Diploma Programme

# Biology guide

First assessment 2025

International Baccalaureate®
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**Diploma Programme**
**Biology guide**

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The International Baccalaureate Organization (known as the IB) offers four high-quality and challenging educational programmes for a worldwide community of schools, aiming to create a better, more peaceful world. This publication is one of a range of materials produced to support these programmes.

# IB mission statement

The International Baccalaureate aims to develop inquiring, knowledgeable and caring young people who help to create a better and more peaceful world through intercultural understanding and respect.

To this end the organization works with schools, governments and international organizations to develop challenging programmes of international education and rigorous assessment.

These programmes encourage students across the world to become active, compassionate and lifelong learners who understand that other people, with their differences, can also be right.


# IB learner profile

**The aim of all IB programmes is to develop internationally minded people who, recognizing their common humanity and shared guardianship of the planet, help to create a better and more peaceful world.**

## As IB learners we strive to be:

### INQUIRERS
We nurture our curiosity, developing skills for inquiry and research. We know how to learn independently and with others. We learn with enthusiasm and sustain our love of learning throughout life.

### KNOWLEDGEABLE
We develop and use conceptual understanding, exploring knowledge across a range of disciplines. We engage with issues and ideas that have local and global significance.

### THINKERS
We use critical and creative thinking skills to analyse and take responsible action on complex problems. We exercise initiative in making reasoned, ethical decisions.

### COMMUNICATORS
We express ourselves confidently and creatively in more than one language and in many ways. We collaborate effectively, listening carefully to the perspectives of other individuals and groups.

### PRINCIPLED
We act with integrity and honesty, with a strong sense of fairness and justice, and with respect for the dignity and rights of people everywhere. We take responsibility for our actions and their consequences.

### OPEN-MINDED
We critically appreciate our own cultures and personal histories, as well as the values and traditions of others. We seek and evaluate a range of points of view, and we are willing to grow from the experience.

### CARING
We show empathy, compassion and respect. We have a commitment to service, and we act to make a positive difference in the lives of others and in the world around us.

### RISK-TAKERS
We approach uncertainty with forethought and determination; we work independently and cooperatively to explore new ideas and innovative strategies. We are resourceful and resilient in the face of challenges and change.

### BALANCED
We understand the importance of balancing different aspects of our lives—intellectual, physical, and emotional—to achieve well-being for ourselves and others. We recognize our interdependence with other people and with the world in which we live.

### REFLECTIVE
We thoughtfully consider the world and our own ideas and experience. We work to understand our strengths and weaknesses in order to support our learning and personal development.

**The IB learner profile represents 10 attributes valued by IB World Schools. We believe these attributes, and others like them, can help individuals and groups become responsible members of local, national and global communities.**

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# Contents

# Purpose of this document

This publication is intended to guide the planning, teaching and assessment of biology in schools. Subject teachers are the primary audience, although it is expected that teachers will use the guide to inform students and parents about the subject.

This guide can be found on the subject page of the Programme Resource Centre at resources.ibo.org, a password-protected International Baccalaureate (IB) website designed to support IB teachers. It can also be purchased from the IB store at store.ibo.org.

## Additional resources

Additional publications such as specimen papers and markschemes, teacher support material (TSM), subject reports and grade descriptors can also be found on the Programme Resource Centre. Past examination papers as well as markschemes can be purchased from the IB store.

Teachers are encouraged to check the Programme Resource Centre for additional resources created or used by other teachers. Teachers can provide details of useful resources, for example: websites, books, videos, journals or teaching ideas.

## Acknowledgement

The IB wishes to thank the educators and associated schools for generously contributing time and resources to the production of this guide.

| **First assessment 2025** |
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# The Diploma Programme

The Diploma Programme (DP) is a rigorous pre-university course of study designed for students in the 16 to 19 age range. It is a broad-based two-year course that aims to encourage students to be knowledgeable and inquiring, but also caring and compassionate. There is a strong emphasis on encouraging students to develop intercultural understanding, open-mindedness, and the attitudes necessary for them to respect and evaluate a range of points of view.

## The Diploma Programme model

The course is presented as six academic areas enclosing a central core (see figure 1). It encourages the concurrent study of a broad range of academic areas. Students study two modern languages (or a modern language and a classical language), a humanities or social science subject, an experimental science, mathematics and one of the creative arts. It is this comprehensive range of subjects that makes the DP a demanding course of study designed to prepare students effectively for university entrance. In each of the academic areas students have flexibility in making their choices, which means they can choose subjects that particularly interest them and that they may wish to study further at university.

*Figure 1*

*Diploma Programme model*

# Choosing the right combination

**Students are required to choose one subject from each of the six academic areas, although they can, instead of an arts subject, choose two subjects from another area.** Normally, three subjects (and not more than four) are taken at higher level (HL), and the others are taken at standard level (SL). The IB recommends 240 teaching hours for HL subjects and 150 hours for SL. Subjects at HL are studied in greater depth and breadth than at SL.

At both levels, many skills are developed, especially those of critical thinking and analysis. At the end of the course, students' abilities are measured by means of external assessment. Many subjects contain some element of coursework assessed by teachers.

# The core of the Diploma Programme model

All DP students participate in the three course elements that make up the core of the model.

Theory of knowledge (TOK) is a course that is fundamentally about critical thinking and inquiry into the process of knowing rather than about learning a specific body of knowledge. The TOK course examines the nature of knowledge and how we know what we claim to know. It does this by encouraging students to analyse knowledge claims and explore questions about the construction of knowledge. The task of TOK is to emphasize connections between areas of shared knowledge and link them to personal knowledge in such a way that an individual becomes more aware of their own perspectives and how they might differ from others.

In TOK, students explore the means of producing knowledge within the core theme of "knowledge and the knower" as well as within various optional themes (knowledge and technology, knowledge and politics, knowledge and language, knowledge and religion, and knowledge and indigenous societies) and areas of knowledge (the arts, natural sciences, human sciences, history and mathematics). The course also encourages students to make comparisons between different areas of knowledge and reflect on how knowledge is arrived at in the various disciplines, what the disciplines have in common, and the differences between them.

Creativity, activity, service (CAS) is at the heart of the DP. The emphasis in CAS is on helping students to develop their own identities, in accordance with the ethical principles embodied in the IB mission statement and the IB learner profile. It involves students in a range of activities alongside their academic studies throughout the DP. The three strands of CAS are creativity (arts and other experiences that involve creative thinking), activity (physical exertion contributing to a healthy lifestyle) and service (an unpaid and voluntary exchange that has a learning benefit for the student). Possibly, more than any other component in the DP, CAS contributes to the IB's mission to create a better and more peaceful world through intercultural understanding and respect.

The extended essay (EE), including the world studies extended essay, offers the opportunity for IB students to investigate a topic of special interest, in the form of a 4,000-word piece of independent research. The area of research undertaken is chosen from one of the students' six DP subjects, or in the case of the interdisciplinary world studies essay, two subjects, and acquaints them with the independent research and writing skills expected at university. This leads to a major piece of formally presented, structured writing, in which ideas and findings are communicated in a reasoned and coherent manner, appropriate to the subject or subjects chosen. It is intended to promote high-level research and writing skills, intellectual discovery and creativity. An authentic learning experience, it provides students with an opportunity to engage in personal research on a topic of choice, under the guidance of a supervisor.

# Approaches to teaching and approaches to learning

Approaches to teaching and approaches to learning (ATL) across the DP refers to deliberate strategies, skills and attitudes that permeate the teaching and learning environment. These approaches and tools, intrinsically linked with the learner profile attributes, enhance student learning and assist student preparation for the DP assessment and beyond. The aims of approaches to teaching and learning in the DP are to:

- empower teachers as teachers of learners as well as teachers of content
- empower teachers to create clearer strategies for facilitating learning experiences in which students are more meaningfully engaged in structured inquiry and greater critical and creative thinking
- promote both the aims of individual subjects (making them more than course aspirations) and linking previously isolated knowledge (concurrency of learning)
- encourage students to develop an explicit variety of skills that will equip them to continue to be actively engaged in learning after they leave school, and to help them not only obtain university admission through better grades but also prepare for success during tertiary education and beyond
- enhance further the coherence and relevance of the students' DP experience
- allow schools to identify the distinctive nature of an IB DP education, with its blend of idealism and practicality.

The five ATL (developing thinking skills, social skills, communication skills, self-management skills and research skills) along with the six approaches to teaching (teaching that is inquiry-based, conceptually focused, contextualized, collaborative, differentiated and informed by assessment) encompass the key values and principles that underpin IB pedagogy.

# The IB mission statement and the IB learner profile

The DP aims to develop in students the knowledge, skills and attitudes they will need to fulfil the aims of the IB, as expressed in the organization's mission statement and the learner profile. Teaching and learning in the DP represent the reality in daily practice of the organization's educational philosophy.

# Academic integrity

Academic integrity in the DP is a set of values and behaviours informed by the attributes of the learner profile. In teaching, learning and assessment, academic integrity serves to promote personal integrity, engender respect for the integrity of others and their work, and ensure that all students have an equal opportunity to demonstrate the knowledge and skills they acquire during their studies.

All coursework—including work submitted for assessment—is to be authentic, based on the student's individual and original ideas with the ideas and work of others fully acknowledged. Assessment tasks that require teachers to provide guidance to students or that require students to work collaboratively must be completed in full compliance with the detailed guidelines provided by the IB for the relevant subjects.

For further information on academic integrity in the IB and the DP, please consult the IB publications *Academic integrity, Effective citing and referencing*, *Diploma Programme: From principles into practice* and the general regulations in *Diploma Programme Assessment procedures* (updated annually). Specific information regarding academic integrity as it pertains to external and internal assessment components of this DP subject can be found in this guide.

# Acknowledging the ideas or work of another person

Coordinators and teachers are reminded that candidates must acknowledge all sources used in work submitted for assessment. The following is intended as a clarification of this requirement.

DP candidates submit work for assessment in a variety of media that may include audiovisual material, text, graphs, images and/or data published in print or electronic sources. If a candidate uses the work or ideas of another person, the candidate must acknowledge the source using a standard style of referencing in a consistent manner. A candidate's failure to acknowledge a source will be investigated by the IB as a potential breach of regulations that may result in a penalty imposed by the IB final award committee.

The IB does not prescribe which style(s) of referencing or in-text citation should be used by candidates; this is left to the discretion of appropriate faculty/staff in the candidate's school. The wide range of subjects, response languages and the diversity of referencing styles make it impractical and restrictive to insist on particular styles. In practice, certain styles may prove most commonly used, but schools are free to choose a style that is appropriate for the subject concerned and the language in which candidates' work is written. Regardless of the reference style adopted by the school for a given subject, it is expected that the minimum information given includes: name of author, date of publication, title of source, and page numbers as applicable.

Candidates are expected to use a standard style and use it consistently so that credit is given to all sources used, including sources that have been paraphrased or summarized. When writing text candidates must clearly distinguish between their words and those of others by the use of quotation marks (or other method, such as indentation) followed by an appropriate citation that denotes an entry in the bibliography. If an electronic source is cited, the date of access must be indicated. Candidates are not expected to show faultless expertise in referencing, but are expected to demonstrate that all sources have been acknowledged. Candidates must be advised that audiovisual material, text, graphs, images and/or data published in print or in electronic sources that is not their own must also attribute the source. Again, an appropriate style of referencing/citation must be used.

## Learning diversity and learning support requirements

Schools must ensure that equal access arrangements and reasonable adjustments are provided to candidates with learning support requirements that are in line with the IB documents *Access and inclusion policy* and *Learning diversity and inclusion in IB programmes: Removing barriers to learning.*

The publications *Meeting student learning diversity in the classroom* and *The IB guide to inclusive education: a resource for whole school development* are available to support schools in the ongoing process of increasing access and engagement by removing barriers to learning.

## Programme standards and practices

The programme standards and practices are a set of principles for schools to ensure quality and fidelity in the implementation of IB programmes. Teaching and learning are important markers of quality and effective practice in schools; thus the expectations teachers and learners share across all IB programmes can be found in the programme standards and practices.

The programme standards and practices provide a framework to help teachers understand their rights and responsibilities in IB World Schools as they develop learning environments and experiences for their students. The IB recognizes that in order for effective teaching to take place, teachers must be supported in their understanding, well-being, environment and resources. Teachers use the core tenets of IB philosophy and pedagogy (approaches to teaching, ATL, the learner profile and international-mindedness) to design learning experiences that prepare learners to fulfil the aims and objectives outlined in this guide.

To learn more about teachers' rights and responsibilities, please see the IB publication *Programme standards and practices* on the Programme Resource Centre.

# Nature of science

## What is nature of science?

Nature of science (NOS) is an overarching theme in the biology, chemistry and physics courses that seeks to explore conceptual understandings related to the purpose, features and impact of scientific knowledge.

## What do we want to know in science?

Nobel laureate and influential popularizer of science, Richard Feynman, once described the process of science using the analogy of watching an unknown board game being played "... and you don't know the rules of the game, but you're allowed to look at the board from time to time. And from these observations, you try to figure out what the rules are of the game, [and] the rules of the pieces moving" (Feynman et al., 1963).

## What is the scientific endeavour?

Classifying such observations and underlying patterns in the natural world is the essence of what scientists do, underpinned by the assumption that the universe exists as an external reality accessible to the human experience. The varied and often non-linear processes used in scientific methodologies have several key features in common to maximize the validity and reliability of knowledge produced. The development of falsifiable hypotheses, a requirement for replicable data, and the utilization of peer-review may be among the most essential of these and help differentiate a scientific process from a pseudoscientific one. The communal and collaborative nature of this approach further strengthens the objectivity of science by ensuring the inclusion of diverse perspectives and shared responsibility for its outcomes.

## What type of knowledge do we produce?

Formal scientific knowledge may encompass several categories including representative models, explanatory theories and descriptive laws. As the focus of each discipline of natural science differs, so too does the balance of their contributions to each category. What remains constant, however, is the acknowledgement of assumptions, exceptions and limitations of scientific knowledge to provide realistic parameters to our understanding of the natural world. Claims of certainty are treated with caution given the presence of paradigmatic shifts throughout the history of science.

## What is the impact of scientific knowledge?

As well as the pursuit of knowledge for its own sake, it is useful to consider the interplay of science with other areas of society. Although advances in technology traditionally fuelled great leaps in scientific understanding, in recent times it may be more common to see science as a driver of technological development. In addition, the implications of science within environmental, political, social, cultural and economic domains can also be profound. These connections illustrate the importance of local, national and international scientific bodies that engage with the public understanding of science and heighten the responsibility of scientists to adhere to principles of academic integrity in their research.

*Table 1*

***Aspects of nature of science***

| Aspects | How are scientific knowledge claims generated, tested, communicated, evaluated and used? What issues arise from these actions? |
|---|---|
| **Observations** | Scientists act as observers, looking at Earth and all other parts of the universe, to obtain data about natural phenomena. Observations can be made directly using human senses, or with the aid of instruments such as electronic sensors. Unexpected or unplanned observations can open up new research fields. |
| **Patterns and trends** | Scientists analyse their observations, looking for patterns or trends, and try to draw general conclusions by inductive reasoning. They also look for discrepancies. Scientists classify objects through pattern recognition. A trend may take the form of a positive or negative correlation between variables. Correlations may be based on a causal relationship, but correlation does not prove causation. |
| **Hypotheses** | Scientists make provisional explanations for the patterns that they have observed in natural phenomena. These hypotheses can be tested, with further observations or experiments, to obtain support for a hypothesis or show that it is false. |
| **Experiments** | Scientists design and perform experiments to obtain data, which can be used to test hypotheses. The quality of experimental evidence depends on careful control of variables and on the quantity of data generated. Progress in science often follows technological developments that allow new experimental techniques. Creativity and imagination play a role in experimental design, interpretation and conclusion. |
| **Measurement** | Quantitative measurements are more objective than qualitative observations, but all measurements are limited in precision and accuracy. Measurements are repeated to strengthen the reliability of data. Random errors in measurement due to unknown or unpredictable differences lead to imprecision and uncertainty, whereas systematic errors lead to inaccuracy. |
| **Models** | Scientists construct models as artificial representations of natural phenomena. They are useful when direct observation or experimentation is difficult. Models are simplifications of complex systems and can be physical representations, abstract diagrams, mathematical equations or algorithms. All models have limitations that need to be considered in their application. |
| **Evidence** | Scientists adopt a sceptical attitude to claims and evaluate them using evidence. Some claims cannot be tested using verifiable evidence, so cannot be falsified. They are therefore not scientific. Scientific knowledge must be supported by evidence. |
| **Theories** | Scientists develop general explanations that are widely applicable, based on observed patterns or tested hypotheses. Predictions can be generated from these theories by deductive reasoning. If these predictions are tested, they may corroborate a theory or show that it is false and should be rejected. Paradigm shifts take place when a new theory replaces an old one. The term “law” is sometimes used for statements that allow predictions to be made about natural phenomena without explaining them. |
| **Falsification** | Scientists can use evidence to falsify a claim formulated as a hypothesis, theory or model, but they cannot prove with certainty that such a claim is true. There is therefore inherent uncertainty in all scientific knowledge. Nonetheless, many theories in science are corroborated by strong evidence and allow for prediction and explanation. Scientists must remain open-minded with respect to new evidence. |
| **Science as a shared endeavour** | Scientists communicate and collaborate throughout the world. Agreed conventions and common terminology facilitate unambiguous communication. Peer review is |

| Aspects | How are scientific knowledge claims generated, tested, communicated, evaluated and used? What issues arise from these actions? |
|---|---|
| | essential to verify the research methods of knowledge claims prior to their publication in journals. |
| **Global impact of science** | Scientists have an obligation to assess the risks associated with their work and must aim to do no harm. Developments in science may have ethical, environmental, political, social, cultural and economic consequences that must be considered during decision-making. The pursuit of science may have unintended consequences. Research proposals are often filtered through ethics boards. Scientists have a responsibility to communicate their findings to the public with honesty and clarity. |

# How is NOS different from TOK?

In contrast to the specificity of understanding of science, the TOK course encourages students to think critically about the concepts that underpin knowledge production. For example, peer review is used as a tool to support objectivity in scientific research. Through the study of TOK, students question the limitations of the peer review process and extend their thinking to an assessment of objectivity in other areas of knowledge.

# Nature of biology

The word "biology" was introduced by German naturalist Gottfried Reinhold in 1802. Since then, our understanding of living organisms has expanded considerably with the advent of techniques and technologies such as imaging and molecular sequencing methods. Of all the sciences, biology is a study that takes more of a pragmatic view than a theoretical approach.

The earliest evidence of life on Earth dates from at least 3.5 billion years ago. Through reproduction and natural selection, life has diversified tremendously, occupying a wide variety of niches. This diversity makes biology both a deeply fascinating and significantly challenging study.

The study of life makes progress through not only advances in techniques, but also pattern recognition, controlled experiments and collaboration between scientists. Unifying themes provide frameworks for interpretation and help us make sense of the living world: Form and function, Unity and diversity, Continuity and change, and Interaction and interdependence are four of the themes around which this biology syllabus is constructed, although other frameworks are possible.

The scale of life in biology ranges from the molecules and cells of organisms to ecosystems and the biosphere. This way of considering complex systems as simpler components—an approach known as reductionism—makes systems more manageable to study. It is the foundation of controlled experiments and has thus enabled major discoveries, but it provides an incomplete view of life. At each level of biological organization, different properties exist. Living systems are based on interactions, interdependence and integration of components between all levels of biological organization.

A student of biology should gain not only a conceptual understanding of the subject, but also an awareness of how biologists construct knowledge claims and the limitations of these methods.

## Distinction between SL and HL

Students at SL and HL share the following.

- An understanding of science through a stimulating experimental programme
- The nature of science as an overarching theme
- The study of a concept-based syllabus
- One piece of internally assessed work, the scientific investigation
- The collaborative sciences project

The SL course provides students with a fundamental understanding of biology and experience of the associated skills. The HL course requires students to increase their knowledge and understanding of the subject, and so provides a solid foundation for further study at university level.

The SL course has a recommended 150 teaching hours, compared to 240 hours for the HL course. This difference is reflected in the additional content studied by HL students. Some of the HL content is conceptually more demanding and explored in greater depth. The distinction between SL and HL is therefore one of both breadth and depth. The increased breadth and depth at HL result in increased networked knowledge, requiring the student to make more connections between diverse areas of the syllabus.

# Biology and the core

## Biology and theory of knowledge

The TOK course plays a special role in the DP by providing opportunities for students to reflect on the nature, scope and limitations of knowledge and the process of knowing through an exploration of knowledge questions.

The areas of knowledge (AOK) are specific branches of knowledge, each of which can be seen to have a distinct nature and sometimes use different methods of gaining knowledge. In TOK, students explore five compulsory AOK: history, the human sciences, the natural sciences, mathematics and the arts.

There are several different ways in which aspects of the biology course can be connected to the exploration of knowledge. During the teaching and learning of the biology course, teachers and students evaluate knowledge claims by exploring questions concerning their validity, reliability, credibility and certainty, as well as individual and cultural perspectives on them.

Exploration of the relationship between knowledge and TOK concepts can help students to deepen their understanding and make connections between disciplines. For example, while discussing the depletion of energy sources and the constant need for new energy resources to meet energy demands, students can explore the concepts of responsibility, power and justification.

Many aspects of the biology course lend themselves to the exploration of knowledge questions. Some examples are provided in the following table.

*Table 2*

***Examples of knowledge questions***

| Learning opportunities | Knowledge question |
|---|---|
| D3.2 Inheritance | What factors contribute to the refinement or replacement of knowledge in the natural sciences? |
| A2.1 Origin of cells | What is the role of imagination and intuition in the creation of hypotheses in the natural sciences? |
| D1.1 DNA replication | How do the tools that we use shape the knowledge that we produce? |
| A3.2 Classification and cladistics | To what extent do the classification systems we use in the pursuit of knowledge affect the conclusions that we reach? |
| D4.1 Natural selection | What is the role of paradigm shifts in the progression of scientific knowledge? |

For more information, please refer to the *Theory of knowledge guide* and the *Theory of knowledge teacher support material.*

## Biology and the extended essay

Students who choose to write an EE in biology undertake independent research as part of an in-depth study of a focused topic. The topic for study may be generated from the biology course or may relate to a subject area beyond the syllabus content. This detailed study will help develop research, thinking, self-management and communication skills, which will support students' learning in the biology course, and in further studies.

### Examples of areas for research topics

- Context: An assessment of the factors affecting species population, using databases or other secondary sources.
  - Example: The impact of predation by the red fox (*Vulpes vulpes*) on Canada geese (*Branta canadensis*) nesting populations in Alaska.

- Context: Experiments on factors affecting all aspects of plant growth, flowering and germination
  - Example: A comparison of the effect of salt (sodium chloride) concentration on germination in radishes (*Raphanus raphanistrum*) and beet (*Beta vulgaris*).
- Context: Factors affecting enzyme-based reactions in cells.
  - Example: The effect of processing temperature (60–120°C) of soybean (*Glycine max*) meal on urease activity in freshly powdered soybeans.
- Context: Using microorganism growth assays to monitor the presence of toxic chemicals in the environment.
  - Example: The viability of yeast stained with methylene blue in aqueous ethanol solutions (0–4.0%).

**World studies (context: environmental and/or economic sustainability)**

- Context: Trade in seed plants and food security based on agricultural practices.
  - Example: Sustainable food security in Nepal based on a range of millet species and the need to protect genetic diversity.

*Note: When students are referring to organisms in an examination, either the common name or the scientific name is acceptable.*

Students and supervisors must ensure that an EE does not duplicate other work submitted for the diploma.

For more information, please refer to the *Extended essay guide* and the *Extended essay teacher support material*.

## Biology and creativity, activity, service

The CAS component of the DP core provides many opportunities for students to link science concepts and topics to practical experiences. Teachers can highlight how knowledge and understanding developed through the course might inform meaningful experiences. Outside the classroom, CAS experiences might also ignite students' passion for addressing topics inside the biology classroom.

Some examples of relevant CAS experiences are as follows.

- Organizing a science club for students in lower years
- Implementing environmental initiatives within the school or local community, such as recycling, composting and roof gardens
- Organizing or participating in a social media outreach or advocacy campaign, for example, on an environmental or health concern

CAS experiences can be a single event or may be an extended series of events. It is important that CAS experiences be distinct from and not submitted as part of a biology assessment.

