	✓			
	Conducting Experiments and testing solutions	✓	✓		
	Analysing and interpreting data				✓
	Communicating, evaluating and defending ideas with evidence				✓
	Making informed decisions and taking responsible actions				✓
	Using and developing models				✓
	Constructing explanations and designing solutions			✓	✓

Candidates are NOT allowed to refer to note books, text books or any other information in the Practical Examination.

Apparatus List

This list given below has been drawn up in order to give guidance to Centres concerning the apparatus that is expected to be generally available for examination purposes. The list is not intended to be exhaustive and practical examinations may require additional apparatus and materials that will be specified in the Confidential Instructions, e.g. enzymes, indicators, plastic straws, etc. Furthermore, general laboratory glassware and items that are commonly regarded as standard equipment in a Biology laboratory (e.g. Bunsen burners, tripods and gauze, thermostatic water-baths, safety goggles, disposable gloves, paper towels, etc.) are not included in this list.

Unless otherwise stated, the rate of allocation is "per candidate".

Light microscope, with high- and low-power objective lens and fitted eyepiece graticule
Stage micrometer
Microscope slides and coverslips
Mounted needles
Hand lens (not less than ×6)
Half-metre rule or metre rule
Ruler in mm
Syringes (e.g. 1 cm^3, 5 cm^3, 10 cm^3)
Droppers or Pasteur pipettes
Measuring cylinders
Beakers
Petri dishes
Test-tubes (some of which should be heat-resistant)
Test-tube rack and holder
Boiling tubes
Boiling tube rack
Small containers
Glass rod
Corks or rubber bungs to fit test-tubes and boiling tubes
Knife or scalpel
Forceps
Cork borer (2 candidates to 1)
Capillary tubes
Vaseline/petroleum jelly (or similar)
Specimen tubes
Visking tubing
Silicone tubing
Thermometer: –10 °C to +110 °C
Stopwatch
White tile
Filter paper and funnel

Mortar and pestle (2 candidates to 1)
Spatulas
Glass marker pen
Cotton wool
Black paper
Aluminium foil
Balance to 0.01 g (to be made accessible to candidates)
Retort stand and clamp
Bench lamp
Distilled or deionised water
Microfuge tubes and rack
Micropipettes (e.g. 20 µl, 1000 µl, etc.)(2 candidates to 1) and disposable tips
Inoculating loops
Agarose gel electrophoresis cell (including tank, lid, cables, gel tray, comb) and power supply (to be made accessible to candidates)
TAE/TBE buffer
Agarose powder
Nutrient medium

The apparatus and material requirements for Paper 4 will vary year on year. Centres will be notified in advance of the details of the apparatus and materials required for each practical examination.

Reagents

This list given below has been drawn up in order to give guidance to Centres concerning the standard reagents that are expected to be generally available for examination purposes. The list is not intended to be exhaustive and Centres will be notified in advance of the full list of all the reagents required for each practical examination.

iodine in potassium iodide solution
Benedict's solution
biuret reagent
sucrose (use AR for non-reducing sugar test)
glucose
starch
potassium hydroxide
sodium chloride
dilute hydrochloric acid
hydrogencarbonate indicator (bicarbonate indicator)
sodium hydrogencarbonate (sodium bicarbonate)
limewater
universal indicator paper and chart
litmus paper
methylene blue
DCPIP (2,6-dichlorophenolindophenol)

4.3.7 Mathematical Requirements

Questions set in the examination may involve the basic processes of mathematics for the calculation and use of decimals, means, ratios and percentages.

Candidates may be required to (i) construct graphs or present data in other suitable graphical forms, and (ii) calculate rates of processes. Candidates should be aware of the problems of drawing conclusions from limited data and should appreciate levels of significance, standard deviation and probability, and the use of R_o value, Hardy-Weinberg equation ($p^2 + 2pq + q^2 = 1$), *t*- and chi-squared tests (only for H2 and H3 Biology).

Notes on the Use of Statistics in Biology (only for H2 and H3 Biology)

Candidates should know how to apply a *t*-test and a chi-squared test. *t*-tests are of value in much of Biology, while the chi-squared test allows the evaluation of the results of breeding experiments and ecological sampling. Each of these tests is dealt with fully in many books on statistics for Biology.