For more information, please refer to the *Creativity, activity, service guide* and the *Creativity, activity, serviceteacher support material*.

# Biology and international-mindedness

Science has been, and continues to be, a truly international endeavour. From the beginnings of seismology in China, through material science in Mesopotamia to astronomy in the Islamic Golden Age, the search for an objective understanding of the natural world transcends the limitations imposed by national boundaries. The scientific process, requiring curiosity, insight and an open-minded approach, benefits from the widest possible participation across genders and cultures through inclusivity and diversity.

Given the global nature of many scientific issues, international organizations often have a focus on the engagement of science with the public domain. The World Health Organization and the Intergovernmental Panel on Climate Change are two well-known examples that model a responsibility to inform nations of scientific progress on an equitable basis. Underlying this responsibility is the interest of promoting a peaceful and sustainable future.

Advancements in technology, along with the cost of modern research facilities, continues to reinforce the role of international collaborative work. This was clearly demonstrated through the global initiatives focused on addressing the COVID-19 pandemic. Specifically, the initiatives that were undertaken to develop the necessary knowledge and technology to create vaccines.

The importance of collaboration in contemporary science is reflected by the large number of international organizations tasked with collating and sharing data with the scientific community. Access to shared knowledge through websites and databases must be integrated into classroom teaching as it plays an important role in validating experimental work.

In addition to integrating technology and collaborative work, the collaborative sciences project provides an excellent opportunity for students to engage with global issues.

# Biology and the IB learner profile

Each box provides an example of how each learner profile attribute could be modelled by learners and teachers.

| Example attribute |
| --- |
| • Learners who best embody the attribute with reference to science.<br>• Directing teachers with possible routes to develop the attribute in the classroom.<br>• Practical ways in which learners demonstrate the attribute in the process of “doing” science. |

## Attributes of the IB learner profile

| Inquirer |
| --- |
| • Inquirers are curious, they actively use research skills, work independently and show enthusiasm about the world around them.<br>• Teachers facilitate skill development and promote inquiry; they provide students with opportunities to ask questions, search for answers, and experiment.<br>• Learners use their inquiry skills to extend their scientific knowledge and engage with research. |

| Knowledgeable |
| --- |
| • Learners explore concepts, ideas and issues related to science in order to broaden and deepen their understanding of factual and procedural knowledge.<br>• Access to a variety of resources and opportunities provides learner agency to develop scientific knowledge and understanding.<br>• Learners apply their knowledge to unfamiliar contexts and make connections between concepts and facts to illustrate their understanding of science. |

| Thinker |
| --- |
| • Learners are eager to solve complex problems and reflect on their thinking strategies.<br>• Teachers provide opportunities for learners to critically analyse their approaches and methods and deepen their understanding of science, allowing them to be creative in finding solutions to problems.<br>• Learners practise reasoning and critical thinking by testing assumptions, formulating hypotheses, interpreting data and drawing conclusions from the evidence provided. |

| Communicator |
| --- |
| • Learners collaborate effectively with others and use a variety of modes of communication to express their ideas and opinions. |

| Communicator |
| --- |
| • Teachers facilitate group work, encourage open discussions and the use of the scientific language to provide models for successful communication.<br>• Learners demonstrate effective communication skills as part of collaborative activities through listening to others and sharing ideas. |

| Principled |
| --- |
| • Learners take responsibility for their work, promote shared values and act in an ethical manner.<br>• Teachers can provide opportunities to model principled behaviour including acknowledging the work of others and citing sources. The collaborative sciences project provides opportunities for learners to take a principled stance.<br>• Learners appreciate the importance of integrity in data collection and consider all data, even that which does not match their original hypothesis. |

| Open-minded |
| --- |
| • Open-minded learners accept that different perspectives, models or hypotheses exist, and these can be used to enhance scientific understanding.<br>• Teachers can provide models that were at the time supported by data or observations, but through reasoning, deduction or falsification may be rejected or refined.<br>• Learners need to be prepared to have their perspectives and ideas challenged through the study of science. |

| Caring |
| --- |
| • Learners act to protect the environment and to improve the lives of others.<br>• Teachers can draw attention to how daily choices have consequences by challenging learners to adopt sustainable practice and providing support to help fellow learners. Reference should be made to the *Sciences experimentation guidelines*.<br>• Learners can connect curriculum content to global challenges such as healthcare, energy supply or food production. The collaborative sciences project provides an opportunity for learners to support each other to enable their group to achieve their goal successfully. |

| Risk-taker |
| --- |
| • Risk-takers seek new opportunities to develop their learning and explore new approaches to solve problems. They actively thrive on challenges.<br>• Teachers can provide support and guidance for learners, encouraging them to explore new techniques or methods of learning. This might include scaffolds for the use of language, the design of experiments and the analysis of data. As learners grow in confidence, these supports can be phased out giving them more freedom to choose their own approach.<br>• Learners should be prepared for the next set of experimental data to falsify their ideas as uncertainty is a feature of science. They understand that this is a step forward in their understanding. |

| Balanced |
| --- |
| • Balanced learners look holistically at all aspects of their development and ensure that various tasks are given appropriate attention without focusing on one to the detriment of others.<br>• Teachers should encourage learners to consider a balanced perspective on scientific issues without bias. |

| Balanced |
| --- |
| • Learners need to organize their own time effectively, giving themselves sufficient time to complete all parts of their learning without negatively impacting on the emotional and social aspects of their lives. |

| Reflective |
| --- |
| • Reflective learners consider why and how they achieve success, and also how they could change their approach when learning is difficult.<br>• Teachers provide opportunities for learners to continually review strategies, methods, techniques and approaches to problem-solving in order to improve their conceptual understandings in science. Assessment criteria or checklists can help learners to consider the quality of their work in a guided way.<br>• Learners develop skills and concepts throughout the course, networking their knowledge by continually reflecting on their understanding. |

# Approaches to the teaching and learning of biology

## The approaches to learning framework

### What are approaches to learning skills and why do we teach them?

The approaches to learning (ATL) framework seeks to develop in students affective, cognitive and metacognitive skills that will support their learning processes during and beyond their IB experience. The development of ATL skills is closely connected with the IB learner profile attributes and therefore helps to advance the IB mission. The ATL skills are an integral part of IB learning and teaching that should be developed across the whole programme—it is not expected that a single course should ever address all of them.

### How are they organized?

The ATL framework for IB programmes consists of five general skill categories: thinking skills, communication skills, social skills, research skills and self-management skills. Each of these categories covers a broad range, as shown by the examples presented in the table below. The ATL skill categories are closely linked and interrelated and therefore individual skills may be relevant to more than one category.

### How do we teach them?

ATL skills can be learned and taught, improved with practice and developed incrementally. The table below illustrates, through a number of examples, how the biology course can support ATL skill development. The examples shown in the table are not exhaustive. Teachers are encouraged to adapt them for use in their school context and collaboratively identify further examples of ATL skill development.

Further information on the ATL framework and strategies for the development of the ATL skills can be found in the *Biology teacher support material* and the *Diploma Programme Approaches to teaching and learning website*.

*Table 3*

***ATL skills and development***

| Skill category | Examples of ATL skill development in the classroom |
|---|---|
| **Thinking skills** | • Being curious about the natural world<br>• Asking questions and framing hypotheses based upon sensible scientific rationale<br>• Designing procedures and models<br>• Reflecting on the credibility of results<br>• Providing a reasoned argument to support conclusions<br>• Evaluating and defending ethical positions<br>• Combining different ideas in order to create new understandings<br>• Applying key ideas and facts in new contexts<br>• Engaging with, and designing, linking questions<br>• Experimenting with new strategies for learning<br>• Reflecting at all stages of the assessment and learning cycle |
| **Communication skills** | • Practising active listening skills |

| Skill category | Examples of ATL skill development in the classroom |
|---|---|
| | • Evaluating extended writing in terms of relevance and structure<br>• Applying interpretive techniques to different forms of media<br>• Reflecting on the needs of the audience when creating engaging presentations<br>• Clearly communicating complex ideas in response to open-ended questions<br>• Using digital media for communicating information<br>• Using terminology, symbols and communication conventions consistently and correctly<br>• Presenting data appropriately<br>• Delivering constructive criticism appropriately |
| **Social skills** | • Working collaboratively to achieve a common goal<br>• Assigning and accepting specific roles during group activities<br>• Appreciating the diverse talents and needs of others<br>• Resolving conflicts during collaborative work<br>• Actively seeking and considering the perspective of others<br>• Reflecting on the impact of personal behaviour or comments on others<br>• Constructively assessing the contribution of peers |
| **Research skills** | • Evaluating information sources for accuracy, bias, credibility and relevance<br>• Explicitly discussing the importance of academic integrity and full acknowledgement of the ideas of others<br>• Using a single, standard method of referencing and citation<br>• Comparing, contrasting and validating information<br>• Using search engines and libraries effectively |
| **Self-management skills** | • Breaking down major tasks into a sequence of stages<br>• Being punctual and meeting deadlines<br>• Taking risks and regarding setbacks as opportunities for growth<br>• Avoiding unnecessary distractions<br>• Drafting, revising and improving academic work<br>• Setting learning goals and adjusting them in response to experience<br>• Seeking and acting on feedback |

# Experimental programme

Integral to the student experience of a biology course is the learning that takes place through scientific inquiry within the classroom, laboratory or in the field. Experimentation through a variety of forms can be used to introduce a topic, address a phenomenon or allow students to consider and examine authentic questions and curiosities.

A school’s experimental programme should allow students to experience the full breadth and depth of the course, develop scientific skills and demonstrate safe, competent and methodical use of a range of tools, techniques and equipment. Students should therefore be encouraged to develop investigations to support their learning through open-ended inquiry with a focus on laboratory and fieldwork experiments, databases, simulations and modelling.

# Conceptual learning

Concept-based teaching and learning is encouraged across the continuum of IB programmes.

Concepts are mental representations of categories. They are constructed, modified and activated by the learner through learning experiences. Concepts do not exist in isolation but are interrelated. Conceptual understanding is always a work in progress—it is continually being developed and refined.

Conceptual understanding is therefore an outcome of a non-linear, ongoing process of evolving understandings, adapting previous understandings, and identifying and dispelling misconceptions. It consists of making connections between prior and new knowledge to construct and build an awareness of this network of knowledge.

Concepts vary in their level of abstraction and universality.

- They can be organizing ideas that are applicable in many contexts and have relevance both within and across subject areas.
- They can provide a deep understanding of specific knowledge fields (or fields of knowledge) and help to organize knowledge further, as well as reveal connections between different areas of the subject.

For example, consider the following sequence of three concepts.

Function > Excretion > Ultrafiltration

Understanding of the concept of ultrafiltration is part of the understanding of excretion, which in turn helps to develop an understanding of form and function in biology.

## Outcomes of a concept-based approach

Fostering critical thinking, the outcome of a concept-based approach is that students are able to:

- identify examples of a concept
- organize, reflect on, modify and expand their network of knowledge
- apply concepts to existing and future knowledge
- apply their conceptual understanding as a scientific thinking tool for predicting outcomes, justifying conclusions and evaluating knowledge claims.

## Structure of the syllabus and conceptual understanding

The biology syllabus comprises four themes, each made up of two concepts. Each theme is a lens through which the syllabus content can be viewed.

- **Theme A:** Unity and diversity
- **Theme B:** Form and function
- **Theme C:** Interaction and interdependence
- **Theme D:** Continuity and change

The arrangement of syllabus content follows four levels of biological organization, which also serve as conceptual lenses.

- **Level 1:** Molecules
- **Level 2:** Cells
- **Level 3:** Organisms
- **Level 4:** Ecosystems

The content is further arranged into topics, each with two guiding questions as signposts for inquiry. These questions help students view the content of the syllabus through the conceptual lenses of both the themes and the levels of biological organization.

Linking questions strengthen students' understanding by making connections. Linking questions encourage students to apply concepts from one topic to another. The ideal outcome of the linking questions is networked knowledge.

The linking questions in the guide are not exhaustive. Students and teachers may encounter other connections between understandings and concepts in the syllabus, leading them to create their own linking questions.

# Teaching biology in context

The study of biology enables constructive engagement with topical scientific issues. By contextualizing biological concepts, scientific knowledge claims can be evaluated more effectively, and informed choices on such issues as human health and the environment can be made. Biological research has brought innovation and benefit to many fields and continues to be at the heart of seeking effective solutions to many global challenges. It is therefore important to explore applications of biology in our world while teaching the course to elicit interest, understanding and curiosity.

Teaching the content of the course in relation to specific contexts supports the pedagogical principle of teaching in local and global contexts as part of the approaches to teaching framework and offers a number of advantages. First, it helps students relate their learning to genuine applications of biology, highlighting the relevance to global issues as well as the significance in students' own contexts. Second, it develops an appreciation for the interaction between scientific solutions and their implications, be it ethical, environmental or economic. Third, it helps to illustrate some of the NOS aspects underpinning the course.

The *Biology teacher support material* highlights possible areas that could be visited throughout the course and that may provide context for some topics to stimulate the application of ideas and problem-solving skills. Consideration of these and related areas may help provide ideas for the scientific investigation, the collaborative sciences project, TOK exhibition, CAS, or an EE in biology or world studies.

# Engaging with sensitive topics

Students and teachers are encouraged to engage with exciting, stimulating and personally relevant topics and issues that may be, at times, sensitive or personally challenging. Teachers should be aware of this and provide guidance on how to engage with such topics in a responsible manner. Consideration should be given to the personal, political and spiritual values of others.

# Prior learning

Past experience shows that students will be able to study biology at SL successfully with no background in, or previous knowledge of, science. Their approach to learning, characterized by the IB learner profile attributes, will be significant here.

However, for most students considering the study of biology at HL, while there is no intention to restrict access, some previous exposure to formal science education would be necessary. Specific topic details are not specified but students who have undertaken the IB Middle Years Programme (MYP) or studied an equivalent national science qualification or a school-based science course would be well prepared for an HL subject.

# Links to the Middle Years Programme

The MYP sciences courses seek to promote skills and attitudes needed to apply scientific knowledge in theoretical, experimental and authentic contexts. A strong foundation is established for DP sciences in which learners will capitalize on—and continue advancing—their skills and attitudes to develop knowledge and understanding commensurate with pre-university level science.

The MYP offers a framework for learning and teaching while maintaining flexibility with curriculum content. The content in MYP sciences courses can therefore vary greatly from one school to another. Content in DP sciences courses is more prescribed, and this is one of the main differences teachers will notice when comparing the two programmes.

A connected, conceptual curriculum where learning is inquiry-based and contextualized is the pedagogical principle that underpins both programmes and indeed the entire IB continuum (International Baccalaureate, 2019).

Conceptual learning focuses on organizing ideas and their interconnections. A conceptual approach is encouraged in IB programmes because it promotes deep learning and facilitates the construction of further knowledge. Conceptual understanding aids the application of knowledge in unfamiliar and novel contexts. This skill is reflected in the aims and assessment objectives of both programmes.

Broad concepts frame MYP learning and teaching with the purpose of unifying ideas across subject areas. Discipline-specific related concepts are intended to provide disciplinary depth (International Baccalaureate, 2014). Key and related concepts are not required in the DP, although some teachers may find that they wish to continue developing a curriculum around them. In DP sciences, overarching concepts are manifested in the course roadmaps and the NOS. DP sciences seek to highlight the interconnectedness of the course understandings. The intention is to promote conceptual understanding and further the construction of learners' knowledge networks.

Both MYP and DP teaching involve inquiry-based approaches, which foster a high degree of student engagement, collaboration and interaction. The inquiry, design, experimental, analysis, evaluation and communication skills encouraged by criteria B and C will serve students well as they prepare to undertake the scientific investigation for the internal assessment (IA). In addition, MYP students will gain familiarity with criterion-related assessment and the use of assessment criteria, which will further support their understanding of the DP sciences IA criteria.

IB programmes encourage the exploration of scientific principles in connection to local and global contexts. Doing so helps students ground abstract concepts in more concrete local and global real-world situations as well as cultivating international-mindedness (see the "Approaches to teaching" section in *Diploma Programme Approaches to teaching and learning website*). Teachers should therefore weave opportunities for contextualization into the curriculum. MYP sciences criterion D analyses the real-world application of science. In the DP, sciences teachers are encouraged to frequently anchor their teaching in real-world applications that are invoked throughout the course of the programme.

In addition to equipping students with scientific knowledge and skills, the MYP and DP sciences courses share similar guiding principles that seek to develop in students the learner profile attributes.

# Links to the Career-related Programme

In the Career-related Programme (CP), students study at least two DP subjects, a core consisting of four components, as well as a career-related study, which is determined by the local context and aligned with student needs. The CP has been designed to add value to students' career-related studies. This provides the context for the choice of DP courses. The biology course can assist CP students planning careers in a variety of professional fields where, for example, a sound understanding of science skills is important. These include environmental science, forensic science and healthcare. Biology helps students understand the underlying science in the contemporary world, and it encourages the development of strong problem-solving, critical thinking and ethical approaches that will assist students in the global workplace.

# Collaborative sciences project

The collaborative sciences project is an interdisciplinary sciences project, providing a worthwhile challenge to DP and CP students, addressing real-world problems that can be explored through the sciences. The nature of the challenge should allow students to integrate factual, procedural and conceptual knowledge developed through the study of their disciplines.

Through the identification and research of complex issues, students can develop an understanding of how interrelated systems, mechanisms and processes impact a problem. Students will then apply their collective understanding to develop solution-focused strategies that address the issue. With a critical lens they will evaluate and reflect on the inherent complexity of solving real-world problems.

Students will develop an understanding of the extent of global interconnectedness between regional, national, and local communities, which will empower them to become active and engaged citizens of the world. While addressing local and global issues, students will appreciate that the issues of today exist across national boundaries and can only be solved through collective action and international cooperation.

The collaborative sciences project supports the development of students' ATL skills, including teambuilding, negotiation and leadership. It facilitates an appreciation of the environment, and the social and ethical implications of science and technology.

Full details of the requirements are in the *Collaborative sciences project guide*.

# Aims

The course enables students, through the overarching theme of the NOS, to:

1. develop conceptual understanding that allows connections to be made between different areas of the subject, and to other DP sciences subjects
2. acquire and apply a body of knowledge, methods, tools and techniques that characterize science
3. develop the ability to analyse, evaluate and synthesize scientific information and claims
4. develop the ability to approach unfamiliar situations with creativity and resilience
5. design and model solutions to local and global problems in a scientific context
6. develop an appreciation of the possibilities and limitations of science
7. develop technology skills in a scientific context
8. develop the ability to communicate and collaborate effectively
9. develop awareness of the ethical, environmental, economic, cultural and social impact of science.

# Assessment objectives

The assessment objectives for biology reflect those parts of the aims that will be formally assessed either internally or externally. It is the intention of this course that students are able to fulfil the following assessment objectives.

1. Demonstrate knowledge of:
    a. terminology, facts and concepts
    b. skills, techniques and methodologies.
2. Understand and apply knowledge of:
    a. terminology and concepts
    b. skills, techniques and methodologies.
3. Analyse, evaluate, and synthesize:
    a. experimental procedures
    b. primary and secondary data
    c. trends, patterns and predictions.
4. Demonstrate the application of skills necessary to carry out insightful and ethical investigations.

# Assessment objectives in practice

Assessments align with the course's aims, objectives and conceptual approach; the NOS and subject-specific skills are also assessed. This allows students to demonstrate learning effectively through varied tasks that are reliably and accurately marked or moderated by subject-area educators and experts.

| Assessment objective | Which component addresses this assessment objective? | How is the assessment objective addressed? |
|---|---|---|
| **AO1** Demonstrate knowledge | Paper 1<br>Paper 2<br>Scientific investigation | Students respond to a range of multiple-choice, short-answer questions and extended-response questions.<br>Students investigate and answer a research question that is their own. |
| **AO2** Understand and apply knowledge | Paper 1<br>Paper 2<br>Scientific investigation | Students respond to a range of multiple-choice, short-answer, data-based and extended-response questions.<br>Students investigate and answer a research question that is their own. |
| **AO3** Analyse, evaluate, and synthesize | Paper 1<br>Paper 2<br>Scientific investigation | Students respond to a range of multiple-choice, short-answer, data-based and extended-response questions.<br>Students investigate and answer a research question that is their own. |
| **AO4** Demonstrate the application of skills necessary to carry out insightful and ethical investigations | Scientific investigation | Students investigate and answer a research question that is their own. |

| Component | Approximate weighting of assessment objectives (%) | |
|---|---|---|
| | AO1 + AO2 | AO3 |
| Paper 1 | 50 | 50 |
| Paper 2 | 50 | 50 |
| Internal assessment | Covers AO1, AO2, AO3 and AO4 | |

# Syllabus outline

| Syllabus component | Teaching hours | |
|---|---|---|
| | SL | HL |
| **Syllabus content** | **110** | **180** |
| A: Unity and diversity | 19 | 33 |
| B: Form and function | 26 | 39 |
| C: Interaction and interdependence | 31 | 48 |
| D: Continuity and change | 34 | 60 |
| **Experimental programme** | **40** | **60** |
| Practical work | 20 | 40 |
| Collaborative sciences project | 10 | 10 |
| Scientific investigation | 10 | 10 |
| **Total teaching hours** | **150** | **240** |

The recommended teaching time is 150 hours to complete SL courses and 240 hours to complete HL courses as stated in the general regulations (in *Diploma Programme Assessment procedures*).

# Syllabus roadmap

The aim of the syllabus is to integrate **concepts**, **topic content** and the **nature of science** through inquiry. Students and teachers are encouraged to personalize their approach to the syllabus to best fit their interests.

| Theme | Level of organization | | | |
|---|---|---|---|---|
| | 1. Molecules | 2. Cells | 3. Organisms | 4. Ecosystems |
| **A**<br>**Unity and diversity** | Common ancestry has given living organisms many shared features while evolution has resulted in the rich biodiversity of life on Earth. | | | |
| | **A1.1** Water<br>**A1.2** Nucleic acids | **A2.1** Origins of cells *[HL only]*<br>**A2.2** Cell structure<br>**A2.3** Viruses *[HL only]* | **A3.1** Diversity of organisms<br>**A3.2** Classification and cladistics *[HL only]* | **A4.1** Evolution and speciation<br>**A4.2** Conservation of biodiversity |
| **B**<br>**Form and function** | Adaptations are forms that correspond to function. These adaptations persist from generation to generation because they increase the chances of survival. | | | |
| | **B1.1** Carbohydrates and lipids<br>**B1.2** Proteins | **B2.1** Membranes and membrane transport<br>**B2.2** Organelles and compartmentaliza-tion<br>**B2.3** Cell specialization | **B3.1** Gas exchange<br>**B3.2** Transport<br>**B3.3** Muscle and motility *[HL only]* | **B4.1** Adaptation to environment<br>**B4.2** Ecological niches |
| **C**<br>**Interaction and interdependence** | Systems are based on interactions, interdependence and integration of components. Systems result in emergence of new properties at each level of biological organization. | | | |
| | **C1.1** Enzymes and metabolism<br>**C1.2** Cell respiration<br>**C1.3** Photosynthesis | **C2.1** Chemical signalling *[HL only]*<br>**C2.2** Neural signalling | **C3.1** Integration of body systems<br>**C3.2** Defence against disease | **C4.1** Populations and communities<br>**C4.2** Transfers of energy and matter |
| **D**<br>**Continuity and change** | Living things have mechanisms for maintaining equilibrium and for bringing about transformation. Environmental change is a driver of evolution by natural selection. | | | |
| | **D1.1** DNA replication<br>**D1.2** Protein synthesis<br>**D1.3** Mutations and gene editing | **D2.1** Cell and nuclear division<br>**D2.2** Gene expression *[HL only]*<br>**D2.3** Water potential | **D3.1** Reproduction<br>**D3.2** Inheritance<br>**D3.3** Homeostasis | **D4.1** Natural selection<br>**D4.2** Stability and change<br>**D4.3** Climate change |

**Download:** Biology syllabus roadmap (PDF)

# Syllabus format

## A1.1 Topic name

The name of the topic is preceded by the letter for the theme (A–D) and the number for the level of biological organization (1–4) as listed in the syllabus roadmap.

**Relevant theme and level of organization**

The theme and level of organization show the conceptual lenses through which the topic can be viewed.

**Recommended teaching time**

The approximate number of recommended hours for teaching the topic are given together for **standard level and higher level**.

**Additional hours for higher level** are listed separately after the core teaching hours.

The recommended teaching time includes related experimental work, relevant material from "Skills in the study of biology", and assessment of learning. However, it excludes the time allocated for the experimental programme.

### Guiding questions

- These are overarching questions that frame the topic and guide inquiry.
- They help to link the material to the theme or to the level of biological organization.

### Course content

Content listed under the **SL and HL** heading should be taught to both standard and higher level students.

Sections marked as **additional higher level** should be taught only to HL students.

Each topic is divided into numbered **understandings** which are in turn divided into a content statement and guidance. Some understandings will also include reference to the application of skills and NOS.

| |
|---|
| A1.1.1—The **content statement** indicates the content to be taught. |
| **Guidance** provides clarifications to the scope and requirements of the content statement and applications of skills within the content statement.<br>**Application of skills** includes directed activities that connect the "understanding" with a skill.<br>The application directs an action such as drawing from observation or a micrograph, interpreting data, utilizing statistics, or designing or carrying out an experiment.<br>The following are not examples of the application of skills: drawing a diagram unaided to illustrate comprehension of a content statement, and learning examples to support the content statement.<br>**Nature of science (NOS)** relates the content statement to the overarching theme of NOS. |

### Linking questions

- Two linking questions are provided at the end of each topic. The questions encourage students to recognize that the topics can be viewed through lenses other than a single theme or level of biological organization. They connect concepts from one topic to another. The intended outcome is networked knowledge.
- Teachers and students are encouraged to create their own linking questions.

# Skills in the study of biology

The skills and techniques students must experience through the course are encompassed within the tools. These support the application and development of the inquiry process in the delivery of the biology course.

Tools

- **Tool 1:** Experimental techniques
- **Tool 2:** Technology
- **Tool 3:** Mathematics

Inquiry process

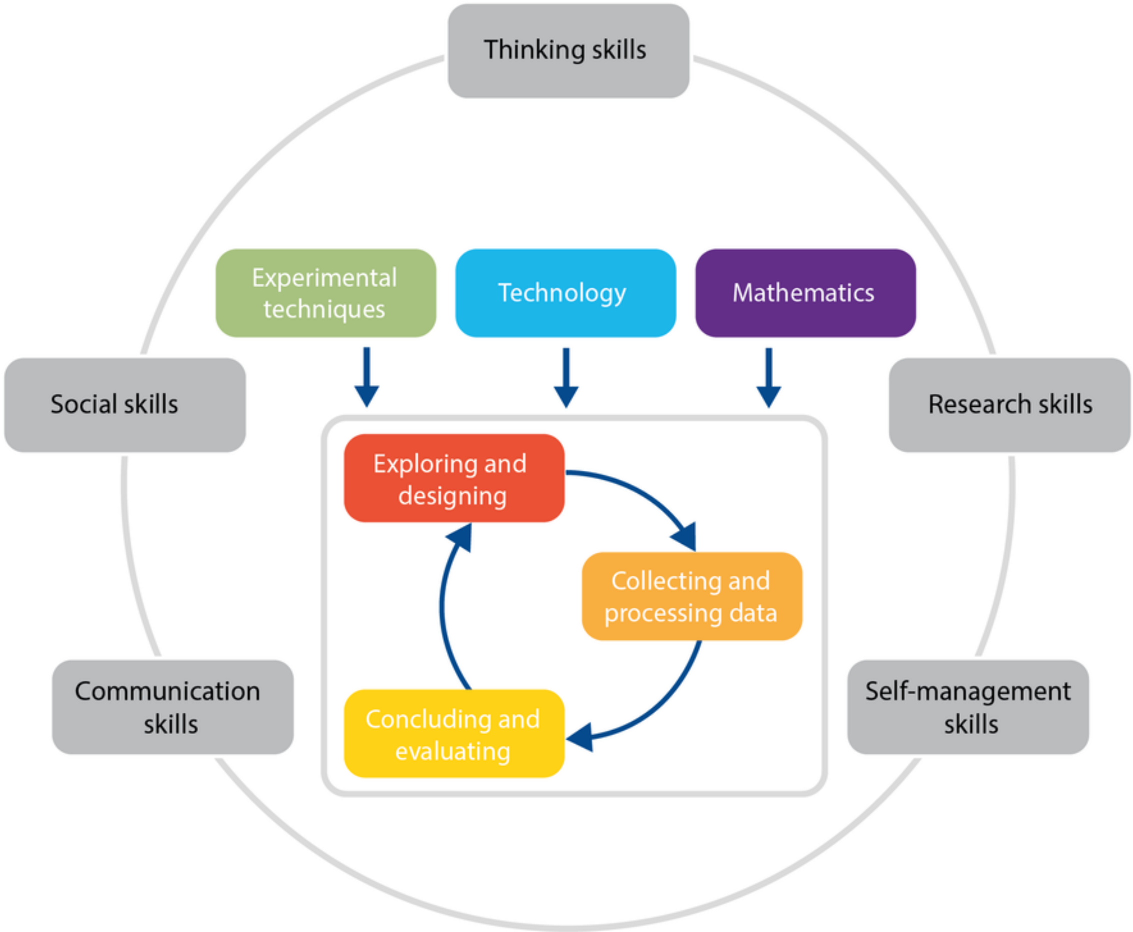
- **Inquiry 1:** Exploring and designing
- **Inquiry 2:** Collecting and processing data
- **Inquiry 3:** Concluding and evaluating

Teachers are encouraged to provide opportunities for students to encounter and practise the skills throughout the programme. Rather than being taught as stand-alone topics, they should be integrated into the teaching of the syllabus when they are relevant to the syllabus topics being covered. The skills in the study of biology can be assessed through internal and external assessment.

The approaches to learning provide the framework for the development of these skills.

*Figure 2*

*Skills for biology*




# Tools

## Tool 1: Experimental techniques

| Skill | Description |
|---|---|
| Addressing safety of self, others and the environment | Recognize and address relevant safety, ethical or environmental issues in an investigation. |
| Measuring variables | Understand how to accurately measure the following to an appropriate level of precision.<br>• Mass<br>• Volume<br>• Time<br>• Temperature<br>• Length<br>Make careful observations, including the following.<br>• Counts<br>• Drawing annotated diagrams from observation |

| Skill | Description |
|---|---|
| | • Making appropriate qualitative observations<br>• Classifying |
| Applying techniques | Show awareness of the purpose and practice of:<br>• paper or thin layer chromatography<br>• colorimetry or spectrophotometry<br>• serial dilutions<br>• physical and digital molecular modelling<br>• a light microscope and eye piece graticule<br>• preparation of temporary mounts<br>• identifying and classifying organisms<br>• using a variety of sampling techniques/using random and systematic sampling<br>• karyotyping and karyograms<br>• cladogram analysis. |

## Tool 2: Technology

| Skill | Description |
|---|---|
| Applying technology to collect data | • Use sensors.<br>• Identify and extract data from databases.<br>• Generate data from models and simulations. |
| Applying technology to process data | • Use spreadsheets to manipulate data.<br>• Represent data in a graphical form.<br>• Use computer modelling.<br>• Carry out image analysis. |

## Tool 3: Mathematics

| Skill | Description |
|---|---|
| Applying general mathematics | • Use basic arithmetic and algebraic calculations to solve problems.<br>• Carry out calculations involving: decimals, fractions, percentages, ratios, proportions, frequencies (including allele frequencies), densities, approximations and reciprocals.<br>• Calculate measures of central tendency: mean, median and mode.<br>• Apply measures of dispersion: range, standard deviation (SD), standard error (SE), interquartile range (IQR).<br>• Use and interpret scientific notation (for example, $3.5 \times 10^6$).<br>• Use approximation and estimation.<br>• Calculate scales of magnification.<br>• Calculate rates of change from graphical or tabulated data.<br>• Understand direct and inverse proportionality between variables, as well as positive and negative correlations between variables.<br>• Calculate and interpret percentage change and percentage difference. |

| Skill | Description |
|---|---|
| | • Distinguish between continuous and discrete variables.<br>• Calculating the actual size from a micrograph that has a scale bar.<br>• Apply the Simpson reciprocal index.<br>• Apply the Lincoln index.<br>• Apply the chi-squared test.<br>• Apply the *t*-test. |
| Using units, symbols and numerical values | • Apply and use International System of Units (SI) prefixes and units or non-SI metric units.<br>• Express quantities and uncertainties to an appropriate number of decimal places. |
| Processing uncertainties | • Understand the significance of uncertainties in raw and processed data.<br>• Record uncertainties in measurements as a range (±) to an appropriate level of precision.<br>• Express ranges, degrees of precision, standard error or standard deviations as error bars.<br>• Express measurement and processed uncertainties to an appropriate number of decimal places or level of precision.<br>• Apply the coefficient of determination ($R^2$) to evaluate the fit of a trend line.<br>• Interpret values of the correlation coefficient ($r$) and identify correlations as positive or negative.<br>• Apply and interpret appropriate tests of statistical significance (for example, chi-squared test). |
| Graphing | • Sketch graphs, with labelled but unscaled axes, to qualitatively describe trends.<br>• Construct and interpret tables, charts and graphs for raw and processed data including bar charts, histograms, scatter graphs, line and curve graphs, logarithmic graphs, pie charts, and box-and-whisker plot.<br>• Plot linear and non-linear graphs showing the relationship between two variables with appropriate scales and axes.<br>• Draw lines or curves of best fit.<br>• Interpret features of graphs including gradient, changes in gradient, intercepts, maxima and minima.<br>• Draw and interpret uncertainty/error bars.<br>• Extrapolate and interpolate graphs.<br>• Design dichotomous keys.<br>• Represent energy flow in the form of food chains, food webs and pyramids of energy.<br>• Represent familial genetic relationships using pedigree charts. |

# Inquiry process

## Inquiry 1: Exploring and designing

| Skill | Description |
|---|---|
| Exploring | • Demonstrate independent thinking, initiative, and insight.<br>• Consult a variety of sources.<br>• Select sufficient and relevant sources of information.<br>• Formulate research questions and hypotheses.<br>• State and explain predictions using scientific understanding. |
| Designing | • Demonstrate creativity in the designing, implementation and presentation of the investigation.<br>• Develop investigations that involve hands-on laboratory experiments, databases, simulations, modelling and surveys.<br>• Identify and justify the choice of dependent, independent and control variables.<br>• Justify the range and quantity of measurements.<br>• Design and explain a valid methodology.<br>• Pilot methodologies. |
| Controlling variables | Appreciate when and how to:<br>• calibrate measuring apparatus<br>• maintain constant environmental conditions of systems<br>• choose representative random samples and minimize sampling errors.<br>• set up a control run where appropriate. |

## Inquiry 2: Collecting and processing data

| Skill | Description |
|---|---|
| Collecting data | • Identify and record relevant qualitative observations.<br>• Collect and record sufficient relevant quantitative data.<br>• Identify and address issues that arise during data collection. |
| Processing data | • Carry out relevant and accurate data processing. |
| Interpreting results | • Interpret qualitative and quantitative data.<br>• Interpret diagrams, graphs and charts.<br>• Identify, describe and explain patterns, trends and relationships.<br>• Identify and justify the removal or inclusion of outliers in data (no mathematical processing is required).<br>• Assess accuracy, precision, reliability and validity. |

## Inquiry 3: Concluding and evaluating

| Skill | Description |
|---|---|
| Concluding | • Interpret processed data and analysis to draw and justify conclusions. |

| Skill | Description |
|---|---|
| | • Compare the outcomes of an investigation to the accepted scientific context.<br>• Relate the outcomes of an investigation to the stated research question or hypothesis.<br>• Discuss the impact of uncertainties on the conclusions. |
| Evaluating | • Evaluate hypotheses.<br>• Identify and discuss sources and impacts of random and systematic errors.<br>• Evaluate the implications of methodological weaknesses, limitations and assumptions on conclusions.<br>• Explain realistic and relevant improvements to an investigation. |

# Syllabus content

## A1.1 Water

Unity and diversity—Molecules

**Standard level and higher level: 2 hours**

**Additional higher level: 1 hour**

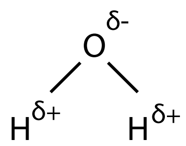
### Guiding questions

- What physical and chemical properties of water make it essential for life?
- What are the challenges and opportunities of water as a habitat?

### SL and HL

| A1.1.1—Water as the medium for life |
| --- |
| Students should appreciate that the first cells originated in water and that water remains the medium in which most processes of life occur. |

| A1.1.2—Hydrogen bonds as a consequence of the polar covalent bonds within water molecules |
| --- |
| Students should understand that polarity of covalent bonding within water molecules is due to unequal sharing of electrons and that hydrogen bonding due to this polarity occurs between water molecules. Students should be able to represent two or more water molecules and hydrogen bonds between them with the notation shown below to indicate polarity. |




| A1.1.3—Cohesion of water molecules due to hydrogen bonding and consequences for organisms |
| --- |
| Include transport of water under tension in xylem and the use of water surfaces as habitats due to the effect known as surface tension. |

| A1.1.4—Adhesion of water to materials that are polar or charged and impacts for organisms |
| --- |
| Include capillary action in soil and in plant cell walls. |

| A1.1.5—Solvent properties of water linked to its role as a medium for metabolism and for transport in plants and animals |
| --- |
| Emphasize that a wide variety of hydrophilic molecules dissolve in water and that most enzymes catalyse reactions in aqueous solution. Students should also understand that the functions of some molecules in cells depend on them being hydrophobic and insoluble. |

| A1.1.6—Physical properties of water and the consequences for animals in aquatic habitats |
|---|
| Include buoyancy, viscosity, thermal conductivity and specific heat capacity. Contrast the physical properties of water with those of air and illustrate the consequences using examples of animals that live in water and in air or on land, such as the black-throated loon (*Gavia arctica*) and the ringed seal (*Pusa hispida*).<br>*Note: When students are referring to an organism in an examination, either the common name or the scientific name is acceptable.* |

## Additional higher level

| A1.1.7—Extraplanetary origin of water on Earth and reasons for its retention |
|---|
| The abundance of water over billions of years of Earth's history has allowed life to evolve. Limit hypotheses for the origin of water on Earth to asteroids and reasons for retention to gravity and temperatures low enough to condense water. |

| A1.1.8—Relationship between the search for extraterrestrial life and the presence of water |
|---|
| Include the idea of the "Goldilocks zone". |

## Linking questions

- How do the various intermolecular forces of attraction affect biological systems?
- What biological processes only happen at or near surfaces?

# A1.2 Nucleic acids

Unity and diversity—Molecules

**Standard level and higher level: 3 hours**

**Additional higher level: 2 hours**

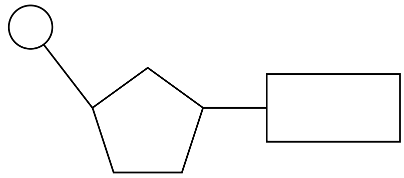
## Guiding questions

- How does the structure of nucleic acids allow hereditary information to be stored?
- How does the structure of DNA facilitate accurate replication?

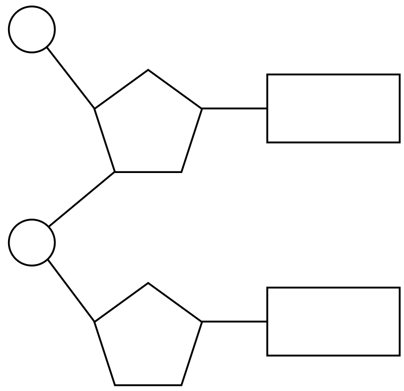
## SL and HL

| A1.2.1—DNA as the genetic material of all living organisms |
|---|
| Some viruses use RNA as their genetic material but viruses are not considered to be living. |

| A1.2.2—Components of a nucleotide |
|---|
| In diagrams of nucleotides use circles, pentagons and rectangles to represent relative positions of phosphates, pentose sugars and bases. |



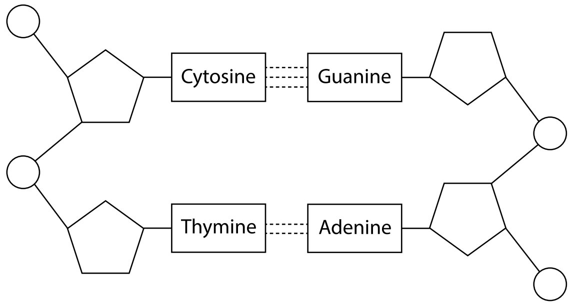
| A1.2.3—Sugar–phosphate bonding and the sugar–phosphate “backbone” of DNA and RNA |
|---|
| Sugar–phosphate bonding makes a continuous chain of covalently bonded atoms in each strand of DNA or RNA nucleotides, which forms a strong “backbone” in the molecule. |



| A1.2.4—Bases in each nucleic acid that form the basis of a code |
|---|
| Students should know the names of the nitrogenous bases. |

| A1.2.5—RNA as a polymer formed by condensation of nucleotide monomers |
|---|
| Students should be able to draw and recognize diagrams of the structure of single nucleotides and RNA polymers. |

| A1.2.6—DNA as a double helix made of two antiparallel strands of nucleotides with two strands linked by hydrogen bonding between complementary base pairs |
|---|
| In diagrams of DNA structure, students should draw the two strands antiparallel, but are not required to draw the helical shape. Students should show adenine (A) paired with thymine (T), and guanine (G) paired with cytosine (C). Students are not required to memorize the relative lengths of the purine and pyrimidine bases, or the numbers of hydrogen bonds. |




| A1.2.7—Differences between DNA and RNA |
|---|
| Include the number of strands present, the types of nitrogenous bases and the type of pentose sugar. Students should be able to sketch the difference between ribose and deoxyribose. Students should be familiar with examples of nucleic acids. |

| A1.2.8—Role of complementary base pairing in allowing genetic information to be replicated and expressed |
|---|
| Students should understand that complementarity is based on hydrogen bonding. |

| A1.2.9—Diversity of possible DNA base sequences and the limitless capacity of DNA for storing information |
|---|
| Explain that diversity by any length of DNA molecule and any base sequence is possible. Emphasize the enormous capacity of DNA for storing data with great economy. |

| A1.2.10—Conservation of the genetic code across all life forms as evidence of universal common ancestry |
|---|
| Students are not required to memorize any specific examples. |

## Additional higher level

| A1.2.11—Directionality of RNA and DNA |
|---|
| Include 5' to 3' linkages in the sugar–phosphate backbone and their significance for replication, transcription and translation. |

| A1.2.12—Purine-to-pyrimidine bonding as a component of DNA helix stability |
|---|
| Adenine–thymine (A–T) and cytosine–guanine (C–G) pairs have equal length, so the DNA helix has the same three-dimensional structure, regardless of the base sequence. |

| A1.2.13—Structure of a nucleosome |
|---|
| Limit to a DNA molecule wrapped around a core of eight histone proteins held together by an additional histone protein attached to linker DNA. <br> **Application of skills:** Students are required to use molecular visualization software to study the association between the proteins and DNA within a nucleosome. |

| A1.2.14—Evidence from the Hershey–Chase experiment for DNA as the genetic material |
|---|

| |
|---|
| Students should understand how the results of the experiment support the conclusion that DNA is the genetic material.<br>**NOS:** Students should appreciate that technological developments can open up new possibilities for experiments. When radioisotopes were made available to scientists as research tools, the Hershey–Chase experiment became possible. |

| A1.2.15—Chargaff's data on the relative amounts of pyrimidine and purine bases across diverse life forms |
|---|
| **NOS:** Students should understand how the "problem of induction" is addressed by the "certainty of falsification". In this case, Chargaff's data falsified the tetranucleotide hypothesis that there was a repeating sequence of the four bases in DNA. |

## Linking questions

- What makes RNA more likely to have been the first genetic material, rather than DNA?
- How can polymerization result in emergent properties?

# A2.1 Origins of cells

Unity and diversity—Cells

**Additional higher level: 2 hours**

## Guiding questions

- What plausible hypothesis could account for the origin of life?
- What intermediate stages could there have been between non-living matter and the first living cells?

## Additional higher level

*Note: There is no SL content in A2.1.*

| A2.1.1—Conditions on early Earth and the pre-biotic formation of carbon compounds |
|---|
| Include the lack of free oxygen and therefore ozone, higher concentrations of carbon dioxide and methane, resulting in higher temperatures and ultraviolet light penetration. The conditions may have caused a variety of carbon compounds to form spontaneously by chemical processes that do not now occur. |

| A2.1.2—Cells as the smallest units of self-sustaining life |
|---|
| Discuss the differences between something that is living and something that is non-living. Include reasons that viruses are considered to be non-living. |

| A2.1.3—Challenge of explaining the spontaneous origin of cells |
|---|
| Cells are highly complex structures that can currently only be produced by division of pre-existing cells. Students should be aware that catalysis, self-replication of molecules, self-assembly and the emergence of compartmentalization were necessary requirements for the evolution of the first cells.<br>**NOS:** Students should appreciate that claims in science, including hypotheses and theories, must be testable. In some cases, scientists have to struggle with hypotheses that are difficult to test. In this case the exact conditions on pre-biotic Earth cannot be replicated and the first protocells did not fossilize. |

| A2.1.4—Evidence for the origin of carbon compounds |
|---|
| Evaluate the Miller–Urey experiment. |

| A2.1.5—Spontaneous formation of vesicles by coalescence of fatty acids into spherical bilayers |
| --- |
| Formation of a membrane-bound compartment is needed to allow internal chemistry to become different from that outside the compartment. |

| A2.1.6—RNA as a presumed first genetic material |
| --- |
| RNA can be replicated and has some catalytic activity so it may have acted initially as both the genetic material and the enzymes of the earliest cells. Ribozymes in the ribosome are still used to catalyse peptide bond formation during protein synthesis. |

| A2.1.7—Evidence for a last universal common ancestor |
| --- |
| Include the universal genetic code and shared genes across all organisms. Include the likelihood of other forms of life having evolved but becoming extinct due to competition from the last universal common ancestor (LUCA) and descendants of LUCA. |

| A2.1.8—Approaches used to estimate dates of the first living cells and the last universal common ancestor |
| --- |
| Students should develop an appreciation of the immense length of time over which life has been evolving on Earth. |

| A2.1.9—Evidence for the evolution of the last universal common ancestor in the vicinity of hydrothermal vents |
| --- |
| Include fossilized evidence of life from ancient seafloor hydrothermal vent precipitates and evidence of conserved sequences from genomic analysis. |

## Linking questions

- For what reasons is heredity an essential feature of living things?
- What is needed for structures to be able to evolve by natural selection?

# A2.2 Cell structure

Unity and diversity—Cells

**Standard level and higher level: 4 hours**

**Additional higher level: 1 hour**

## Guiding questions

- What are the features common to all cells and the features that differ?
- How is microscopy used to investigate cell structure?