Candidates are not expected to remember the following equations or what the symbols stand for. They are expected to be able to use the equations to calculate standard deviations, to test for significant differences between the means of two small unpaired samples and to perform a chi-squared test on suitable data from genetics or ecology. Candidates will be given access to the equations, the meaning of the symbols, a *t*-table and a chi-squared table.

standard deviation $s = \sqrt{\dfrac{\Sigma(x - \bar{x})^2}{n-1}}$

t-test $t = \dfrac{|\bar{x}_1 - \bar{x}_2|}{\sqrt{\left(\dfrac{s_1^2}{n_1} + \dfrac{s_2^2}{n_2}\right)}}$ $\quad v = n_1 + n_2 - 2$

χ^2 test $\chi^2 = \Sigma \dfrac{(O - E)^2}{E}$ $\quad v = c - 1$

Key to symbols:

*S** = standard deviation	$\bar{x}$ = mean	*c* = number of classes
∑ = 'sum of …'	*n* = sample size (number of observations)	
O = observed 'value'	E = expected 'value'	
x = observation	v = degrees of freedom	

*Candidates should note that, on some calculators, the symbol σ may appear instead of the symbol *s*.
Candidates are not expected to be familiar with the term standard error, nor to appreciate the difference between s_n (σ_n) and s_{n-1} (σ_{n-1}). χ^2 tests will only be expected on one row of data. Candidates should have a brief understanding of what is meant by the term *normal distribution* and appreciate levels of significance. (Tables will be provided.) Questions involving the use or understanding of a *t*-test or a χ^2 test may be set but detailed computation will not be required.

Calculators
Any calculator used must be on the Singapore Examinations and Assessment Board list of approved calculators.

4.3.8 Glossary of Terms

It is hoped that the glossary (which is relevant only to science subjects) will prove helpful to candidates as a guide; it is neither exhaustive nor definitive. The glossary has been deliberately kept brief not only with respect to the number of terms included but also to the descriptions of their meanings. Candidates should appreciate that the meaning of a term must depend in part on its context.

1. *Analyse* is a context-specific term involving the identification of the constituent parts of a complex situation or result, an assessment of their individual implications and a consideration of how these relate to one another and to scientific knowledge and understanding. Analysis may require further processing of mathematical data to reveal underlying trends and patterns.

2. *Calculate* is used when a numerical answer is required. In general, working should be shown, especially where two or more steps are involved.

3. *Classify* requires candidates to group things based on common characteristics.

4. *Comment* is intended as an open-ended instruction, inviting candidates to recall or infer points of interest relevant to the context of the question, taking account of the number of marks available.

5. *Compare* requires candidates to provide both the similarities and differences between things or concepts.

6. *Deduce* is used in a similar way as predict except that some supporting statement is required, e.g. reference to a law/principle, or the necessary reasoning is to be included in the answer.

7. *Define (the term(s)...)* is intended literally. Only a formal statement or equivalent paraphrase being required.

8. *Describe* requires candidates to state in words (using diagrams where appropriate) the main points of the topic. It is often used with reference either to particular phenomena or to particular experiments. In the former instance, the term usually implies that the answer should include reference to (visual) observations associated with the phenomena.
   In other contexts, describe and give an account of should be interpreted more generally, i.e. the candidate has greater discretion about the nature and the organisation of the material to be included in the answer. Describe and explain may be coupled in a similar way to state and explain.

9. *Determine* often implies that the quantity concerned cannot be measured directly but is obtained by calculation, substituting measured or known values of other quantities into a standard formula, e.g. relative molecular mass.

10. *Discuss* requires candidates to give a critical account of the points involved in the topic.

11. *Draw* is often used in the context of drawing biological specimens. This is an instruction to make a freehand diagram to show the structures observed, as accurately as possible with respect to shape and proportion. Lines delimiting distinct regions should be continuous.

12. *Estimate* implies a reasoned order of magnitude statement or calculation of the quantity concerned, making such simplifying assumptions as may be necessary about points of principle and about the values of quantities not otherwise included in the question.

13. *Evaluate* is a context-specific term requiring a critical use of information to make a judgement or determination of a particular value or quality (e.g. accuracy). Evaluation of the validity of an experimental procedure, a set of results or a conclusion involves an assessment of the extent to which the procedures, results or conclusions are likely to obtain or represent a 'true' outcome. This will require consideration of the advantages and disadvantages, strengths and weaknesses, and limitations of the underlying approach, as well as other relevant criteria as applicable, and their relative importance.

14. *Explain* may imply reasoning or some reference to theory, depending on the context.

15. *Find* is a general term that may variously be interpreted as calculate, measure, determine etc.

16. *Justify* requires candidates to give reasoning in support of an answer (for example, a decision, conclusion, explanation, or claim), based on a consideration of available evidence, including experimental data, together with relevant scientific knowledge and understanding.