## SL and HL

| A2.2.1—Cells as the basic structural unit of all living organisms |
| --- |
| **NOS:** Students should be aware that deductive reason can be used to generate predictions from theories. Based on cell theory, a newly discovered organism can be predicted to consist of one or more cells. |

| A2.2.2—Microscopy skills |
| --- |
| **Application of skills:** Students should have experience of making temporary mounts of cells and tissues, staining, measuring sizes using an eyepiece graticule, focusing with coarse and fine adjustments, calculating actual size and magnification, producing a scale bar and taking photographs. |

**NOS:** Students should appreciate that measurement using instruments is a form of quantitative observation.

| A2.2.3—Developments in microscopy |
| --- |
| Include the advantages of electron microscopy, freeze fracture, cryogenic electron microscopy, and the use of fluorescent stains and immunofluorescence in light microscopy. |

| A2.2.4—Structures common to cells in all living organisms |
| --- |
| Typical cells have DNA as genetic material and a cytoplasm composed mainly of water, which is enclosed by a plasma membrane composed of lipids. Students should understand the reasons for these structures. |

| A2.2.5—Prokaryote cell structure |
| --- |
| Include these cell components: cell wall, plasma membrane, cytoplasm, naked DNA in a loop and 70S ribosomes. The type of prokaryotic cell structure required is that of Gram-positive eubacteria such as *Bacillus* and *Staphylococcus*. Students should appreciate that prokaryote cell structure varies. However, students are not required to know details of the variations such as the lack of cell walls in phytoplasmas and mycoplasmas. |

| A2.2.6—Eukaryote cell structure |
| --- |
| Students should be familiar with features common to eukaryote cells: a plasma membrane enclosing a compartmentalized cytoplasm with 80S ribosomes; a nucleus with chromosomes made of DNA bound to histones, contained in a double membrane with pores; membrane-bound cytoplasmic organelles including mitochondria, endoplasmic reticulum, Golgi apparatus and a variety of vesicles or vacuoles including lysosomes; and a cytoskeleton of microtubules and microfilaments. |

| A2.2.7—Processes of life in unicellular organisms |
| --- |
| Include these functions: homeostasis, metabolism, nutrition, movement, excretion, growth, response to stimuli and reproduction. |

| A2.2.8—Differences in eukaryotic cell structure between animals, fungi and plants |
| --- |
| Include presence and composition of cell walls, differences in size and function of vacuoles, presence of chloroplasts and other plastids, and presence of centrioles, cilia and flagella. |

| A2.2.9—Atypical cell structure in eukaryotes |
| --- |
| Use numbers of nuclei to illustrate one type of atypical cell structure in aseptate fungal hyphae, skeletal muscle, red blood cells and phloem sieve tube elements. |

| A2.2.10—Cell types and cell structures viewed in light and electron micrographs |
| --- |
| **Application of skills:** Students should be able to identify cells in light and electron micrographs as prokaryote, plant or animal. In electron micrographs, students should be able to identify these structures: nucleoid region, prokaryotic cell wall, nucleus, mitochondrion, chloroplast, sap vacuole, Golgi apparatus, rough and smooth endoplasmic reticulum, chromosomes, ribosomes, cell wall, plasma membrane and microvilli. |

| A2.2.11—Drawing and annotation based on electron micrographs |
| --- |
| **Application of skills:** Students should be able to draw and annotate diagrams of organelles (nucleus, mitochondria, chloroplasts, sap vacuole, Golgi apparatus, rough and smooth endoplasmic reticulum and |

| |
|---|
| chromosomes) as well as other cell structures (cell wall, plasma membrane, secretory vesicles and microvilli) shown in electron micrographs. Students are required to include the functions in their annotations. |

## Additional higher level

| A2.2.12—Origin of eukaryotic cells by endosymbiosis |
|---|
| Evidence suggests that all eukaryotes evolved from a common unicellular ancestor that had a nucleus and reproduced sexually. Mitochondria then evolved by endosymbiosis. In some eukaryotes, chloroplasts subsequently also had an endosymbiotic origin. Evidence should include the presence in mitochondria and chloroplasts of 70S ribosomes, naked circular DNA and the ability to replicate.<br>**NOS:** Students should recognize that the strength of a theory comes from the observations the theory explains and the predictions it supports. A wide range of observations are accounted for by the theory of endosymbiosis. |

| A2.2.13—Cell differentiation as the process for developing specialized tissues in multicellular organisms |
|---|
| Students should be aware that the basis for differentiation is different patterns of gene expression often triggered by changes in the environment. |

| A2.2.14—Evolution of multicellularity |
|---|
| Students should be aware that multicellularity has evolved repeatedly. Many fungi and eukaryotic algae and all plants and animals are multicellular. Multicellularity has the advantages of allowing larger body size and cell specialization. |

## Linking questions

- What explains the use of certain molecular building blocks in all living cells?
- What are the features of a compelling theory?

# A2.3 Viruses

Unity and diversity—Cells

**Additional higher level: 2 hours**

## Guiding questions

- How can viruses exist with so few genes?
- In what ways do viruses vary?

## Additional higher level

*Note: There is no SL content in A2.3.*

| A2.3.1—Structural features common to viruses |
|---|
| Relatively few features are shared by all viruses: small, fixed size; nucleic acid (DNA or RNA) as genetic material; a capsid made of protein; no cytoplasm; and few or no enzymes. |

| A2.3.2—Diversity of structure in viruses |
|---|
| Students should understand that viruses are highly diverse in their shape and structure. Genetic material may be RNA or DNA, which can be either single- or double-stranded. Some viruses are enveloped in host |

| |
|---|
| cell membrane and others are not enveloped. Virus examples include bacteriophage lambda, coronaviruses and HIV. |

| A2.3.3—Lytic cycle of a virus |
|---|
| Students should appreciate that viruses rely on a host cell for energy supply, nutrition, protein synthesis and other life functions. Use bacteriophage lambda as an example of the phases in a lytic cycle. |

| A.2.3.4—Lysogenic cycle of a virus |
|---|
| Use bacteriophage lambda as an example. |

| A2.3.5—Evidence for several origins of viruses from other organisms |
|---|
| The diversity of viruses suggests several possible origins. Viruses share an extreme form of obligate parasitism as a mode of existence, so the structural features that they have in common could be regarded as convergent evolution. The genetic code is shared between viruses and living organisms. |

| A2.3.6—Rapid evolution in viruses |
|---|
| Include reasons for very rapid rates of evolution in some viruses. Use two examples of rapid evolution: evolution of influenza viruses and of HIV. Consider the consequences for treating diseases caused by rapidly evolving viruses. |

## Linking questions

- What mechanisms contribute to convergent evolution?
- To what extent is the natural history of life characterized by increasing complexity or simplicity?

# A3.1 Diversity of organisms

Unity and diversity—Organisms

**Standard level and higher level: 3 hours**

**Additional higher level: 2 hours**

## Guiding questions

- What is a species?
- What patterns are seen in the diversity of genomes within and between species?

## SL and HL

| A3.1.1—Variation between organisms as a defining feature of life |
|---|
| Students should understand that no two individuals are identical in all their traits. The patterns of variation are complex and are the basis for naming and classifying organisms. |

| A3.1.2—Species as groups of organisms with shared traits |
|---|
| This is the original morphological concept of the species as used by Linnaeus. |

| A3.1.3—Binomial system for naming organisms |
|---|

| |
|---|
| Students should know that the first part of the name identifies the genus, with the second part of the name distinguishing the species. Species in the same genus have similar traits. The genus name is given an initial capital letter but the species name is lowercase. |

| A3.1.4—Biological species concept |
|---|
| According to the biological species concept, a species is a group of organisms that can breed and produce fertile offspring. Include possible challenges associated with this definition of a species and that competing species definitions exist. |

| A3.1.5—Difficulties distinguishing between populations and species due to divergence of non-interbreeding populations during speciation |
|---|
| Students should understand that speciation is the splitting of one species into two or more. It usually happens gradually rather than by a single act, with populations becoming more and more different in their traits. It can therefore be an arbitrary decision whether two populations are regarded as the same or different species. |

| A3.1.6—Diversity in chromosome numbers of plant and animal species |
|---|
| Students should know in general that diversity exists. As an example, students should know that humans have 46 chromosomes and chimpanzees have 48. Students are not required to know other specific chromosome numbers but should appreciate that diploid cells have an even number of chromosomes. |

| A3.1.7—Karyotyping and karyograms |
|---|
| **Application of skills:** Students should be able to classify chromosomes by banding patterns, length and centromere position. Students should evaluate the evidence for the hypothesis that chromosome 2 in humans arose from the fusion of chromosomes 12 and 13 with a shared primate ancestor.<br>**NOS:** Students should be able to distinguish between testable hypotheses such as the origin of chromosome 2 and non-testable statements. |

| A3.1.8—Unity and diversity of genomes within species |
|---|
| Students should understand that the genome is all the genetic information of an organism. Organisms in the same species share most of their genome but variations such as single-nucleotide polymorphisms give some diversity. |

| A3.1.9—Diversity of eukaryote genomes |
|---|
| Genomes vary in overall size, which is determined by the total amount of DNA. Genomes also vary in base sequence. Variation between species is much larger than variation within a species. |

| A3.1.10—Comparison of genome sizes |
|---|
| **Application of skills:** Students should extract information about genome size for different taxonomic groups from a database to compare genome size to organism complexity. |

| A3.1.11—Current and potential future uses of whole genome sequencing |
|---|
| Include the increasing speed and decreasing costs. For current uses, include research into evolutionary relationships and for potential future uses, include personalized medicine. |

## Additional higher level

| A3.1.12—Difficulties applying the biological species concept to asexually reproducing species and to bacteria that have horizontal gene transfer |
| --- |
| The biological species concept does not work well with groups of organisms that do not breed sexually or where genes can be transferred from one species to another. |

| A3.1.13—Chromosome number as a shared trait within a species |
| --- |
| Cross-breeding between closely related species is unlikely to produce fertile offspring if parent chromosome numbers are different. |

| A3.1.14—Engagement with local plant or animal species to develop a dichotomous key |
| --- |
| **Application of skills:** Students should engage with local plant or animal species to develop a dichotomous key. |

| A3.1.15—Identification of species from environmental DNA in a habitat using barcodes |
| --- |
| Using barcodes and environmental DNA allows the biodiversity of habitats to be investigated rapidly. |

## Linking questions

- What might cause a species to persist or go extinct?
- How do species exemplify both continuous and discontinuous patterns of variation?

# A3.2 Classification and cladistics

Unity and diversity—Organisms

**Additional higher level: 3 hours**

## Guiding questions

- What tools are used to classify organisms into taxonomic groups?
- How do cladistic methods differ from traditional taxonomic methods?

## Additional higher level

*Note: There is no SL content in A3.2.*

| A3.2.1—Need for classification of organisms |
| --- |
| Classification is needed because of the immense diversity of species. After classification is completed, a broad range of further study is facilitated. |

| A3.2.2—Difficulties classifying organisms into the traditional hierarchy of taxa |
| --- |
| The traditional hierarchy of kingdom, phylum, class, order, family, genus and species does not always correspond to patterns of divergence generated by evolution.<br>**NOS:** A fixed ranking of taxa (kingdom, phylum and so on) is arbitrary because it does not reflect the gradation of variation. Cladistics offers an alternative approach to classification using unranked clades. This is an example of the paradigm shift that sometimes occurs in scientific theories. |

| A3.2.3—Advantages of classification corresponding to evolutionary relationships |
| --- |

| |
|---|
| The ideal classification follows evolutionary relationships, so all the members of a taxonomic group have evolved from a common ancestor. Characteristics of organisms within such a group can be predicted because they are shared within a clade. |

| A3.2.4—Clades as groups of organisms with common ancestry and shared characteristics |
|---|
| The most objective evidence for placing organisms in the same clade comes from base sequences of genes or amino acid sequences of proteins. Morphological traits can be used to assign organisms to clades. |

| A3.2.5—Gradual accumulation of sequence differences as the basis for estimates of when clades diverged from a common ancestor |
|---|
| This method of estimating times is known as the “molecular clock”. The molecular clock can only give estimates because mutation rates are affected by the length of the generation time, the size of a population, the intensity of selective pressure and other factors. |

| A3.2.6—Base sequences of genes or amino acid sequences of proteins as the basis for constructing cladograms |
|---|
| Examples can be simple and based on sample data to illustrate the tool.<br>**NOS:** Students should recognize that different criteria for judgement can lead to different hypotheses. Here, parsimony analysis is used to select the most probable cladogram, in which observed sequence variation between clades is accounted for with the smallest number of sequence changes. |

| A3.2.7—Analysing cladograms |
|---|
| Students should be able to deduce evolutionary relationships, common ancestors and clades from a cladogram. They should understand the terms “root”, “node” and “terminal branch” and also that a node represents a hypothetical common ancestor. |

| A3.2.8—Using cladistics to investigate whether the classification of groups corresponds to evolutionary relationships |
|---|
| A case study of transfer of plant species between families could be used to develop understanding, for example the reclassification of the figwort family (*Scrophulariaceae*). However, students are not required to memorize the details of the case study.<br>**NOS:** Students should appreciate that theories and other scientific knowledge claims may eventually be falsified. In this example, similarities in morphology due to convergent evolution rather than common ancestry suggested a classification that by cladistics has been shown to be false.<br>*Note: When students are referring to organisms in an examination, either the common name or the scientific name is acceptable.* |

| A3.2.9—Classification of all organisms into three domains using evidence from rRNA base sequences |
|---|
| This is the revolutionary reclassification with an extra taxonomic level above kingdoms that was proposed in 1977. |

## Linking questions

- How can similarities between distantly related organisms be explained?
- What are some examples of ideas over which biologists disagree?

# A4.1 Evolution and speciation

Unity and diversity—Ecosystems

**Standard level and higher level: 4 hours**

**Additional higher level: 1 hour**

## Guiding questions

- What is the evidence for evolution?
- How do analogous and homologous structures exemplify commonality and diversity?

## SL and HL

| A4.1.1—Evolution as change in the heritable characteristics of a population |
|---|
| This definition helps to distinguish Darwinian evolution from Lamarckism. Acquired changes that are not genetic in origin are not regarded as evolution.<br>**NOS:** The theory of evolution by natural selection predicts and explains a broad range of observations and is unlikely ever to be falsified. However, the nature of science makes it impossible to formally prove that it is true by correspondence. It is a pragmatic truth and is therefore referred to as a theory, despite all the supporting evidence. |

| A4.1.2—Evidence for evolution from base sequences in DNA or RNA and amino acid sequences in proteins |
|---|
| Sequence data gives powerful evidence of common ancestry. |

| A4.1.3—Evidence for evolution from selective breeding of domesticated animals and crop plants |
|---|
| Variation between different domesticated animal breeds and varieties of crop plant, and between them and the original wild species, shows how rapidly evolutionary changes can occur. |

| A4.1.4—Evidence for evolution from homologous structures |
|---|
| Include the example of pentadactyl limbs. |

| A4.1.5—Convergent evolution as the origin of analogous structures |
|---|
| Students should understand that analogous structures have the same function but different evolutionary origins. Students should know at least one example of analogous features. |

| A4.1.6—Speciation by splitting of pre-existing species |
|---|
| Students should appreciate that this is the only way in which new species have appeared. Students should also understand that speciation increases the total number of species on Earth, and extinction decreases it. Students should also understand that gradual evolutionary change in a species is not speciation. |

| A4.1.7—Roles of reproductive isolation and differential selection in speciation |
|---|
| Include geographical isolation as a means of achieving reproductive isolation. Use the separation of bonobos and common chimpanzees by the Congo River as a specific example of divergence due to differential selection. |

## Additional higher level

| A4.1.8—Differences and similarities between sympatric and allopatric speciation |
|---|

| |
|---|
| Students should understand that reproductive isolation can be geographic, behavioural or temporal. |

| A4.1.9—Adaptive radiation as a source of biodiversity |
|---|
| Adaptive radiation allows closely related species to coexist without competing, thereby increasing biodiversity in ecosystems where there are vacant niches. |

| A4.1.10—Barriers to hybridization and sterility of interspecific hybrids as mechanisms for of preventing the mixing of alleles between species |
|---|
| Courtship behaviour often prevents hybridization in animal species. A mule is an example of a sterile hybrid. |

| A4.1.11—Abrupt speciation in plants by hybridization and polyploidy |
|---|
| Use knotweed or smartweed (genus *Persicaria*) as an example because it contains many species that have been formed by these processes.<br>*Note: When students are referring to organisms in an examination, either the common name or the scientific name is acceptable.* |

## Linking questions

- How does the theory of evolution by natural selection predict and explain the unity and diversity of life on Earth?
- What counts as strong evidence in biology?

# A4.2 Conservation of biodiversity

Unity and diversity—Ecosystems

**Standard level and higher level: 3 hours**

## Guiding questions

- What factors are causing the sixth mass extinction of species?
- How can conservationists minimize the loss of biodiversity?

## SL and HL

| A4.2.1—Biodiversity as the variety of life in all its forms, levels and combinations |
|---|
| Include ecosystem diversity, species diversity and genetic diversity. |

| A4.2.2—Comparisons between current number of species on Earth and past levels of biodiversity |
|---|
| Millions of species have been discovered, named and described but there are many more species to be discovered. Evidence from fossils suggests that there are currently more species alive on Earth today than at any time in the past.<br>**NOS:** Classification is an example of pattern recognition but the same observations can be classified in different ways. For example, “splitters” recognize more species than “lumpers” in a taxonomic group. |

| A4.2.3—Causes of anthropogenic species extinction |
|---|
| This should be a study of the causes of the current sixth mass extinction, rather than of non-anthropogenic causes of previous mass extinctions. |

| |
|---|
| To give a range of causes, carry out three or more brief case studies of species extinction: North Island giant moas (*Dinornis novaezealandiae*) as an example of the loss of terrestrial megafauna, Caribbean monk seals (*Neomonachus tropicalis*) as an example of the loss of a marine species, and one other species that has gone extinct from an area that is familiar to students.<br>*Note: When students are referring to organisms in an examination, either the common name or the scientific name is acceptable.* |

| A4.2.4—Causes of ecosystem loss |
|---|
| Students should study only causes that are directly or indirectly anthropogenic. Include two case studies of ecosystem loss. One should be the loss of mixed dipterocarp forest in Southeast Asia, and the other should, if possible, be of a lost ecosystem from an area that is familiar to students. |

| A4.2.5—Evidence for a biodiversity crisis |
|---|
| Evidence can be drawn from Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services reports and other sources. Results from reliable surveys of biodiversity in a wide range of habitats around the world are required. Students should understand that surveys need to be repeated to provide evidence of change in species richness and evenness. Note that there are opportunities for contributions from both expert scientists and citizen scientists.<br>**NOS:** To be verifiable, evidence usually has to come from a published source, which has been peer-reviewed and allows methodology to be checked. Data recorded by citizens rather than scientists brings not only benefits but also unique methodological concerns. |

| A4.2.6—Causes of the current biodiversity crisis |
|---|
| Include human population growth as an overarching cause, together with these specific causes: hunting and other forms of over-exploitation; urbanization; deforestation and clearance of land for agriculture with consequent loss of natural habitat; pollution and spread of pests, diseases and invasive alien species due to global transport. |

| A4.2.7—Need for several approaches to conservation of biodiversity |
|---|
| No single approach by itself is sufficient, and different species require different measures. Include in situ conservation of species in natural habitats, management of nature reserves, rewilding and reclamation of degraded ecosystems, ex situ conservation in zoos and botanic gardens and storage of germ plasm in seed or tissue banks. |

| A4.2.8—Selection of evolutionarily distinct and globally endangered species for conservation prioritization in the EDGE of Existence programme |
|---|
| Students should understand the rationale behind focusing conservation efforts on evolutionarily distinct and globally endangered species (EDGE).<br>**NOS:** Issues such as which species should be prioritized for conservation efforts have complex ethical, environmental, political, social, cultural and economic implications and therefore need to be debated. |

*Note: There is no additional higher level content in A4.2.*

## Linking questions

- In what ways is diversity a property of life at all levels of biological organization?
- How does variation contribute to the stability of ecological communities?

# B1.1 Carbohydrates and lipids

Form and function—Molecules

**Standard level and higher level: 4 hours**

## Guiding questions

- In what ways do variations in form allow diversity of function in carbohydrates and lipids?
- How do carbohydrates and lipids compare as energy storage compounds?

## SL and HL

| B1.1.1—Chemical properties of a carbon atom allowing for the formation of diverse compounds upon which life is based |
|---|
| Students should understand the nature of a covalent bond. Students should also understand that a carbon atom can form up to four single bonds or a combination of single and double bonds with other carbon atoms or atoms of other non-metallic elements. Include among the diversity of carbon compounds examples of molecules with branched or unbranched chains and single or multiple rings.<br>**NOS:** Students should understand that scientific conventions are based on international agreement (SI metric unit prefixes “kilo”, “centi”, “milli”, “micro” and “nano”). |

| B1.1.2—Production of macromolecules by condensation reactions that link monomers to form a polymer |
|---|
| Students should be familiar with examples of polysaccharides, polypeptides and nucleic acids. |

| B1.1.3—Digestion of polymers into monomers by hydrolysis reactions |
|---|
| Water molecules are split to provide the -H and -OH groups that are incorporated to produce monomers, hence the name of this type of reaction. |

| B1.1.4—Form and function of monosaccharides |
|---|
| Students should be able to recognize pentoses and hexoses as monosaccharides from molecular diagrams showing them in the ring forms. Use glucose as an example of the link between the properties of a monosaccharide and how it is used, emphasizing solubility, transportability, chemical stability and the yield of energy from oxidation as properties. |

| B1.1.5—Polysaccharides as energy storage compounds |
|---|
| Include the compact nature of starch in plants and glycogen in animals due to coiling and branching during polymerization, the relative insolubility of these compounds due to large molecular size and the relative ease of adding or removing alpha-glucose monomers by condensation and hydrolysis to build or mobilize energy stores. |

| B1.1.6—Structure of cellulose related to its function as a structural polysaccharide in plants |
|---|
| Include the alternating orientation of beta-glucose monomers, giving straight chains that can be grouped in bundles and cross-linked with hydrogen bonds. |

| B1.1.7—Role of glycoproteins in cell–cell recognition |
|---|
| Include ABO antigens as an example. |

| B1.1.8—Hydrophobic properties of lipids |
|---|

| |
|---|
| Lipids are substances in living organisms that dissolve in non-polar solvents but are only sparingly soluble in aqueous solvents. Lipids include fats, oils, waxes and steroids. |

| B1.1.9—Formation of triglycerides and phospholipids by condensation reactions |
|---|
| One glycerol molecule can link three fatty acid molecules or two fatty acid molecules and one phosphate group. |

| B1.1.10—Difference between saturated, monounsaturated and polyunsaturated fatty acids |
|---|
| Include the number of double carbon (C=C) bonds and how this affects melting point. Relate this to the prevalence of different types of fatty acids in oils and fats used for energy storage in plants and endotherms respectively. |

| B1.1.11—Triglycerides in adipose tissues for energy storage and thermal insulation |
|---|
| Students should understand that the properties of triglycerides make them suited to long-term energy storage functions. Students should be able to relate the use of triglycerides as thermal insulators to body temperature and habitat. |

| B1.1.12—Formation of phospholipid bilayers as a consequence of the hydrophobic and hydrophilic regions |
|---|
| Students should use and understand the term "amphipathic". |

| B1.1.13—Ability of non-polar steroids to pass through the phospholipid bilayer |
|---|
| Include oestradiol and testosterone as examples. Students should be able to identify compounds as steroids from molecular diagrams. |

*Note: There is no additional higher level content in B1.1.*

## Linking questions

- How can compounds synthesized by living organisms accumulate and become carbon sinks?
- What are the roles of oxidation and reduction in biological systems?

# B1.2 Proteins

Form and function—Molecules

**Standard level and higher level: 2 hours**

**Additional higher level: 2 hours**

## Guiding questions

- What is the relationship between amino acid sequence and the diversity in form and function of proteins?
- How are protein molecules affected by their chemical and physical environments?

## SL and HL

| B1.2.1—Generalized structure of an amino acid |
|---|
| Students should be able to draw a diagram of a generalized amino acid showing the alpha carbon atom with amine group, carboxyl group, R-group and hydrogen attached. |

| B1.2.2—Condensation reactions forming dipeptides and longer chains of amino acids |
|---|
| Students should be able to write the word equation for this reaction and draw a generalized dipeptide after modelling the reaction with molecular models. |

| B1.2.3—Dietary requirements for amino acids |
|---|
| Essential amino acids cannot be synthesized and must be obtained from food. Non-essential amino acids can be made from other amino acids. Students are not required to give examples of essential and non-essential amino acids. Vegan diets require attention to ensure essential amino acids are consumed. |

| B1.2.4—Infinite variety of possible peptide chains |
|---|
| Include the ideas that 20 amino acids are coded for in the genetic code, that peptide chains can have any number of amino acids, from a few to thousands, and that amino acids can be in any order. Students should be familiar with examples of polypeptides. |

| B1.2.5—Effect of pH and temperature on protein structure |
|---|
| Include the term "denaturation". |

## Additional higher level

| B1.2.6—Chemical diversity in the R-groups of amino acids as a basis for the immense diversity in protein form and function |
|---|
| Students are not required to give specific examples of R-groups. However, students should understand that R-groups determine the properties of assembled polypeptides. Students should appreciate that R-groups are hydrophobic or hydrophilic and that hydrophilic R-groups are polar or charged, acidic or basic. |

| B1.2.7—Impact of primary structure on the conformation of proteins |
|---|
| Students should understand that the sequence of amino acids and the precise position of each amino acid within a structure determines the three-dimensional shape of proteins. Proteins therefore have precise, predictable and repeatable structures, despite their complexity. |

| B1.2.8—Pleating and coiling of secondary structure of proteins |
|---|
| Include hydrogen bonding in regular positions to stabilize alpha helices and beta-pleated sheets. |

| B1.2.9—Dependence of tertiary structure on hydrogen bonds, ionic bonds, disulfide covalent bonds and hydrophobic interactions |
|---|
| Students are not required to name examples of amino acids that participate in these types of bonding, apart from pairs of cysteines forming disulfide bonds. Students should understand that amine and carboxyl groups in R-groups can become positively or negatively charged by binding or dissociation of hydrogen ions and that they can then participate in ionic bonding. |

| B1.2.10—Effect of polar and non-polar amino acids on tertiary structure of proteins |
|---|
| In proteins that are soluble in water, hydrophobic amino acids are clustered in the core of globular proteins. Integral proteins have regions with hydrophobic amino acids, helping them to embed in membranes. |

| B1.2.11—Quaternary structure of non-conjugated and conjugated proteins |
|---|

| |
|---|
| Include insulin and collagen as examples of non-conjugated proteins and haemoglobin as an example of a conjugated protein.<br>**NOS:** Technology allows imaging of structures that would be impossible to observe with the unaided senses. For example, cryogenic electron microscopy has allowed imaging of single-protein molecules and their interactions with other molecules. |

| B1.2.12—Relationship of form and function in globular and fibrous proteins |
|---|
| Students should know the difference in shape between globular and fibrous proteins and understand that their shapes make them suitable for specific functions. Use insulin and collagen to exemplify how form and function are related. |

## Linking questions

- How do abiotic factors influence the form of molecules?
- What is the relationship between the genome and the proteome of an organism?

# B2.1 Membranes and membrane transport

Form and function—Cells

**Standard level and higher level: 4 hours**

**Additional higher level: 2 hours**

## Guiding questions

- How do molecules of lipid and protein assemble into biological membranes?
- What determines whether a substance can pass through a biological membrane?

## SL and HL

| B2.1.1—Lipid bilayers as the basis of cell membranes |
|---|
| Phospholipids and other amphipathic lipids naturally form continuous sheet-like bilayers in water. |

| B2.1.2—Lipid bilayers as barriers |
|---|
| Students should understand that the hydrophobic hydrocarbon chains that form the core of a membrane have low permeability to large molecules and hydrophilic particles, including ions and polar molecules, so membranes function as effective barriers between aqueous solutions. |

| B2.1.3—Simple diffusion across membranes |
|---|
| Use movement of oxygen and carbon dioxide molecules between phospholipids as an example of simple diffusion across membranes. |

| B2.1.4—Integral and peripheral proteins in membranes |
|---|
| Emphasize that membrane proteins have diverse structures, locations and functions. Integral proteins are embedded in one or both of the lipid layers of a membrane. Peripheral proteins are attached to one or other surface of the bilayer. |

| B2.1.5—Movement of water molecules across membranes by osmosis and the role of aquaporins |
|---|
| Include an explanation in terms of random movement of particles, impermeability of membranes to solutes and differences in solute concentration. |

| B2.1.6—Channel proteins for facilitated diffusion |
|---|
| Students should understand how the structure of channel proteins makes membranes selectively permeable by allowing specific ions to diffuse through when channels are open but not when they are closed. |

| B2.1.7—Pump proteins for active transport |
|---|
| Students should appreciate that pumps use energy from adenosine triphosphate (ATP) to transfer specific particles across membranes and therefore that they can move particles against a concentration gradient. |

| B2.1.8—Selectivity in membrane permeability |
|---|
| Facilitated diffusion and active transport allow selective permeability in membranes. Permeability by simple diffusion is not selective and depends only on the size and hydrophilic or hydrophobic properties of particles. |

| B.2.1.9—Structure and function of glycoproteins and glycolipids |
|---|
| Limit to carbohydrate structures linked to proteins or lipids in membranes, location of carbohydrates on the extracellular side of membranes, and roles in cell adhesion and cell recognition. |

| B2.1.10—Fluid mosaic model of membrane structure |
|---|
| Students should be able to draw a two-dimensional representation of the model and include peripheral and integral proteins, glycoproteins, phospholipids and cholesterol. They should also be able to indicate hydrophobic and hydrophilic regions. |

## Additional higher level

| B2.1.11—Relationships between fatty acid composition of lipid bilayers and their fluidity |
|---|
| Unsaturated fatty acids in lipid bilayers have lower melting points, so membranes are fluid and therefore flexible at temperatures experienced by a cell. Saturated fatty acids have higher melting points and make membranes stronger at higher temperatures. Students should be familiar with an example of adaptations in membrane composition in relation to habitat. |

| B2.1.12—Cholesterol and membrane fluidity in animal cells |
|---|
| Students should understand the position of cholesterol molecules in membranes and also that cholesterol acts as a modulator (adjustor) of membrane fluidity, stabilizing membranes at higher temperatures and preventing stiffening at lower temperatures. |

| B2.1.13—Membrane fluidity and the fusion and formation of vesicles |
|---|
| Include the terms “endocytosis” and “exocytosis”, and examples of each process. |

| B2.1.14—Gated ion channels in neurons |
|---|
| Include nicotinic acetylcholine receptors as an example of a neurotransmitter-gated ion channel and sodium and potassium channels as examples of voltage-gated channels. |

| B2.1.15—Sodium–potassium pumps as an example of exchange transporters |
|---|
| Include the importance of these pumps in generating membrane potentials. |

| B2.1.16—Sodium-dependent glucose cotransporters as an example of indirect active transport |
| --- |
| Include the importance of these cotransporters in glucose absorption by cells in the small intestine and glucose reabsorption by cells in the nephron. |

| B2.1.17—Adhesion of cells to form tissues |
| --- |
| Include the term "cell-adhesion molecules" (CAMs) and the understanding that different forms of CAM are used for different types of cell–cell junction. Students are not required to have detailed knowledge of the different CAMs or junctions. |

## Linking questions

- What processes depend on active transport in biological systems?
- What are the roles of cell membranes in the interaction of a cell with its environment?

# B2.2 Organelles and compartmentalization

Form and function—Cells

**Standard level and higher level: 1 hour**

**Additional higher level: 2 hours**

## Guiding questions

- How are organelles in cells adapted to their functions?
- What are the advantages of compartmentalization in cells?

## SL and HL

| B2.2.1—Organelles as discrete subunits of cells that are adapted to perform specific functions |
| --- |
| Students should understand that the cell wall, cytoskeleton and cytoplasm are not considered organelles, and that nuclei, vesicles, ribosomes and the plasma membrane are.<br>**NOS:** Students should recognize that progress in science often follows development of new techniques. For example, study of the function of individual organelles became possible when ultracentrifuges had been invented and methods of using them for cell fractionation had been developed. |

| B2.2.2—Advantage of the separation of the nucleus and cytoplasm into separate compartments |
| --- |
| Limit to separation of the activities of gene transcription and translation—post-transcriptional modification of mRNA can happen before the mRNA meets ribosomes in the cytoplasm. In prokaryotes this is not possible—mRNA may immediately meet ribosomes. |

| B2.2.3—Advantages of compartmentalization in the cytoplasm of cells |
| --- |
| Include concentration of metabolites and enzymes and the separation of incompatible biochemical processes. Include lysosomes and phagocytic vacuoles as examples. |

## Additional higher level

| B2.2.4—Adaptations of the mitochondrion for production of ATP by aerobic cell respiration |
| --- |

| |
|---|
| Include these adaptations: a double membrane with a small volume of intermembrane space, large surface area of cristae and compartmentalization of enzymes and substrates of the Krebs cycle in the matrix. |

| B2.2.5—Adaptations of the chloroplast for photosynthesis |
|---|
| Include these adaptations: the large surface area of thylakoid membranes with photosystems, small volumes of fluid inside thylakoids, and compartmentalization of enzymes and substrates of the Calvin cycle in the stroma. |

| B2.2.6—Functional benefits of the double membrane of the nucleus |
|---|
| Include the need for pores in the nuclear membrane and for the nucleus membrane to break into vesicles during mitosis and meiosis. |

| B2.2.7—Structure and function of free ribosomes and of the rough endoplasmic reticulum |
|---|
| Contrast the synthesis by free ribosomes of proteins for retention in the cell with synthesis by membrane-bound ribosomes on the rough endoplasmic reticulum of proteins for transport within the cell and secretion. |

| B2.2.8—Structure and function of the Golgi apparatus |
|---|
| Limit to the roles of the Golgi apparatus in processing and secretion of protein. |

| B2.2.9—Structure and function of vesicles in cells |
|---|
| Include the role of clathrin in the formation of vesicles. |

## Linking questions

- What are examples of structure–function correlations at each level of biological organization?
- What separation techniques are used by biologists?

# B2.3 Cell specialization

Form and function—Cells

**Standard level and higher level: 2 hours**

**Additional higher level: 1 hours**

## Guiding questions

- What are the roles of stem cells in multicellular organisms?
- How are differentiated cells adapted to their specialized functions?

## SL and HL

| B2.3.1—Production of unspecialized cells following fertilization and their development into specialized cells by differentiation |
|---|
| Students should understand the impact of gradients on gene expression within an early-stage embryo. |

| B2.3.2—Properties of stem cells |
|---|
| Limit to the capacity of cells to divide endlessly and differentiate along different pathways. |

| B2.3.3—Location and function of stem cell niches in adult humans |
| --- |
| Limit to two example locations and the understanding that the stem cell niche can maintain the cells or promote their proliferation and differentiation. Bone marrow and hair follicles are suitable examples. |

| B2.3.4—Differences between totipotent, pluripotent and multipotent stem cells |
| --- |
| Students should appreciate that cells in early-stage animal embryos are totipotent but soon become pluripotent, whereas stem cells in adult tissue such as bone marrow are multipotent. |

| B2.3.5—Cell size as an aspect of specialization |
| --- |
| Consider the range of cell size in humans including male and female gametes, red and white blood cells, neurons and striated muscle fibres. |

| B2.3.6—Surface area-to-volume ratios and constraints on cell size |
| --- |
| Students should understand the mathematical ratio between volume and surface area and that exchange of materials across a cell surface depends on its area whereas the need for exchange depends on cell volume.<br>**NOS:** Students should recognize that models are simplified versions of complex systems. In this case, surface-area-to-volume relationship can be modelled using cubes of different side lengths. Although the cubes have a simpler shape than real organisms, scale factors operate in the same way. |

## Additional higher level

| B2.3.7—Adaptations to increase surface area-to-volume ratios of cells |
| --- |
| Include flattening of cells, microvilli and invagination. Use erythrocytes and proximal convoluted tubule cells in the nephron as examples. |

| B2.3.8—Adaptations of type I and type II pneumocytes in alveoli |
| --- |
| Limit to extreme thinness to reduce distances for diffusion in type I pneumocytes and the presence of many secretory vesicles (lamellar bodies) in the cytoplasm that discharge surfactant to the alveolar lumen in type II pneumocytes. Alveolar epithelium is an example of a tissue where more than one cell type is present, because different adaptations are required for the overall function of the tissue. |

| B2.3.9—Adaptations of cardiac muscle cells and striated muscle fibres |
| --- |
| Include the presence of contractile myofibrils in both muscle types and hypotheses for these differences: branching (branched or unbranched), and length and numbers of nuclei. Also include a discussion of whether a striated muscle fibre is a cell. |

| B2.3.10—Adaptations of sperm and egg cells |
| --- |
| Limit to gametes in humans. |

## Linking questions

- What are the advantages of small size and large size in biological systems?
- How do cells become differentiated?

# B3.1 Gas exchange

Form and function—Organisms

**Standard level and higher level: 3 hours**

**Additional higher level: 1 hour**

## Guiding questions

- How are multicellular organisms adapted to carry out gas exchange?
- What are the similarities and differences in gas exchange between a flowering plant and a mammal?

## SL and HL

| B3.1.1—Gas exchange as a vital function in all organisms |
|---|
| Students should appreciate that the challenges become greater as organisms increase in size because surface area-to-volume ratio decreases with increasing size, and the distance from the centre of an organism to its exterior increases. |

| B3.1.2—Properties of gas-exchange surfaces |
|---|
| Include permeability, thin tissue layer, moisture and large surface area. |

| B3.1.3—Maintenance of concentration gradients at exchange surfaces in animals |
|---|
| Include dense networks of blood vessels, continuous blood flow, and ventilation with air for lungs and with water for gills. |

| B3.1.4—Adaptations of mammalian lungs for gas exchange |
|---|
| Limit to the alveolar lungs of a mammal. Adaptations should include the presence of surfactant, a branched network of bronchioles, extensive capillary beds and a high surface area. |

| B3.1.5—Ventilation of the lungs |
|---|
| Students should understand the role of the diaphragm, intercostal muscles, abdominal muscles and ribs. |

| B3.1.6—Measurement of lung volumes |
|---|
| **Application of skills:** Students should make measurements to determine tidal volume, vital capacity, and inspiratory and expiratory reserves. |

| B3.1.7—Adaptations for gas exchange in leaves |
|---|
| Leaf structure adaptations should include the waxy cuticle, epidermis, air spaces, spongy mesophyll, stomatal guard cells and veins. |

| B3.1.8—Distribution of tissues in a leaf |
|---|
| Students should be able to draw and label a plan diagram to show the distribution of tissues in a transverse section of a dicotyledonous leaf. |

| B3.1.9—Transpiration as a consequence of gas exchange in a leaf |
|---|
| Students should be aware of the factors affecting the rate of transpiration. |

| B3.1.10—Stomatal density |
|---|
| **Application of skills:** Students should use micrographs or perform leaf casts to determine stomatal density.<br>**NOS:** Reliability of quantitative data is increased by repeating measurements. In this case, repeated counts of the number of stomata visible in the field of view at high power illustrate the variability of biological material and the need for replicate trials. |

## Additional higher level

| B3.1.11—Adaptations of foetal and adult haemoglobin for the transport of oxygen |
|---|
| Include cooperative binding of oxygen to haem groups and allosteric binding of carbon dioxide. |

| B3.1.12—Bohr shift |
|---|
| Students should understand how an increase in carbon dioxide causes increased dissociation of oxygen and the benefits of this for actively respiring tissues. |

| B3.1.13—Oxygen dissociation curves as a means of representing the affinity of haemoglobin for oxygen at different oxygen concentrations |
|---|
| Explain the S-shaped form of the curve in terms of cooperative binding. |

## Linking questions

- How do multicellular organisms solve the problem of access to materials for all their cells?
- What is the relationship between gas exchange and metabolic processes in cells?

# B3.2 Transport

Form and function—Organisms

**Standard level and higher level: 3 hours**

**Additional higher level: 2 hours**

## Guiding questions

- What adaptations facilitate transport of fluids in animals and plants?
- What are the differences and similarities between transport in animals and plants?

## SL and HL

| B3.2.1—Adaptations of capillaries for exchange of materials between blood and the internal or external environment |
|---|
| Adaptations should include a large surface area due to branching and narrow diameters, thin walls, and fenestrations in some capillaries where exchange needs to be particularly rapid. |

| B3.2.2—Structure of arteries and veins |
|---|
| **Application of skills:** Students should be able to distinguish arteries and veins in micrographs from the structure of a vessel wall and its thickness relative to the diameter of the lumen. |

| B3.2.3—Adaptations of arteries for the transport of blood away from the heart |
|---|

| |
|---|
| Students should understand how the layers of muscle and elastic tissue in the walls of arteries help them to withstand and maintain high blood pressures. |

| B3.2.4—Measurement of pulse rates |
|---|
| **Application of skills:** Students should be able to determine heart rate by feeling the carotid or radial pulse with fingertips. Traditional methods could be compared with digital ones. |

| B3.2.5—Adaptations of veins for the return of blood to the heart |
|---|
| Include valves to prevent backflow and the flexibility of the wall to allow it to be compressed by muscle action. |

| B3.2.6—Causes and consequences of occlusion of the coronary arteries |
|---|
| **Application of skills:** Students should be able to evaluate epidemiological data relating to the incidence of coronary heart disease.<br>**NOS:** Students should understand that correlation coefficients quantify correlations between variables and allow the strength of the relationship to be assessed. Low correlation coefficients or lack of any correlation could provide evidence against a hypothesis, but even strong correlations such as that between saturated fat intake and coronary heart disease do not prove a causal link. |

| B3.2.7—Transport of water from roots to leaves during transpiration |
|---|
| Students should understand that loss of water by transpiration from cell walls in leaf cells causes water to be drawn out of xylem vessels and through cell walls by capillary action, generating tension (negative pressure potentials). It is this tension that draws water up in the xylem. Cohesion ensures a continuous column of water. |

| B3.2.8—Adaptations of xylem vessels for transport of water |
|---|
| Include the lack of cell contents and incomplete or absent end walls for unimpeded flow, lignified walls to withstand tensions, and pits for entry and exit of water. |

| B3.2.9—Distribution of tissues in a transverse section of the stem of a dicotyledonous plant |
|---|
| **Application of skills:** Students should be able to draw plan diagrams from micrographs to identify the relative positions of vascular bundles, xylem, phloem, cortex and epidermis. Students should annotate the diagram with the main functions of these structures. |

| B3.2.10—Distribution of tissues in a transverse section of the root of a dicotyledonous plant |
|---|
| **Application of skills:** Students should be able to draw diagrams from micrographs to identify vascular bundles, xylem and phloem, cortex and epidermis. |

## Additional higher level

| B3.2.11—Release and reuptake of tissue fluid in capillaries |
|---|
| Tissue fluid is formed by pressure filtration of plasma in capillaries. This is promoted by the higher pressure of blood from arterioles. Lower pressure in venules allows tissue fluid to drain back into capillaries. |

| B3.2.12—Exchange of substances between tissue fluid and cells in tissues |
|---|
| Discuss the composition of plasma and tissue fluid. |

| B3.2.13—Drainage of excess tissue fluid into lymph ducts |
|---|
| Limit to the presence of valves and thin walls with gaps in lymph ducts and return of lymph to the blood circulation. |

| B3.2.14—Differences between the single circulation of bony fish and the double circulation of mammals |
|---|
| Simple circuit diagrams are sufficient to show the sequence of organs through which blood passes. |

| B3.2.15—Adaptations of the mammalian heart for delivering pressurized blood to the arteries |
|---|
| Include form–function adaptations of these structures: cardiac muscle, pacemaker, atria, ventricles, atrioventricular and semilunar valves, septum and coronary vessels. Students should be able to identify these features on a diagram of the heart in the frontal plane and trace the unidirectional flow of blood from named veins to arteries. |

| B3.2.16—Stages in the cardiac cycle |
|---|
| **Application of skills:** Students should understand the sequence of events in the left side of the heart that follow the initiation of the heartbeat by the sinoatrial node (the "pacemaker"). Students should be able to interpret systolic and diastolic blood pressure measurements from data and graphs. |

| B3.2.17—Generation of root pressure in xylem vessels by active transport of mineral ions |
|---|
| Root pressure is positive pressure potential, generated to cause water movement in roots and stems when transport in xylem due to transpiration is insufficient, for example when high humidity prevents transpiration or in spring, before leaves on deciduous plants have opened. |

| B3.2.18—Adaptations of phloem sieve tubes and companion cells for translocation of sap |
|---|
| Include sieve plates, reduced cytoplasm and organelles, no nucleus for sieve tube elements and presence of many mitochondria for companion cells and plasmodesmata between them. Students should appreciate how these adaptations ease the flow of sap and enhance loading of carbon compounds into phloem sieve tubes at sources and unloading of them at sinks. |

## Linking questions

- How do pressure differences contribute to the movement of materials in an organism?
- What processes happen in cycles at each level of biological organization?

# B3.3 Muscle and motility

Form and function—Organisms

**Additional higher level: 3 hours**

## Guiding questions

- How do muscles contract and cause movement?
- What are the benefits to animals of having muscle tissue?

## Additional higher level

*Note: There is no SL content in B3.3.*

| B3.3.1—Adaptations for movement as a universal feature of living organisms |
|---|

| |
|---|
| Students should explore the concept of movement by considering a range of organisms including one motile and one sessile species. |

| B3.3.2—Sliding filament model of muscle contraction |
|---|
| Students should understand how a sarcomere contracts by the sliding of actin and myosin filaments. |

| B3.3.3—Role of the protein titin and antagonistic muscles in muscle relaxation |
|---|
| The immense protein titin helps sarcomeres to recoil after stretching and also prevents overstretching. Antagonistic muscles are needed because muscle tissue can only exert force when it contracts. |

| B3.3.4—Structure and function of motor units in skeletal muscle |
|---|
| Include the motor neuron, muscle fibres and the neuromuscular junctions that connect them. |

| B3.3.5—Roles of skeletons as anchorage for muscles and as levers |
|---|
| Students should appreciate that arthropods have exoskeletons and vertebrates have endoskeletons. |

| B3.3.6—Movement at a synovial joint |
|---|
| Include the roles of bones, cartilage, synovial fluid, ligaments, muscles and tendons. Use the human hip joint as an example. Students are not required to name muscles and ligaments, but they should be able to name the femur and pelvis. |

| B3.3.7—Range of motion of a joint |
|---|
| **Application of skills:** Students should compare the range of motion of a joint in a number of dimensions. Students should measure joint angles using computer analysis of images or a goniometer. |

| B3.3.8—Internal and external intercostal muscles as an example of antagonistic muscle action to facilitate internal body movements |
|---|
| Students should appreciate that the different orientations of muscle fibres in the internal and external layers of intercostal muscles mean that they move the ribcage in opposite directions and that, when one of these layers contracts, it stretches the other, storing potential energy in the sarcomere protein titin. |

| B3.3.9—Reasons for locomotion |
|---|
| Include foraging for food, escaping from danger, searching for a mate and migration, with at least one example of each. |

| B3.3.10—Adaptations for swimming in marine mammals |
|---|
| Include streamlining, adaptation of limbs to form flippers and of the tail to form a fluke with up-and-down movement, and changes to the airways to allow periodic breathing between dives. |

## Linking questions

- What are the advantages and disadvantages of dispersal of offspring from their parents?
- In what ways does locomotion contribute to evolution within living organisms?

# B4.1 Adaptation to environment

Form and function—Ecosystems

**Standard level and higher level: 3 hours**

## Guiding questions

- How are the adaptations and habitats of species related?
- What causes the similarities between ecosystems within a terrestrial biome?

## SL and HL

| B4.1.1—Habitat as the place in which a community, species, population or organism lives |
|---|
| A description of the habitat of a species can include both geographical and physical locations, and the type of ecosystem. |

| B4.1.2—Adaptations of organisms to the abiotic environment of their habitat |
|---|
| Include a grass species adapted to sand dunes and a tree species adapted to mangrove swamps. |

| B4.1.3—Abiotic variables affecting species distribution |
|---|
| Include examples of abiotic variables for both plants and animals. Students should understand that the adaptations of a species give it a range of tolerance. |

| B4.1.4—Range of tolerance of a limiting factor |
|---|
| **Application of skills:** Students should use transect data to correlate the distribution of plant or animal species with an abiotic variable. Students should collect this data themselves from a natural or semi-natural habitat. Semi-natural habitats have been influenced by humans but are dominated by wild rather than cultivated species. Sensors could be used to measure abiotic variables such as temperature, light intensity and soil pH. |

| B4.1.5—Conditions required for coral reef formation |
|---|
| Coral reefs are used here as an example of a marine ecosystem. Factors should include water depth, pH, salinity, clarity and temperature. |

| B4.1.6—Abiotic factors as the determinants of terrestrial biome distribution |
|---|
| Students should understand that, for any given temperature and rainfall pattern, one natural ecosystem type is likely to develop. Illustrate this using a graph showing the distribution of biomes with these two climatic variables on the horizontal and vertical axes. |

| B4.1.7—Biomes as groups of ecosystems with similar communities due to similar abiotic conditions and convergent evolution |
|---|
| Students should be familiar with the climate conditions that characterize the tropical forest, temperate forest, taiga, grassland, tundra and hot desert biomes. |

| B4.1.8—Adaptations to life in hot deserts and tropical rainforest |
|---|
| Include examples of adaptations in named species of plants and animals. |

*Note: There is no additional higher level content in B4.1.*

## Linking questions

- What are the properties of the components of biological systems?

- Is light essential for life?