17. *Label* requires candidates to use an appropriate label (and labelling line, where necessary) to accurately show the position of a structure, region or point within a diagram or graph, according to the requirements of the assessment.
18. *List* requires a number of points, generally each of one word, with no elaboration. Where a given number of points is specified, this should not be exceeded.

19. *Measure* implies that the quantity concerned can be directly obtained from a suitable measuring instrument, e.g. length, using a rule, or angle, using a protractor.

20. *Outline* implies brevity, i.e. restricting the answer to giving essentials.

21. *Predict* implies that the candidate is not expected to produce the required answer by recall but by making a logical connection between other pieces of information. Such information may be wholly given in the question or may depend on answers extracted in an early part of the question.

22. *Recognise* is often used to identify facts, characteristics or concepts that are critical (relevant/ appropriate) to the understanding of a situation, event, process or phenomenon.

23. *Sketch*, when applied to graph work, implies that the shape and/or position of the curve need only be qualitatively correct, but candidates should be aware that, depending on the context, some quantitative aspects may be looked for, e.g. passing through the origin, having an intercept, asymptote or discontinuity at a particular value.
In diagrams, sketch implies that a simple, freehand drawing is acceptable: nevertheless, care should be taken over proportions and the clear exposition of important details.

24. *State* implies a concise answer with little or no supporting argument, e.g. a numerical answer that can be obtained 'by inspection'.

25. *Suggest* is used in two main contexts, i.e. either to imply that there is no unique answer (e.g. in chemistry, two or more substances may satisfy the given conditions describing an 'unknown'), or to imply that candidates are expected to apply their general knowledge to a 'novel' situation, one that may be formally 'not in the syllabus'.

26. *What is meant by (the term(s)...)* normally implies that a definition should be given, together with some relevant comment on the significance or context of the term(s) concerned, especially where two or more terms are included in the question. The amount of supplementary comment intended should be interpreted in the light of the indicated mark value.

SECTION 5:
RESOURCES AND REFERENCES

5. RESOURCES AND REFERENCES

Links to available instructional resources (e.g. print materials, resources on SLS, demo/lab kits, learning journeys) have been incorporated in the description of the LEs in Section 2.

Teachers may find reference to the following books helpful.

1. Alberts, B., Bray, D., Hopkin, K., Johnson, A. D., Lewis, J., Raff, M., Roberts, K. and Walter, P. (2013) Essential Cell Biology (Fourth Edition) (Garland Science) ISBN 0853696470
2. Alberts, B., Johnson, A., Lewis, J., Morgan, D., Raff, M., Roberts, K. and Walter, P. (2014) Molecular Biology of the Cell (Sixth Edition) (Garland Science) ISBN 0815344643
3. Boohan, R (2016). The Language of Mathematics in Science: A Guide for Teachers of 11–16 Science (Association for Science Education). ISBN 9780863574559 https://www.ase.org.uk/mathsinscience
4. Boyle, M. and Senior, K. (2002) Biology Collins Advanced Science (Collins Educational, www.collinseducational.com) ISBN 0007136005
5. Bryson, B. (2019) The Body: A Guide for Occupants (Doubleday) ISBN 9780385539302
6. Burnet, L. (1986) Essentials Genetics: A Course Book (Cambridge University Press) ISBN 9780521313803
7. Burnet, L. (1988) Exercises in Applied Genetics (Cambridge University Press) ISBN 9780521338837
8. Calladine, C. R. and Drew, H. R. (2004) Understanding DNA (Third Edition) (Academic Press www.apcatalog.com) ISBN 0121550893
9. Campbell, N. A. and Reece, J. B. (2005) Biology (Eighth Edition) (Addison Wesley-Benjamin Cummings, www.aw-bc.com) ISBN 9780321501561
10. Clegg, C. J. and MacKean, D. J. (2000) Advanced Biology, Principles and Applications (Second Edition) (John Murray) ISBN 0719576709
11. Dobzhansky, T (March 1973) Nothing in Biology Makes Sense Except in the Light of Evolution, American Biology Teacher vol. 35 (3)
12. Drlica, K. (2004) Understanding DNA and Gene Cloning: A Guide for the Curious (Wiley and Sons) ISBN 9780471434160
13. Gregory, J. (2000) Applications of Genetics (Second Edition) Cambridge Advanced Sciences (Cambridge University Press, www.cambridge.org) ISBN 0521787254
14. Hayward, G. (1990) Applied Genetics (Bath Science 16-19) (Nelson Thornes, www.nelsonthornes.com) ISBN 0 174385110
15. Hogan, Kelley and Palladino, M. A. (2009) Stem Cells and Cloning, 2/E (Benjamin Cummings) ISBN 0321590023
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