# B4.2 Ecological niches

Form and function—Ecosystems

**Standard level and higher level: 4 hours**

## Guiding questions

- What are the advantages of specialized modes of nutrition to living organisms?
- How are the adaptations of a species related to its niche in an ecosystem?

## SL and HL

| B4.2.1—Ecological niche as the role of a species in an ecosystem |
| --- |
| Include the biotic and abiotic interactions that influence growth, survival and reproduction, including how a species obtains food. |

| B4.2.2—Differences between organisms that are obligate anaerobes, facultative anaerobes and obligate aerobes |
| --- |
| Limit to the tolerance of these groups of organisms to the presence or absence of oxygen gas in their environment. |

| B4.2.3—Photosynthesis as the mode of nutrition in plants, algae and several groups of photosynthetic prokaryotes |
| --- |
| Details of different types of photosynthesis in prokaryotes are not required. |

| B4.2.4—Holozoic nutrition in animals |
| --- |
| Students should understand that all animals are heterotrophic. In holozoic nutrition food is ingested, digested internally, absorbed and assimilated. |

| B4.2.5—Mixotrophic nutrition in some protists |
| --- |
| *Euglena* is a well-known freshwater example of a protist that is both autotrophic and heterotrophic, but many other mixotrophic species are part of oceanic plankton. Students should understand that some mixotrophs are obligate and others are facultative. |

| B4.2.6—Saprotrophic nutrition in some fungi and bacteria |
| --- |
| Fungi and bacteria with this mode of heterotrophic nutrition can be referred to as decomposers. |

| B4.2.7—Diversity of nutrition in archaea |
| --- |
| Students should understand that archaea are one of the three domains of life and appreciate that they are metabolically very diverse. Archaea species use either light, oxidation of inorganic chemicals or oxidation of carbon compounds to provide energy for ATP production. Students are not required to name examples. |

| B4.2.8—Relationship between dentition and the diet of omnivorous and herbivorous representative members of the family Hominidae |
| --- |

| |
|---|
| **Application of skills:** Students should examine models or digital collections of skulls to infer diet from the anatomical features. Examples may include *Homo sapiens* (humans), *Homo floresiensis* and *Paranthropus robustus*.<br>**NOS:** Deductions can be made from theories. In this example, observation of living mammals led to theories relating dentition to herbivorous or carnivorous diets. These theories allowed the diet of extinct organisms to be deduced. |

| B4.2.9—Adaptations of herbivores for feeding on plants and of plants for resisting herbivory |
|---|
| For herbivore adaptations, include piercing and chewing mouthparts of leaf-eating insects. Plants resist herbivory using thorns and other physical structures. Plants also produce toxic secondary compounds in seeds and leaves. Some animals have metabolic adaptations for detoxifying these toxins. |

| B4.2.10—Adaptations of predators for finding, catching and killing prey and of prey animals for resisting predation |
|---|
| Students should be aware of chemical, physical and behavioural adaptations in predators and prey. |

| B4.2.11—Adaptations of plant form for harvesting light |
|---|
| Include examples from forest ecosystems to illustrate how plants in forests use different strategies to reach light sources, including trees that reach the canopy, lianas, epiphytes growing on branches of trees, strangler epiphytes, shade-tolerant shrubs and herbs growing on the forest floor. |

| B4.2.12—Fundamental and realized niches |
|---|
| Students should appreciate that fundamental niche is the potential of a species based on adaptations and tolerance limits and that realized niche is the actual extent of a species niche when in competition with other species. |

| B4.2.13—Competitive exclusion and the uniqueness of ecological niches |
|---|
| Include elimination of one of the competing species or the restriction of both to a part of their fundamental niche as possible outcomes of competition between two species. |

*Note: There is no additional higher level content in B4.2.*

## Linking questions

- What are the relative advantages of specificity and versatility?
- For each form of nutrition, what are the unique inputs, processes and outputs?

# C1.1 Enzymes and metabolism

Interaction and interdependence—Molecules

**Standard level and higher level: 3 hours**

**Additional higher level: 2 hours**

## Guiding questions

- In what ways do enzymes interact with other molecules?
- What are the interdependent components of metabolism?

## SL and HL

| C1.1.1—Enzymes as catalysts |
|---|
| Students should understand the benefit of increasing rates of reaction in cells. |

| C1.1.2—Role of enzymes in metabolism |
|---|
| Students should understand that metabolism is the complex network of interdependent and interacting chemical reactions occurring in living organisms. Because of enzyme specificity, many different enzymes are required by living organisms, and control over metabolism can be exerted through these enzymes. |

| C1.1.3—Anabolic and catabolic reactions |
|---|
| Examples of anabolism should include the formation of macromolecules from monomers by condensation reactions including protein synthesis, glycogen formation and photosynthesis. Examples of catabolism should include hydrolysis of macromolecules into monomers in digestion and oxidation of substrates in respiration. |

| C1.1.4—Enzymes as globular proteins with an active site for catalysis |
|---|
| Include that the active site is composed of a few amino acids only, but interactions between amino acids within the overall three-dimensional structure of the enzyme ensure that the active site has the necessary properties for catalysis. |

| C1.1.5—Interactions between substrate and active site to allow induced-fit binding |
|---|
| Students should recognize that both substrate and enzymes change shape when binding occurs. |

| C1.1.6—Role of molecular motion and substrate-active site collisions in enzyme catalysis |
|---|
| Movement is needed for a substrate molecule and an active site to come together. Sometimes large substrate molecules are immobilized while sometimes enzymes can be immobilized by being embedded in membranes. |

| C1.1.7—Relationships between the structure of the active site, enzyme–substrate specificity and denaturation |
|---|
| Students should be able to explain these relationships. |

| C1.1.8—Effects of temperature, pH and substrate concentration on the rate of enzyme activity |
|---|
| The effects should be explained with reference to collision theory and denaturation.<br>**Application of skills:** Students should be able to interpret graphs showing the effects.<br>**NOS:** Students should be able to describe the relationship between variables as shown in graphs. They should recognize that generalized sketches of relationships are examples of models in biology. Models in the form of sketch graphs can be evaluated using results from enzyme experiments. |

| C1.1.9—Measurements in enzyme-catalysed reactions |
|---|
| **Application of skills:** Students should determine reaction rates through experimentation and using secondary data. |

| C1.1.10—Effect of enzymes on activation energy |
|---|

| |
|---|
| **Application of skills:** Students should appreciate that energy is required to break bonds within the substrate and that there is an energy yield when bonds are made to form the products of an enzyme-catalysed reaction. Students should be able to interpret graphs showing this effect. |

## Additional higher level

| C1.1.11—Intracellular and extracellular enzyme-catalysed reactions |
|---|
| Include glycolysis and the Krebs cycle as intracellular examples and chemical digestion in the gut as an extracellular example. |

| C1.1.12—Generation of heat energy by the reactions of metabolism |
|---|
| Include the idea that heat generation is inevitable because metabolic reactions are not 100% efficient in energy transfer. Mammals, birds and some other animals depend on this heat production for maintenance of constant body temperature. |

| C1.1.13—Cyclical and linear pathways in metabolism |
|---|
| Use glycolysis, the Krebs cycle and the Calvin cycle as examples. |

| C1.1.14—Allosteric sites and non-competitive inhibition |
|---|
| Students should appreciate that only specific substances can bind to an allosteric site. Binding causes interactions within an enzyme that lead to conformational changes, which alter the active site enough to prevent catalysis. Binding is reversible. |

| C1.1.15—Competitive inhibition as a consequence of an inhibitor binding reversibly to an active site |
|---|
| Use statins as an example of competitive inhibitors. Include the difference between competitive and non-competitive inhibition in the interactions between substrate and inhibitor and therefore in the effect of substrate concentration. |

| C1.1.16—Regulation of metabolic pathways by feedback inhibition |
|---|
| Use the pathway that produces isoleucine as an example of an end product acting as an inhibitor. |

| C1.1.17—Mechanism-based inhibition as a consequence of chemical changes to the active site caused by the irreversible binding of an inhibitor |
|---|
| Use penicillin as an example. Include the change to transpeptidases that confers resistance to penicillin. |

## Linking questions

- What are examples of structure–function relationships in biological macromolecules?
- What biological processes depend on differences or changes in concentration?

# C1.2 Cell respiration

Interaction and interdependence—Molecules

**Standard level and higher level: 2 hours**

**Additional higher level: 3 hours**

## Guiding questions

- What are the roles of hydrogen and oxygen in the release of energy in cells?
- How is energy distributed and used inside cells?

## SL and HL

| C1.2.1—ATP as the molecule that distributes energy within cells |
|---|
| Include the full name of ATP (adenosine triphosphate) and that it is a nucleotide. Students should appreciate the properties of ATP that make it suitable for use as the energy currency within cells. |

| C1.2.2—Life processes within cells that ATP supplies with energy |
|---|
| Include active transport across membranes, synthesis of macromolecules (anabolism), movement of the whole cell or cell components such as chromosomes. |

| C1.2.3—Energy transfers during interconversions between ATP and ADP |
|---|
| Students should know that energy is released by hydrolysis of ATP (adenosine triphosphate) to ADP (adenosine diphosphate) and phosphate, but energy is required to synthesize ATP from ADP and phosphate. Students are not required to know the quantity of energy in kilojoules, but students should appreciate that it is sufficient for many tasks in the cell. |

| C1.2.4—Cell respiration as a system for producing ATP within the cell using energy released from carbon compounds |
|---|
| Students should appreciate that glucose and fatty acids are the principal substrates for cell respiration but that a wide range of carbon/organic compounds can be used. Students should be able to distinguish between the processes of cell respiration and gas exchange. |

| C1.2.5—Differences between anaerobic and aerobic cell respiration in humans |
|---|
| Include which respiratory substrates can be used, whether oxygen is required, relative yields of ATP, types of waste product and where the reactions occur in a cell. Students should be able to write simple word equations for both types of respiration, with glucose as the substrate. Students should appreciate that mitochondria are required for aerobic, but not anaerobic, respiration. |

| C1.2.6—Variables affecting the rate of cell respiration |
|---|
| **Application of skills:** Students should make measurements allowing for the determination of the rate of cell respiration. Students should also be able to calculate the rate of cellular respiration from raw data that they have generated experimentally or from secondary data. |

## Additional higher level

| C1.2.7—Role of NAD as a carrier of hydrogen and oxidation by removal of hydrogen during cell respiration |
|---|
| Students should understand that oxidation is a process of electron loss, so when hydrogen with an electron is removed from a substrate (dehydrogenation) the substrate has been oxidized. They should appreciate that redox reactions involve both oxidation and reduction, and that NAD is reduced when it accepts hydrogen. |

| C1.2.8—Conversion of glucose to pyruvate by stepwise reactions in glycolysis with a net yield of ATP and reduced NAD |
|---|

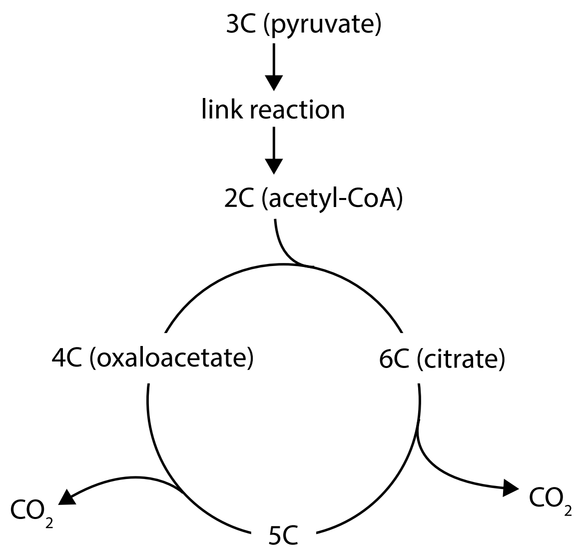
| |
|---|
| Include phosphorylation, lysis, oxidation and ATP formation. Students are not required to know the names of the intermediates, but students should know that each step in the pathway is catalysed by a different enzyme. |

| C1.2.9—Conversion of pyruvate to lactate as a means of regenerating NAD in anaerobic cell respiration |
|---|
| Regeneration of NAD allows glycolysis to continue, with a net yield of two ATP molecules per molecule of glucose. |

| C1.2.10—Anaerobic cell respiration in yeast and its use in brewing and baking |
|---|
| Students should understand that the pathways of anaerobic respiration are the same in humans and yeasts apart from the regeneration of NAD using pyruvate and therefore the final products. |

| C1.2.11—Oxidation and decarboxylation of pyruvate as a link reaction in aerobic cell respiration |
|---|
| Students should understand that lipids and carbohydrates are metabolized to form acetyl groups (2C), which are transferred by coenzyme A to the Krebs cycle. |

| C1.2.12—Oxidation and decarboxylation of acetyl groups in the Krebs cycle with a yield of ATP and reduced NAD |
|---|
| Students are required to name only the intermediates citrate (6C) and oxaloacetate (4C). Students should appreciate that citrate is produced by transfer of an acetyl group to oxaloacetate and that oxaloacetate is regenerated by the reactions of the Krebs cycle, including four oxidations and two decarboxylations. They should also appreciate that the oxidations are dehydrogenation reactions. |




| C1.2.13—Transfer of energy by reduced NAD to the electron transport chain in the mitochondrion |
|---|
| Energy is transferred when a pair of electrons is passed to the first carrier in the chain, converting reduced NAD back to NAD. Students should understand that reduced NAD comes from glycolysis, the link reaction and the Krebs cycle. |

| C1.2.14—Generation of a proton gradient by flow of electrons along the electron transport chain |
|---|

| |
|---|
| Students are not required to know the names of protein complexes. |

| C1.2.15—Chemiosmosis and the synthesis of ATP in the mitochondrion |
|---|
| Students should understand how ATP synthase couples release of energy from the proton gradient with phosphorylation of ADP. |

| C1.2.16—Role of oxygen as terminal electron acceptor in aerobic cell respiration |
|---|
| Oxygen accepts electrons from the electron transport chain and protons from the matrix of the mitochondrion, producing metabolic water and allowing continued flow of electrons along the chain. |

| C.1.2.17—Differences between lipids and carbohydrates as respiratory substrates |
|---|
| Include the higher yield of energy per gram of lipids, due to less oxygen and more oxidizable hydrogen and carbon. Also include glycolysis and anaerobic respiration occurring only if carbohydrate is the substrate, with 2C acetyl groups from the breakdown of fatty acids entering the pathway via acetyl-CoA (acetyl coenzyme A). |

## Linking questions

- In what forms is energy stored in living organisms?
- What are the consequences of respiration for ecosystems?

# C1.3 Photosynthesis

Interaction and interdependence—Molecules

**Standard level and higher level: 3 hours**

**Additional higher level: 3 hours**

## Guiding questions

- How is energy from sunlight absorbed and used in photosynthesis?
- How do abiotic factors interact with photosynthesis?

## SL and HL

| C1.3.1—Transformation of light energy to chemical energy when carbon compounds are produced in photosynthesis |
|---|
| This energy transformation supplies most of the chemical energy needed for life processes in ecosystems. |

| C1.3.2—Conversion of carbon dioxide to glucose in photosynthesis using hydrogen obtained by splitting water |
|---|
| Students should be able to write a simple word equation for photosynthesis, with glucose as the product. $$\text{carbon dioxide} + \text{water} \xrightarrow{\text{light}} \text{glucose} + \text{oxygen}$$ |

| C1.3.3—Oxygen as a by-product of photosynthesis in plants, algae and cyanobacteria |
|---|

| |
|---|
| Students should know the simple word equation for photosynthesis. They should know that the oxygen produced by photosynthesis comes from the splitting of water. |

| |
|---|
| C1.3.4—Separation and identification of photosynthetic pigments by chromatography |
| **Application of skills:** Students should be able to calculate $R_f$ values from the results of chromatographic separation of photosynthetic pigments and identify them by colour and by values. Thin-layer chromatography or paper chromatography can be used. |

| |
|---|
| C1.3.5—Absorption of specific wavelengths of light by photosynthetic pigments |
| Include excitation of electrons within a pigment molecule, transformation of light energy to chemical energy and the reason that only some wavelengths are absorbed. Students should be familiar with absorption spectra. Include both wavelengths and colours of light in the horizontal axis of absorption spectra. |

| |
|---|
| C1.3.6—Similarities and differences of absorption and action spectra |
| **Application of skills:** Students should be able to determine rates of photosynthesis from data for oxygen production and carbon dioxide consumption for varying wavelengths. They should also be able to plot this data to make an action spectrum. |

| |
|---|
| C1.3.7—Techniques for varying concentrations of carbon dioxide, light intensity or temperature experimentally to investigate the effects of limiting factors on the rate of photosynthesis |
| **Application of skills:** Students should be able to suggest hypotheses for the effects of these limiting factors and to test these through experimentation.<br>**NOS:** Hypotheses are provisional explanations that require repeated testing. During scientific research, hypotheses can either be based on theories and then tested in an experiment or be based on evidence from an experiment already carried out. Students can decide in this case whether to suggest hypotheses for the effects of limiting factors on photosynthesis before or after performing their experiments. Students should be able to identify the dependent and independent variable in an experiment. |

| |
|---|
| C1.3.8—Carbon dioxide enrichment experiments as a means of predicting future rates of photosynthesis and plant growth |
| Include enclosed greenhouse experiments and free-air carbon dioxide enrichment experiments (FACE).<br>**NOS:** Finding methods for careful control of variables is part of experimental design. This may be easier in the laboratory but some experiments can only be done in the field. Field experiments include those performed in natural ecosystems. Students should be able to identify a controlled variable in an experiment. |

## Additional higher level

| |
|---|
| C1.3.9—Photosystems as arrays of pigment molecules that can generate and emit excited electrons |
| Students should know that photosystems are always located in membranes and that they occur in cyanobacteria and in the chloroplasts of photosynthetic eukaryotes. Photosystems should be described as molecular arrays of chlorophyll and accessory pigments with a special chlorophyll as the reaction centre from which an excited electron is emitted. |

| |
|---|
| C1.3.10—Advantages of the structured array of different types of pigment molecules in a photosystem |

| |
|---|
| Students should appreciate that a single molecule of chlorophyll or any other pigment would not be able to perform any part of photosynthesis. |

| C1.3.11—Generation of oxygen by the photolysis of water in photosystem II |
|---|
| Emphasize that the protons and electrons generated by photolysis are used in photosynthesis but oxygen is a waste product. The advent of oxygen generation by photolysis had immense consequences for living organisms and geological processes on Earth. |

| C1.3.12—ATP production by chemiosmosis in thylakoids |
|---|
| Include the proton gradient, ATP synthase, and proton pumping by the chain of electron carriers. Students should know that electrons are sourced, either from photosystem I in cyclic photophosphorylation or from photosystem II in non-cyclic photophosphorylation, and then used in ATP production. |

| C1.3.13—Reduction of NADP by photosystem I |
|---|
| Students should appreciate that NADP is reduced by accepting two electrons that have come from photosystem I. It also accepts a hydrogen ion that has come from the stroma. The paired terms "NADP and reduced NADP" or "$NADP^+$ and NADPH" should be paired consistently. |

| C1.3.14—Thylakoids as systems for performing the light-dependent reactions of photosynthesis |
|---|
| Students should appreciate where photolysis of water, synthesis of ATP by chemiosmosis and reduction of NADP occur in a thylakoid. |

| C1.3.15—Carbon fixation by Rubisco |
|---|
| Students should know the names of the substrates RuBP and $CO_2$ and the product glycerate 3-phosphate. They should also know that Rubisco is the most abundant enzyme on Earth and that high concentrations of it are needed in the stroma of chloroplasts because it works relatively slowly and is not effective in low carbon dioxide concentrations. |

| C1.3.16—Synthesis of triose phosphate using reduced NADP and ATP |
|---|
| Students should know that glycerate-3-phosphate (GP) is converted into triose phosphate (TP) using NADPH and ATP. |

| C1.3.17—Regeneration of RuBP in the Calvin cycle using ATP |
|---|
| Students are not required to know details of the individual reactions, but students should understand that five molecules of triose phosphate are converted to three molecules of RuBP, allowing the Calvin cycle to continue. If glucose is the product of photosynthesis, five-sixths of all the triose phosphate produced must be converted back to RuBP. |

| C1.3.18—Synthesis of carbohydrates, amino acids and other carbon compounds using the products of the Calvin cycle and mineral nutrients |
|---|
| Students are not required to know details of metabolic pathways, but students should understand that all of the carbon in compounds in photosynthesizing organisms is fixed in the Calvin cycle and that carbon compounds other than glucose are made by metabolic pathways that can be traced back to an intermediate in the cycle. |

| C1.3.19—Interdependence of the light-dependent and light-independent reactions |
|---|

| |
|---|
| Students should understand how a lack of light stops light-dependent reactions and how a lack of $CO_2$ prevents photosystem II from functioning. |

## Linking questions

- What are the consequences of photosynthesis for ecosystems?
- What are the functions of pigments in living organisms?

# C2.1 Chemical signalling

Interaction and interdependence—Cells

**Additional higher level: 4 hours**

## Guiding questions

- How do cells distinguish between the many different signals that they receive?
- What interactions occur inside animal cells in response to chemical signals?

## Additional higher level

*Note: There is no SL content in C2.1.*

| C2.1.1—Receptors as proteins with binding sites for specific signalling chemicals |
|---|
| Students should use the term "ligand" for the signalling chemical. |

| C.2.1.2—Cell signalling by bacteria in quorum sensing |
|---|
| Include the example of bioluminescence in the marine bacterium *Vibrio fischeri*. |

| C2.1.3—Hormones, neurotransmitters, cytokines and calcium ions as examples of functional categories of signalling chemicals in animals |
|---|
| Students should appreciate the differences between these categories. |

| C2.1.4—Chemical diversity of hormones and neurotransmitters |
|---|
| Consider reasons for a wide range of chemical substances being used as signalling chemicals. Include amines, proteins and steroids as chemical groups of hormones. A range of substances can serve as neurotransmitters including amino acids, peptides, amines and nitrous oxide. |

| C2.1.5—Localized and distant effects of signalling molecules |
|---|
| Contrasts can be drawn between hormones transported by the blood system and neurotransmitters that diffuse across a synaptic gap. |

| C2.1.6—Differences between transmembrane receptors in a plasma membrane and intracellular receptors in the cytoplasm or nucleus |
|---|
| Include distribution of hydrophilic or hydrophobic amino acids in the receptor and whether the signalling chemical penetrates the cell or remains outside. |

| C2.1.7—Initiation of signal transduction pathways by receptors |
|---|
| Students should understand that the binding of a signalling chemical to a receptor sets off a sequence of responses within the cell. |

| C2.1.8—Transmembrane receptors for neurotransmitters and changes to membrane potential |
| --- |
| Use the acetylcholine receptor as an example. Binding to a receptor causes the opening of an ion channel in the receptor that allows positively charged ions to diffuse into the cell. This changes the voltage across the plasma membrane, which may cause other changes. |

| C2.1.9—Transmembrane receptors that activate G proteins |
| --- |
| Students should understand how G protein-coupled receptors convey a signal into cells. They should appreciate that there are many such receptors in humans. |

| C2.1.10—Mechanism of action of epinephrine (adrenaline) receptors |
| --- |
| Include the roles of a G protein and cyclic AMP (cAMP) as the second messenger.<br>**NOS:** Students should be aware that naming conventions are an example of international cooperation in science for mutual benefit. Both "adrenaline" and "epinephrine" were coined by researchers and are based on production of the hormone by the adrenal gland; "adrenaline" comes from Latin *ad* = at and *ren* = kidney and "epinephrine" comes from old Greek *epi* = above and *nephros* = kidney, respectively. Unusually, these two terms persist in common use in different parts of the world. |

| C2.1.11—Transmembrane receptors with tyrosine kinase activity |
| --- |
| Use the protein hormone insulin as an example. Limit this to binding of insulin to a receptor in the plasma membrane, causing phosphorylation of tyrosine inside a cell. This leads to a sequence of reactions ending with movement of vesicles containing glucose transporters to the plasma membrane. |

| C2.1.12—Intracellular receptors that affect gene expression |
| --- |
| Use the steroid hormones oestradiol, progesterone and testosterone as examples. Students should understand that the signalling chemical binds to a site on a receptor, activating it. The activated receptor binds to specific DNA sequences to promote gene transcription. |

| C2.1.13—Effects of the hormones oestradiol and progesterone on target cells |
| --- |
| For oestradiol, limit to cells in the hypothalamus that secrete gonadotropin-releasing hormone. For progesterone, limit to cells in the endometrium. |

| C2.1.14—Regulation of cell signalling pathways by positive and negative feedback |
| --- |
| Limit to an understanding of the difference between these two forms of regulation and a brief outline of one example of each. |

## Linking questions

- What patterns exist in communication in biological systems?
- In what ways is negative feedback evident at all levels of biological organization?

# C2.2 Neural signalling

Interaction and interdependence—Cells

**Standard level and higher level: 3 hours**

**Additional higher level: 3 hours**

## Guiding questions

- How are electrical signals generated and moved within neurons?
- How can neurons interact with other cells?

## SL and HL

| C2.2.1—Neurons as cells within the nervous system that carry electrical impulses |
|---|
| Students should understand that cytoplasm and a nucleus form the cell body of a neuron, with elongated nerve fibres of varying length projecting from it. An axon is a long single fibre. Dendrites are multiple shorter fibres. Electrical impulses are conducted along these fibres. |

| C2.2.2—Generation of the resting potential by pumping to establish and maintain concentration gradients of sodium and potassium ions |
|---|
| Students should understand how energy from ATP drives the pumping of sodium and potassium ions in opposite directions across the plasma membrane of neurons. They should understand the concept of a membrane polarization and a membrane potential and also reasons that the resting potential is negative. |

| C2.2.3—Nerve impulses as action potentials that are propagated along nerve fibres |
|---|
| Students should appreciate that a nerve impulse is electrical because it involves movement of positively charged ions. |

| C2.2.4—Variation in the speed of nerve impulses |
|---|
| Compare the speed of transmission in giant axons of squid and smaller non-myelinated nerve fibres. Also compare the speed in myelinated and non-myelinated fibres.<br>**Application of skills:** Students should be able to describe negative and positive correlations and apply correlation coefficients as a mathematical tool to determine the strength of these correlations. Students should also be able to apply the coefficient of determination ($R^2$) to evaluate the degree to which variation in the independent variable explains the variation in the dependent variable. For example, conduction speed of nerve impulses is negatively correlated with animal size, but positively correlated with axon diameter. |

| C2.2.5—Synapses as junctions between neurons and between neurons and effector cells |
|---|
| Limit to chemical synapses, not electrical, and these can simply be referred to as synapses. Students should understand that a signal can only pass in one direction across a typical synapse. |

| C2.2.6—Release of neurotransmitters from a presynaptic membrane |
|---|
| Include uptake of calcium in response to depolarization of a presynaptic membrane and its action as a signalling chemical inside a neuron. |

| C2.2.7—Generation of an excitatory postsynaptic potential |
|---|
| Include diffusion of neurotransmitters across the synaptic cleft and binding to transmembrane receptors. Use acetylcholine as an example. Students should appreciate that this neurotransmitter exists in many types of synapse including neuromuscular junctions. |

## Additional higher level

| C2.2.8—Depolarization and repolarization during action potentials |
|---|

| |
|---|
| Include the action of voltage-gated sodium and potassium channels and the need for a threshold potential to be reached for sodium channels to open. |

| C2.2.9—Propagation of an action potential along a nerve fibre/axon as a result of local currents |
|---|
| Students should understand how diffusion of sodium ions both inside and outside an axon can cause the threshold potential to be reached. |

| C2.2.10—Oscilloscope traces showing resting potentials and action potentials |
|---|
| **Application of skills:** Students should interpret the oscilloscope trace in relation to cellular events. The number of impulses per second can be measured. |

| C2.2.11—Saltatory conduction in myelinated fibres to achieve faster impulses |
|---|
| Students should understand that ion pumps and channels are clustered at nodes of Ranvier and that an action potential is propagated from node to node. |

| C2.2.12—Effects of exogenous chemicals on synaptic transmission |
|---|
| Use neonicotinoids as an example of a pesticide that blocks synaptic transmission, and cocaine as an example of a drug that blocks reuptake of the neurotransmitter. |

| C2.2.13—Inhibitory neurotransmitters and generation of inhibitory postsynaptic potentials |
|---|
| Students should know that the postsynaptic membrane becomes hyperpolarized. |

| C2.2.14—Summation of the effects of excitatory and inhibitory neurotransmitters in a postsynaptic neuron |
|---|
| Multiple presynaptic neurons interact with all-or-nothing consequences in terms of postsynaptic depolarization. |

| C2.2.15—Perception of pain by neurons with free nerve endings in the skin |
|---|
| Students should know that these nerve endings have channels for positively charged ions, which open in response to a stimulus such as high temperature, acid, or certain chemicals such as capsaicin in chilli peppers. Entry of positively charged ions causes the threshold potential to be reached and nerve impulses then pass through the neurons to the brain, where pain is perceived. |

| C2.2.16—Consciousness as a property that emerges from the interaction of individual neurons in the brain |
|---|
| Emergent properties such as consciousness are another example of the consequences of interaction. |

## Linking questions

- In what ways are biological systems regulated?
- How is the structure of specialized cells related to function?

# C3.1 Integration of body systems

Interaction and interdependence—Organisms

**Standard level and higher level: 5 hours**

**Additional higher level: 2 hours**

## Guiding questions

- What are the roles of nerves and hormones in integration of body systems?
- What are the roles of feedback mechanisms in regulation of body systems?

## SL and HL

| C3.1.1—System integration |
|---|
| This is a necessary process in living systems. Coordination is needed for component parts of a system to collectively perform an overall function. |

| C3.1.2—Cells, tissues, organs and body systems as a hierarchy of subsystems that are integrated in a multicellular living organism |
|---|
| Students should appreciate that this integration is responsible for emergent properties. For example, a cheetah becomes an effective predator by integration of its body systems. |

| C3.1.3—Integration of organs in animal bodies by hormonal and nervous signalling and by transport of materials and energy |
|---|
| Distinguish between the roles of the nervous system and endocrine system in sending messages. Using examples, emphasize the role of the blood system in transporting materials between organs. |

| C3.1.4—The brain as a central information integration organ |
|---|
| Limit to the role of the brain in processing information combined from several inputs and in learning and memory. Students are not required to know details such as the role of slow-acting neurotransmitters. |

| C3.1.5—The spinal cord as an integrating centre for unconscious processes |
|---|
| Students should understand the difference between conscious and unconscious processes. |

| C3.1.6—Input to the spinal cord and cerebral hemispheres through sensory neurons |
|---|
| Students should understand that sensory neurons convey messages from receptor cells to the central nervous system. |

| C3.1.7—Output from the cerebral hemispheres to muscles through motor neurons |
|---|
| Students should understand that muscles are stimulated to contract. |

| C3.1.8—Nerves as bundles of nerve fibres of both sensory and motor neurons |
|---|
| Use a transverse section of a nerve to show the protective sheath, and myelinated and unmyelinated nerve fibres. |

| C3.1.9—Pain reflex arcs as an example of involuntary responses with skeletal muscle as the effector |
|---|
| Use the example of a reflex arc with a single interneuron in the grey matter of the spinal cord and a free sensory nerve ending in a sensory neuron as a pain receptor in the hand. |

| C3.1.10—Role of the cerebellum in coordinating skeletal muscle contraction and balance |
|---|
| Limit to a general understanding of the role of the cerebellum in the overall control of movements of the body. |

| C3.1.11—Modulation of sleep patterns by melatonin secretion as a part of circadian rhythms |
| --- |
| Students should understand the diurnal pattern of melatonin secretion by the pineal gland and how it helps to establish a cycle of sleeping and waking. |

| C3.1.12—Epinephrine (adrenaline) secretion by the adrenal glands to prepare the body for vigorous activity |
| --- |
| Consider the widespread effects of epinephrine in the body and how these effects facilitate intense muscle contraction. |

| C3.1.13—Control of the endocrine system by the hypothalamus and pituitary gland |
| --- |
| Students should have a general understanding, but are not required to know differences between mechanisms used in the anterior and posterior pituitary. |

| C3.1.14—Feedback control of heart rate following sensory input from baroreceptors and chemoreceptors |
| --- |
| Include the location of baroreceptors and chemoreceptors.<br>Baroreceptors monitor blood pressure. Chemoreceptors monitor blood pH and concentrations of oxygen and carbon dioxide. Students should understand the role of the medulla in coordinating responses and sending nerve impulses to the heart to change the heart's stroke volume and heart rate. |

| C3.1.15—Feedback control of ventilation rate following sensory input from chemoreceptors |
| --- |
| Students should understand the causes of pH changes in the blood. These changes are monitored by chemoreceptors in the brainstem and lead to the control of ventilation rate using signals to the diaphragm and intercostal muscles. |

| C3.1.16—Control of peristalsis in the digestive system by the central nervous system and enteric nervous system |
| --- |
| Limit to initiation of swallowing of food and egestion of faeces being under voluntary control by the central nervous system (CNS) but peristalsis between these points in the digestive system being under involuntary control by the enteric nervous system (ENS). The action of the ENS ensures passage of material through the gut is coordinated. |

## Additional higher level

| C3.1.17—Observations of tropic responses in seedlings |
| --- |
| **Application of skills:** Students should gather qualitative data, using diagrams to record their observations of seedlings illustrating tropic responses. They could also collect quantitative data by measuring the angle of curvature of seedlings.<br>**NOS:** Students should be able to distinguish between qualitative and quantitative observations and understand factors that limit the precision of measurements and their accuracy. Strategies for increasing the precision, accuracy and reliability of measurements in tropism experiments could be considered. |

| C3.1.18—Positive phototropism as a directional growth response to lateral light in plant shoots |
| --- |
| Students are not required to know specific examples of other tropisms. |

| C3.1.19—Phytohormones as signalling chemicals controlling growth, development and response to stimuli in plants |
| --- |

| |
|---|
| Students should appreciate that a variety of chemicals are used as phytohormones in plants. |

| C3.1.20—Auxin efflux carriers as an example of maintaining concentration gradients of phytohormones |
|---|
| Auxin can diffuse freely into plant cells but not out of them. Auxin efflux carriers can be positioned in a cell membrane on one side of the cell. If all cells coordinate to concentrate these carriers on the same side, auxin is actively transported from cell to cell through the plant tissue and becomes concentrated in part of the plant. |

| C3.1.21—Promotion of cell growth by auxin |
|---|
| Include auxin's promotion of hydrogen ion secretion into the apoplast, acidifying the cell wall and thus loosening cross links between cellulose molecules and facilitating cell elongation. Concentration gradients of auxin cause the differences in growth rate needed for phototropism. |

| C3.1.22—Interactions between auxin and cytokinin as a means of regulating root and shoot growth |
|---|
| Students should understand that root tips produce cytokinin, which is transported to shoots, and shoot tips produce auxin, which is transported to roots. Interactions between these phytohormones help to ensure that root and shoot growth are integrated. |

| C3.1.23—Positive feedback in fruit ripening and ethylene production |
|---|
| Ethylene (IUPAC name: ethene) stimulates the changes in fruits that occur during ripening, and ripening also stimulates increased production of ethylene. Students should understand the benefit of this positive feedback mechanism in ensuring that fruit ripening is rapid and synchronized. |

## Linking questions

- What are examples of branching (dendritic) and net-like (reticulate) patterns of organization?
- What are the consequences of positive feedback in biological systems?

# C3.2 Defence against disease

Interaction and interdependence—Organisms

**Standard level and higher level: 5 hours**

## Guiding questions

- How do body systems recognize pathogens and fight infections?
- What factors influence the incidence of disease in populations?

## SL and HL

| C3.2.1—Pathogens as the cause of infectious diseases |
|---|
| Students should understand that a broad range of disease-causing organisms can infect humans. A disease-causing organism is known as a pathogen, although typically the term is reserved for viruses, bacteria, fungi and protists. Archaea are not known to cause any diseases in humans.<br>**NOS:** Students should be aware that careful observation can lead to important progress. For example, careful observations during 19th-century epidemics of childbed fever (due to an infection after childbirth) in Vienna and cholera in London led to breakthroughs in the control of infectious disease. |

| C3.2.2—Skin and mucous membranes as a primary defence |
|---|

| |
|---|
| The skin acts as both a physical and chemical barrier to pathogens. Students are not required to draw or label diagrams of skin. |

| C3.2.3—Sealing of cuts in skin by blood clotting |
|---|
| Include release of clotting factors from platelets and the subsequent cascade pathway that results in rapid conversion of fibrinogen to fibrin by thrombin and trapping of erythrocytes to form a clot. No further details are required. |

| C3.2.4—Differences between the innate immune system and the adaptive immune system |
|---|
| Include the idea that the innate system responds to broad categories of pathogen and does not change during an organism's life whereas the adaptive system responds in a specific way to particular pathogens and builds up a memory of pathogens encountered, so the immune response becomes more effective. Students are not required to know any components of the innate immune system other than phagocytes. |

| C3.2.5—Infection control by phagocytes |
|---|
| Include amoeboid movement from blood to sites of infection, where phagocytes recognize pathogens, engulf them by endocytosis and digest them using enzymes from lysosomes. |

| C3.2.6—Lymphocytes as cells in the adaptive immune system that cooperate to produce antibodies |
|---|
| Students should understand that lymphocytes both circulate in the blood and are contained in lymph nodes. They should appreciate that an individual has a very large number of B-lymphocytes that each make a specific type of antibody. |

| C3.2.7—Antigens as recognition molecules that trigger antibody production |
|---|
| Students should appreciate that most antigens are glycoproteins or other proteins and that they are usually located on the outer surfaces of pathogens. Antigens on the surface of erythrocytes may stimulate antibody production if transfused into a person with a different blood group. |

| C3.2.8—Activation of B-lymphocytes by helper T-lymphocytes |
|---|
| Students should understand that there are antigen-specific B-cells and helper T-cells. B-cells produce antibodies and become memory cells only when they have been activated. Activation requires both direct interaction with the specific antigen and contact with a helper T-cell that has also become activated by the same type of antigen. |

| C3.2.9—Multiplication of activated B-lymphocytes to form clones of antibody-secreting plasma cells |
|---|
| There are relatively small numbers of B-cells that respond to a specific antigen. To produce sufficient quantities of antibody, activated B-cells first divide by mitosis to produce large numbers of plasma B-cells that are capable of producing the same type of antibody. |

| C3.2.10—Immunity as a consequence of retaining memory cells |
|---|
| Students should understand that immunity is the ability to eliminate an infectious disease from the body. It is due to the long-term survival of lymphocytes that are capable of making the specific antibodies needed to fight the infection. These are memory cells. |

| C3.2.11—Transmission of HIV in body fluids |
|---|
| Include examples of the mechanisms of HIV (human immunodeficiency virus) transmission. |

| C3.2.12—Infection of lymphocytes by HIV with AIDS as a consequence |
| --- |
| Students should understand that only certain types of lymphocyte are infected and killed, but that a reduction in these lymphocytes limits the ability to produce antibodies and fight opportunistic infections. |

| C3.2.13—Antibiotics as chemicals that block processes occurring in bacteria but not in eukaryotic cells |
| --- |
| Include reasons that antibiotics fail to control infection with viruses. |

| C3.2.14—Evolution of resistance to several antibiotics in strains of pathogenic bacteria |
| --- |
| Students should understand that careful use of antibiotics is necessary to slow the emergence of multiresistant bacteria.<br>**NOS:** Students should recognize that the development of new techniques can lead to new avenues of research; for example, the recent technique of searching chemical libraries is yielding new antibiotics. |

| C3.2.15—Zoonoses as infectious diseases that can transfer from other species to humans |
| --- |
| Illustrate the prevalence of zoonoses as infectious diseases in humans and their varied modes of infection with several examples including tuberculosis, rabies and Japanese encephalitis. Include COVID-19 as an infectious disease that has recently transferred from another species, with profound consequences for humans. |

| C3.2.16—Vaccines and immunization |
| --- |
| Students should understand that vaccines contain antigens, or nucleic acids (DNA or RNA) with sequences that code for antigens, and that they stimulate the development of immunity to a specific pathogen without causing the disease. |

| C3.2.17—Herd immunity and the prevention of epidemics |
| --- |
| Students should understand how members of a population are interdependent in building herd immunity. If a sufficient percentage of a population is immune to a disease, transmission is greatly impeded.<br>**NOS:** Scientists publish their research so that other scientists can evaluate it. The media often report on the research while evaluation is still happening, and consumers need to be aware of this. Vaccines are tested rigorously and the risks of side effects are minimal but not nil. The distinction between pragmatic truths and certainty is poorly understood. |

| C3.2.18—Evaluation of data related to the COVID-19 pandemic |
| --- |
| **Application of skills:** Students should have the opportunity to calculate both percentage difference and percentage change. |

*Note: There is no additional higher level content in C3.2.*

## Linking questions

- How do animals protect themselves from threats?
- How can false-positive and false-negative results be avoided in diagnostic tests?

# C4.1 Populations and communities

Interaction and interdependence—Ecosystems

**Standard level and higher level: 5 hours**

## Guiding questions

- How do interactions between organisms regulate sizes of populations in a community?
- What interactions within a community make its populations interdependent?

## SL and HL

| C4.1.1—Populations as interacting groups of organisms of the same species living in an area |
|---|
| Students should understand that members of a population normally breed and that reproductive isolation is used to distinguish one population of a species from another. |

| C4.1.2—Estimation of population size by random sampling |
|---|
| Students should understand reasons for estimating population size, rather than counting every individual, and the need for randomness in sampling procedures.<br>**NOS:** Students should be aware that random sampling, instead of measuring an entire population, inevitably results in sampling error. In this case the difference between the estimate of population size and the true size of the whole population is the sampling error. |

| C4.1.3—Random quadrat sampling to estimate population size for sessile organisms |
|---|
| Both sessile animals and plants, where the numbers of individuals can be counted, are suitable.<br>**Application of skills:** Students should understand what is indicated by the standard deviation of a mean. Students do not need to memorize the formula used to calculate this. In this example, the standard deviation of the mean number of individuals per quadrat could be determined using a calculator to give a measure of the variation and how evenly the population is spread. |

| C4.1.4—Capture–mark–release–recapture and the Lincoln index to estimate population size for motile organisms |
|---|
| **Application of skills:** Students should use the Lincoln index to estimate population size.<br>Population size estimate = $M \times \frac{N}{R}$, where $M$ is the number of individuals caught and marked initially, $N$ is the total number of individuals recaptured and $R$ is the number of marked individuals recaptured.<br>Students should understand the assumptions made when using this method. |

| C4.1.5—Carrying capacity and competition for limited resources |
|---|
| A simple definition of carrying capacity is sufficient, with some examples of resources that may limit carrying capacity. |

| C4.1.6—Negative feedback control of population size by density-dependent factors |
|---|
| Numbers of individuals in a population may fluctuate due to density-independent factors, but density-dependent factors tend to push the population back towards the carrying capacity. In addition to competition for limited resources, include the increased risk of predation and the transfer of pathogens or pests in dense populations. |

| C4.1.7—Population growth curves |
|---|
| Students should study at least one case study in an ecosystem. Students should understand reasons for exponential growth in the initial phases. A lag phase is not expected as a part of sigmoid population growth.<br>**NOS:** The curve represents an idealized graphical model. Students should recognize that models are often simplifications of complex systems. |

**Application of skills:** Students should test the growth of a population against the model of exponential growth using a graph with a logarithmic scale for size of population on the vertical axis and a non-logarithmic scale for time on the horizontal axis.

C4.1.8—Modelling of the sigmoid population growth curve

**Application of skills:** Students should collect data regarding population growth. Yeast and duckweed are recommended but other organisms that proliferate under experimental conditions could be used.

C4.1.9—Competition versus cooperation in intraspecific relationships

Include reasons for intraspecific competition within a population. Also include a range of real examples of competition and cooperation.

C4.1.10—A community as all of the interacting organisms in an ecosystem

Communities comprise all the populations in an area including plants, animals, fungi and bacteria.

C4.1.11—Herbivory, predation, interspecific competition, mutualism, parasitism and pathogenicity as categories of interspecific relationship within communities

Include each type of ecological interaction using at least one example.

C4.1.12—Mutualism as an interspecific relationship that benefits both species

Include these examples: root nodules in Fabaceae (legume family), mycorrhizae in Orchidaceae (orchid family) and zooxanthellae in hard corals. In each case include the benefits to both organisms.

*Note: When students are referring to organisms in an examination, either the common name or the scientific name is acceptable.*

C4.1.13—Resource competition between endemic and invasive species

Choose one local example to illustrate competitive advantage over endemic species in resource acquisition as the basis for an introduced species becoming invasive.

C4.1.14—Tests for interspecific competition

Interspecific competition is indicated but not proven if one species is more successful in the absence of another. Students should appreciate the range of possible approaches to research: laboratory experiments, field observations by random sampling and field manipulation by removal of one species.

**NOS:** Students should recognize that hypotheses can be tested by both experiments and observations and should understand the difference between them.

C4.1.15—Use of the chi-squared test for association between two species

**Application of skills:** Students should be able to apply chi-squared tests on the presence/absence of two species in several sampling sites, exploring the differences or similarities in distribution. This may provide evidence for interspecific competition.

C4.1.16—Predator–prey relationships as an example of density-dependent control of animal populations

Include a real case study.

C4.1.17—Top-down and bottom-up control of populations in communities

| |
|---|
| Students should understand that both of these types of control are possible, but one or the other is likely to be dominant in a community. |

| C4.1.18—Allelopathy and secretion of antibiotics |
|---|
| These two processes are similar in that a chemical substance is released into the environment to deter potential competitors. Include one specific example of each—where possible, choose a local example. |

*Note: There is no additional higher level content in C4.1.*

## Linking questions

- What are the benefits of models in studying biology?
- What factors can limit capacity in biological systems?

# C4.2 Transfers of energy and matter

Interaction and interdependence—Ecosystems

**Standard level and higher level: 5 hours**

## Guiding questions

- What is the reason matter can be recycled in ecosystems but energy cannot?
- How is the energy that is lost by each group of organisms in an ecosystem replaced?

## SL and HL

| C4.2.1—Ecosystems as open systems in which both energy and matter can enter and exit |
|---|
| Students should know that in closed systems only energy is able to pass in and out. |

| C4.2.2—Sunlight as the principal source of energy that sustains most ecosystems |
|---|
| Include exceptions such as ecosystems in caves and below the levels of light penetration in oceans.<br>**NOS:** Laws in science are generalized principles, or rules of thumb, formulated to describe patterns observed in nature. Unlike theories, they do not offer explanations, but describe phenomena. Like theories, they can be used to make predictions. Students should be able to outline the features of useful generalizations. |

| C4.2.3—Flow of chemical energy through food chains |
|---|
| Students should appreciate that chemical energy passes to a consumer as it feeds on an organism that is the previous stage in a food chain. |

| C4.2.4—Construction of food chains and food webs to represent feeding relationships in a community |
|---|
| Represent relationships in a local community if possible. Arrows indicate the direction of transfer of energy and biomass. |

| C4.2.5—Supply of energy to decomposers as carbon compounds in organic matter coming from dead organisms |
|---|
| Include faeces, dead parts of organisms and dead whole organisms. |

| C4.2.6—Autotrophs as organisms that use external energy sources to synthesize carbon compounds from simple inorganic substances |
|---|
| Students should understand that energy is required for carbon fixation and for the anabolic reactions that build macromolecules. |

| C4.2.7—Use of light as the external energy source in photoautotrophs and oxidation reactions as the energy source in chemoautotrophs |
|---|
| Students should understand that oxidation reactions release energy, so they are useful in living organisms. Include iron-oxidizing bacteria as an example of a chemoautotroph. |

| C4.2.8—Heterotrophs as organisms that use carbon compounds obtained from other organisms to synthesize the carbon compounds that they require |
|---|
| Students should appreciate that complex carbon compounds such as proteins and nucleic acids are digested either externally or internally and are then assimilated by constructing the carbon compounds that are required. |

| C4.2.9—Release of energy in both autotrophs and heterotrophs by oxidation of carbon compounds in cell respiration |
|---|
| Students are not required to be familiar with photoheterotrophs. |

| C4.2.10—Classification of organisms into trophic levels |
|---|
| Use the terms "producer", "primary consumer", "secondary consumer" and "tertiary consumer". Students should appreciate that many organisms have a varied diet and occupy different trophic levels in different food chains. |

| C4.2.11—Construction of energy pyramids |
|---|
| **Application of skills:** Students should use research data from specific ecosystems to represent energy transfer and energy losses between trophic levels in food chains. |

| C4.2.12—Reductions in energy availability at each successive stage in food chains due to large energy losses between trophic levels |
|---|
| Decomposers and detritus feeders are not usually considered to be part of food chains. However, students should understand the role of these organisms in energy transformations in food chains. Consider the causes of energy loss. |

| C4.2.13—Heat loss to the environment in both autotrophs and heterotrophs due to conversion of chemical energy to heat in cell respiration |
|---|
| Include the idea that energy transfers are not 100% efficient so heat is produced both when ATP is produced in cell respiration and when it is used in cells. |

| C4.2.14—Restrictions on the number of trophic levels in ecosystems due to energy losses |
|---|
| At each successive stage in food chains there are fewer organisms or smaller organisms. There is therefore less biomass, but the energy content per unit mass is not reduced. |

| C4.2.15—Primary production as accumulation of carbon compounds in biomass by autotrophs |
|---|

| |
|---|
| The units should be mass (of carbon) per unit area per unit time and are usually g $m^{-2}$ $yr^{-1}$. Students should understand that biomes vary in their capacity to accumulate biomass. Biomass accumulates when autotrophs and heterotrophs grow or reproduce. |

| C4.2.16—Secondary production as accumulation of carbon compounds in biomass by heterotrophs |
|---|
| Students should understand that, due to loss of biomass when carbon compounds are converted to carbon dioxide and water in cell respiration, secondary production is lower than primary production in an ecosystem. |

| C4.2.17—Constructing carbon cycle diagrams |
|---|
| Students should illustrate with a diagram how carbon is recycled in ecosystems by photosynthesis, feeding and respiration. |

| C4.2.18—Ecosystems as carbon sinks and carbon sources |
|---|
| If photosynthesis exceeds respiration there is a net uptake of carbon dioxide and if respiration exceeds photosynthesis there is a net release of carbon dioxide. |

| C4.2.19—Release of carbon dioxide into the atmosphere during combustion of biomass, peat, coal, oil and natural gas |
|---|
| Students should appreciate that these carbon sinks vary in date of formation and that combustion following lightning strikes sometimes happens naturally but that human activities have greatly increased combustion rates. |

| C4.2.20—Analysis of the Keeling Curve in terms of photosynthesis, respiration and combustion |
|---|
| Include analysis of both the annual fluctuations and the long-term trend. |

| C4.2.21—Dependence of aerobic respiration on atmospheric oxygen produced by photosynthesis, and of photosynthesis on atmospheric carbon dioxide produced by respiration |
|---|
| The fluxes involved per year are huge, so this is a major interaction between autotrophs and heterotrophs. |

| C4.2.22—Recycling of all chemical elements required by living organisms in ecosystems |
|---|
| Students should appreciate that all elements used by living organisms, not just carbon, are recycled and that decomposers play a key role. Students are not required to know details of the nitrogen cycle and other nutrient cycles. |

*Note: There is no additional higher level content in C4.2.*

## Linking questions

- What are the direct and indirect consequences of rising carbon dioxide levels in the atmosphere?
- How does the transformation of energy from one form to another make biological processes possible?

# D1.1 DNA replication

Continuity and change—Molecules

**Standard level and higher level: 2 hours**

**Additional higher level: 2 hours**

## Guiding questions

- How is new DNA produced?
- How has knowledge of DNA replication enabled applications in biotechnology?

## SL and HL

| D1.1.1—DNA replication as production of exact copies of DNA with identical base sequences |
|---|
| Students should appreciate that DNA replication is required for reproduction and for growth and tissue replacement in multicellular organisms. |

| D1.1.2—Semi-conservative nature of DNA replication and role of complementary base pairing |
|---|
| Students should understand how these processes allow a high degree of accuracy in copying base sequences. |

| D1.1.3—Role of helicase and DNA polymerase in DNA replication |
|---|
| Limit to the role of helicase in unwinding and breaking hydrogen bonds between DNA strands and the general role of DNA polymerase. |

| D1.1.4—Polymerase chain reaction and gel electrophoresis as tools for amplifying and separating DNA |
|---|
| Students should understand the use of primers, temperature changes and *Taq* polymerase in the polymerase chain reaction (PCR) and the basis of separation of DNA fragments in gel electrophoresis. |

| D1.1.5—Applications of polymerase chain reaction and gel electrophoresis |
|---|
| Students should appreciate the broad range of applications, including DNA profiling for paternity and forensic investigations.<br>**NOS:** Reliability is enhanced by increasing the number of measurements in an experiment or test. In DNA profiling, increasing the number of markers used reduces the probability of a false match. |

## Additional higher level

| D1.1.6—Directionality of DNA polymerases |
|---|
| Students should understand the difference between the 5' and 3' terminals of strands of nucleotides and that DNA polymerases add the 5' of a DNA nucleotide to the 3' end of a strand of nucleotides. |

| D1.1.7—Differences between replication on the leading strand and the lagging strand |
|---|
| Include the terms "continuous", "discontinuous" and "Okazaki fragments". Students should know that replication has to be initiated with RNA primer only once on the leading strand but repeatedly on the lagging strand. |

| D1.1.8—Functions of DNA primase, DNA polymerase I, DNA polymerase III and DNA ligase in replication |
|---|
| Limit to the prokaryotic system. |

| D1.1.9—DNA proofreading |
|---|
| Limit to the action of DNA polymerase III in removing any nucleotide from the 3' terminal with a mismatched base, followed by replacement with a correctly matched nucleotide. |

## Linking questions

- How is genetic continuity ensured between generations?
- What biological mechanisms rely on directionality?

# D1.2 Protein synthesis

Continuity and change—Molecules

**Standard level and higher level: 3 hours**

**Additional higher level: 3 hours**

## Guiding questions

- How does a cell produce a sequence of amino acids from a sequence of DNA bases?
- How is the reliability of protein synthesis ensured?

## SL and HL

| D1.2.1—Transcription as the synthesis of RNA using a DNA template |
|---|
| Students should understand the roles of RNA polymerase in this process. |

| D1.2.2—Role of hydrogen bonding and complementary base pairing in transcription |
|---|
| Include the pairing of adenine (A) on the DNA template strand with uracil (U) on the RNA strand. |

| D1.2.3—Stability of DNA templates |
|---|
| Single DNA strands can be used as a template for transcribing a base sequence, without the DNA base sequence changing. In somatic cells that do not divide, such sequences must be conserved throughout the life of a cell. |

| D1.2.4—Transcription as a process required for the expression of genes |
|---|
| Limit to understanding that not all genes in a cell are expressed at any given time and that transcription, being the first stage of gene expression, is a key stage at which expression of a gene can be switched on and off. |

| D1.2.5—Translation as the synthesis of polypeptides from mRNA |
|---|
| The base sequence of mRNA is translated into the amino acid sequence of a polypeptide. |

| D1.2.6—Roles of mRNA, ribosomes and tRNA in translation |
|---|
| Students should know that mRNA binds to the small subunit of the ribosome and that two tRNAs can bind simultaneously to the large subunit. |

| D1.2.7—Complementary base pairing between tRNA and mRNA |
|---|
| Include the terms “codon” and “anticodon”. |

| D1.2.8—Features of the genetic code |
|---|
| Students should understand the reasons for a triplet code. Students should use and understand the terms “degeneracy” and “universality”. |

| D1.2.9—Using the genetic code expressed as a table of mRNA codons |
| --- |
| Students should be able to deduce the sequence of amino acids coded by an mRNA strand. |

| D1.2.10—Stepwise movement of the ribosome along mRNA and linkage of amino acids by peptide bonding to the growing polypeptide chain |
| --- |
| Focus on elongation of the polypeptide, rather than on initiation and termination. |

| D1.2.11—Mutations that change protein structure |
| --- |
| Include an example of a point mutation affecting protein structure. |

## Additional higher level

| D1.2.12—Directionality of transcription and translation |
| --- |
| Students should understand what is meant by 5' to 3' transcription and 5' to 3' translation. |

| D1.2.13—Initiation of transcription at the promoter |
| --- |
| Consider transcription factors that bind to the promoter as an example. However, students are not required to name the transcription factors. |

| D1.2.14—Non-coding sequences in DNA do not code for polypeptides |
| --- |
| Limit examples to regulators of gene expression, introns, telomeres and genes for rRNAs and tRNAs in eukaryotes. |

| D1.2.15—Post-transcriptional modification in eukaryotic cells |
| --- |
| Include removal of introns and splicing together of exons to form mature mRNA and also the addition of 5' caps and 3' polyA tails to stabilize mRNA transcripts. |

| D1.2.16—Alternative splicing of exons to produce variants of a protein from a single gene |
| --- |
| Students are only expected to understand that splicing together different combinations of exons allows one gene to code for different polypeptides. Specific examples are not required. |

| D1.2.17—Initiation of translation |
| --- |
| Include attachment of the small ribosome subunit to the 5' terminal of mRNA, movement to the start codon, the initiator tRNA and another tRNA, and attachment of the large subunit. Students should understand the roles of the three binding sites for tRNA on the ribosome (A, P and E) during elongation. |

| D1.2.18—Modification of polypeptides into their functional state |
| --- |
| Students should appreciate that many polypeptides must be modified before they can function. The examples chosen should include the two-stage modification of pre-proinsulin to insulin. |

| D1.2.19—Recycling of amino acids by proteasomes |
| --- |
| Limit to the understanding that sustaining a functional proteome requires constant protein breakdown and synthesis. |

## Linking questions

- How does the diversity of proteins produced contribute to the functioning of a cell?
- What biological processes depend on hydrogen bonding?

# D1.3 Mutation and gene editing

Continuity and change—Molecules

**Standard level and higher level: 3 hours**

**Additional higher level: 2 hours**

## Guiding questions

- How do gene mutations occur?
- What are the consequences of gene mutation?

## SL and HL

| D1.3.1—Gene mutations as structural changes to genes at the molecular level |
|---|
| Distinguish between substitutions, insertions and deletions. |

| D1.3.2—Consequences of base substitutions |
|---|
| Students should understand that single-nucleotide polymorphisms (SNPs) are the result of base substitution mutations and that because of the degeneracy of the genetic code they may or may not change a single amino acid in a polypeptide. |

| D1.3.3—Consequences of insertions and deletions |
|---|
| Include the likelihood of polypeptides ceasing to function, either through frameshift changes or through major insertions or deletions. Specific examples are not required. |

| D1.3.4—Causes of gene mutation |
|---|
| Students should understand that gene mutation can be caused by mutagens and by errors in DNA replication or repair. Include examples of chemical mutagens and mutagenic forms of radiation. |

| D1.3.5—Randomness in mutation |
|---|
| Students should understand that mutations can occur anywhere in the base sequences of a genome, although some bases have a higher probability of mutating than others. They should also understand that no natural mechanism is known for making a deliberate change to a particular base with the purpose of changing a trait. |

| D1.3.6—Consequences of mutation in germ cells and somatic cells |
|---|
| Include inheritance of mutated genes in germ cells and cancer in somatic cells. |

| D1.3.7—Mutation as a source of genetic variation |
|---|
| Students should appreciate that gene mutation is the original source of all genetic variation. Although most mutations are either harmful or neutral for an individual organism, in a species they are in the long term essential for evolution by natural selection. |

| |
|---|
| **NOS:** Commercial genetic tests can yield information about potential future health and disease risk. One possible impact is that, without expert interpretation, this information could be problematic. |

## Additional higher level

| D1.3.8—Gene knockout as a technique for investigating the function of a gene by changing it to make it inoperative |
|---|
| Students are not required to know details of techniques. Students should appreciate that a library of knockout organisms is available for some species used as models in research. |

| D1.3.9—Use of the CRISPR sequences and the enzyme Cas9 in gene editing |
|---|
| Students are not required to know the role of the CRISPR–Cas system in prokaryotes. However, students should be familiar with an example of the successful use of this technology.<br>**NOS:** Certain potential uses of CRISPR raise ethical issues that must be addressed before implementation. Students should understand that scientists across the world are subject to different regulatory systems. For this reason, there is an international effort to harmonize regulation of the application of genome editing technologies such as CRISPR. |

| D1.3.10—Hypotheses to account for conserved or highly conserved sequences in genes |
|---|
| Conserved sequences are identical or similar across a species or a group of species; highly conserved sequences are identical or similar over long periods of evolution. One hypothesis for the mechanism is the functional requirements for the gene products and another hypothesis is slower rates of mutation. |

## Linking questions

- How can natural selection lead to both a reduction in variation and an increase in biological diversity?
- How does variation in subunit composition of polymers contribute to function?

# D2.1 Cell and nuclear division

Continuity and change—Cells

**Standard level and higher level: 3 hours**

**Additional higher level: 1 hour**

## Guiding questions

- How can large numbers of genetically identical cells be produced?
- How do eukaryotes produce genetically varied cells that can develop into gametes?

## SL and HL

| D2.1.1—Generation of new cells in living organisms by cell division |
|---|
| In all living organisms, a parent cell—often referred to as a mother cell—divides to produce two daughter cells. |

| D2.1.2—Cytokinesis as splitting of cytoplasm in a parent cell between daughter cells |
|---|
| Students should appreciate that in an animal cell a ring of contractile actin and myosin proteins pinches a cell membrane together to split the cytoplasm, whereas in a plant cell vesicles assemble sections of membrane and cell wall to achieve splitting. |

| D2.1.3—Equal and unequal cytokinesis |
| --- |
| Include the idea that division of cytoplasm is usually, but not in all cases, equal and that both daughter cells must receive at least one mitochondrion and any other organelle that can only be made by dividing a pre-existing structure. Include oogenesis in humans and budding in yeast as examples of unequal cytokinesis. |

| D2.1.4—Roles of mitosis and meiosis in eukaryotes |
| --- |
| Emphasize that nuclear division is needed before cell division to avoid production of anucleate cells. Mitosis maintains the chromosome number and genome of cells, whereas meiosis halves the chromosome number and generates genetic diversity. |

| D2.1.5—DNA replication as a prerequisite for both mitosis and meiosis |
| --- |
| Students should understand that, after replication, each chromosome consists of two elongated DNA molecules (chromatids) held together until anaphase. |

| D2.1.6—Condensation and movement of chromosomes as shared features of mitosis and meiosis |
| --- |
| Include the role of histones in the condensation of DNA by supercoiling and the use of microtubules and microtubule motors to move chromosomes. |

| D2.1.7—Phases of mitosis |
| --- |
| Students should know the names of the phases and how the process as a whole produces two genetically identical daughter cells. |

| D2.1.8—Identification of phases of mitosis |
| --- |
| **Application of skills:** Students should do this using diagrams as well as with cells viewed with a microscope or in a micrograph. |

| D2.1.9—Meiosis as a reduction division |
| --- |
| Students should understand the terms “diploid” and “haploid” and how the two divisions of meiosis produce four haploid nuclei from one diploid nucleus. They should also understand the need for meiosis in a sexual life cycle. Students should be able to outline the two rounds of segregation in meiosis. |

| D2.1.10—Down syndrome and non-disjunction |
| --- |
| Use Down syndrome as an example of an error in meiosis. |

| D2.1.11—Meiosis as a source of variation |
| --- |
| Students should understand how meiosis generates genetic diversity by random orientation of bivalents and by crossing over. |

## Additional higher level

| D2.1.12—Cell proliferation for growth, cell replacement and tissue repair |
| --- |
| Include proliferation for growth within plant meristems and early-stage animal embryos as examples. Include skin as an example of cell proliferation during routine cell replacement and during wound healing. Students are not required to know details of the structure of skin. |

| D2.1.13—Phases of the cell cycle |
| --- |
| Students should understand that cell proliferation is achieved using the cell cycle. Students should understand the sequence of events including G1, S and G2 as the stages of interphase, followed by mitosis and then cytokinesis. |

| D2.1.14—Cell growth during interphase |
| --- |
| Students should appreciate that interphase is a metabolically active period and that growth involves biosynthesis of cell components including proteins and DNA. Numbers of mitochondria and chloroplasts are increased by growth and division of these organelles. |

| D2.1.15—Control of the cell cycle using cyclins |
| --- |
| Limit to the concentration of different cyclins increasing and decreasing during the cell cycle and a threshold level of a specific cyclin required to pass each checkpoint in the cycle. Students are not required to know details of the roles of specific cyclins. |

| D2.1.16—Consequences of mutations in genes that control the cell cycle |
| --- |
| Include mutations in proto-oncogenes that convert them to oncogenes and mutations in tumour suppressor genes, resulting in uncontrolled cell division. |

| D2.1.17—Differences between tumours in rates of cell division and growth and in the capacity for metastasis and invasion of neighbouring tissue |
| --- |
| Include the terms "benign", "malignant", "primary tumour" and "secondary tumour", and distinguish between tumours that do and do not cause cancer.<br>**Application of skills:** Students should observe populations of cells to determine the mitotic index. |

## Linking questions

- What processes support the growth of organisms?
- How does the variation produced by sexual reproduction contribute to evolution?

# D2.2 Gene expression

Continuity and change—Cells

**Additional higher level: 3 hours**

## Guiding questions

- How is gene expression changed in a cell?
- How can patterns of gene expression be conserved through inheritance?

## Additional higher level

*Note: There is no SL in D2.2.*

| D2.2.1—Gene expression as the mechanism by which information in genes has effects on the phenotype |
| --- |
| Students should appreciate that the most common stages in this process are transcription, translation and the function of a protein product, such as an enzyme. |

| D2.2.2—Regulation of transcription by proteins that bind to specific base sequences in DNA |
| --- |

| |
|---|
| Include the role of promoters, enhancers and transcription factors. |

| D2.2.3—Control of the degradation of mRNA as a means of regulating translation |
|---|
| In human cells, mRNA may persist for time periods from minutes up to days, before being broken down by nucleases. |

| D2.2.4—Epigenesis as the development of patterns of differentiation in the cells of a multicellular organism |
|---|
| Emphasize that DNA base sequences are not altered by epigenetic changes, so phenotype but not genotype is altered. |

| D2.2.5—Differences between the genome, transcriptome and proteome of individual cells |
|---|
| No cell expresses all of its genes. The pattern of gene expression in a cell determines how it differentiates. |

| D2.2.6—Methylation of the promoter and histones in nucleosomes as examples of epigenetic tags |
|---|
| Methylation of cytosine in the DNA of a promoter represses transcription and therefore expression of the gene downstream.<br>Methylation of amino acids in histones can cause transcription to be repressed or activated. Students are not required to know details of how this is achieved. |

| D2.2.7—Epigenetic inheritance through heritable changes to gene expression |
|---|
| Limit to the possibility of phenotypic changes in a cell or organism being passed on to daughter cells or offspring without changes in the nucleotide sequence of DNA. This can happen if epigenetic tags, such as DNA methylation or histone modification, remain in place during mitosis or meiosis. |

| D2.2.8—Examples of environmental effects on gene expression in cells and organisms |
|---|
| Include alteration of methyl tags on DNA in response to air pollution as an example. |

| D2.2.9—Consequences of removal of most but not all epigenetic tags from the ovum and sperm |
|---|
| Students can show this by outlining the epigenetic origins of phenotypic differences in tigons and ligers (lion–tiger hybrids). |

| D2.2.10—Monozygotic twin studies |
|---|
| Limit to investigating the effects of the environment on gene expression. |

| D2.2.11—External factors impacting the pattern of gene expression |
|---|
| Limit to one example of a hormone and one example of a biochemical such as lactose or tryptophan in bacteria. |

## Linking questions

- What mechanisms are there for inhibition in biological systems?
- In what ways does the environment stimulate diversification?

# D2.3 Water potential

Continuity and change—Cells

**Standard level and higher level: 2 hours**

**Additional higher level: 2 hours**

## Guiding questions

- What factors affect the movement of water into or out of cells?
- How do plant and animal cells differ in their regulation of water movement?

## SL and HL

| D2.3.1—Solvation with water as the solvent |
|---|
| Include hydrogen bond formation between solute and water molecules, and attractions between both positively and negatively charged ions and polar water molecules. |

| D2.3.2—Water movement from less concentrated to more concentrated solutions |
|---|
| Students should express the direction of movement in terms of solute concentration, not water concentration. Students should use the terms “hypertonic”, “hypotonic” and “isotonic” to compare concentration of solutions. |

| D2.3.3—Water movement by osmosis into or out of cells |
|---|
| Students should be able to predict the direction of net movement of water if the environment of a cell is hypotonic or hypertonic. They should understand that in an isotonic environment there is dynamic equilibrium rather than no movement of water. |

| D2.3.4—Changes due to water movement in plant tissue bathed in hypotonic and those bathed in hypertonic solutions |
|---|
| **Application of skills:** Students should be able to measure changes in tissue length and mass, and analyse data to deduce isotonic solute concentration. Students should also be able to use standard deviation and standard error to help in the analysis of data. Students are not required to memorize formulae for calculating these statistics. Standard deviation and standard error could be determined for the results of this experiment if there are repeats for each concentration. This would allow the reliability of length and mass measurements to be compared. Standard error could be shown graphically as error bars. |

| D2.3.5—Effects of water movement on cells that lack a cell wall |
|---|
| Include swelling and bursting in a hypotonic medium, and shrinkage and crenation in a hypertonic medium. Also include the need for removal of water by contractile vacuoles in freshwater unicellular organisms and the need to maintain isotonic tissue fluid in multicellular organisms to prevent harmful changes. |

| D2.3.6—Effects of water movement on cells with a cell wall |
|---|
| Include the development of turgor pressure in a hypotonic medium and plasmolysis in a hypertonic medium. |

| D2.3.7—Medical applications of isotonic solutions |
|---|

| |
|---|
| Include intravenous fluids given as part of medical treatment and bathing of organs ready for transplantation as examples. |

## Additional higher level

| D2.3.8—Water potential as the potential energy of water per unit volume |
|---|
| Students should understand that it is impossible to measure the absolute quantity of the potential energy of water, so values relative to pure water at atmospheric pressure and 20°C are used. The units are usually kilopascals (kPa). |

| D2.3.9—Movement of water from higher to lower water potential |
|---|
| Students should appreciate the reasons for this movement in terms of potential energy. |

| D2.3.10—Contributions of solute potential and pressure potential to the water potential of cells with walls |
|---|
| Use the equation $\psi_w = \psi_s + \psi_p$. Students should appreciate that solute potentials can range from zero downwards and that pressure potentials are generally positive inside cells, although negative pressure potentials occur in xylem vessels where sap is being transported under tension. |

| D2.3.11—Water potential and water movements in plant tissue |
|---|
| Students should be able to explain in terms of solute and pressure potentials the changes that occur when plant tissue is bathed in either a hypotonic or hypertonic solution. |

## Linking questions

- What variables influence the direction of movement of materials in tissues?
- What are the implications of solubility differences between chemical substances for living organisms?

# D3.1 Reproduction

Continuity and change—Organisms

**Standard level and higher level: 5 hours**

**Additional higher level: 3 hours**

## Guiding questions

- How does asexual or sexual reproduction exemplify themes of change or continuity?
- What changes within organisms are required for reproduction?

## SL and HL

| D3.1.1—Differences between sexual and asexual reproduction |
|---|
| Include these relative advantages: asexual reproduction to produce genetically identical offspring by individuals that are adapted to an existing environment, sexual reproduction to produce offspring with new gene combinations and thus variation needed for adaptation to a changed environment. |

| D3.1.2—Role of meiosis and fusion of gametes in the sexual life cycle |
|---|
| Students should appreciate that meiosis breaks up parental combinations of alleles, and fusion of gametes produces new combinations. Fusion of gametes is also known as fertilization. |

**D3.1.3—Differences between male and female sexes in sexual reproduction**

Include the prime difference that the male gamete travels to the female gamete, so it is smaller, with less food reserves than the egg. From this follow differences in the numbers of gametes and the reproductive strategies of males and females.

**D3.1.4—Anatomy of the human male and female reproductive systems**

Students should be able to draw diagrams of the male-typical and female-typical systems and annotate them with names of structures and functions.

**D3.1.5—Changes during the ovarian and uterine cycles and their hormonal regulation**

Include the roles of oestradiol, progesterone, luteinizing hormone (LH), follicle-stimulating hormone (FSH) and both positive and negative feedback. The ovarian and uterine cycles together constitute the menstrual cycle.

**D3.1.6—Fertilization in humans**

Include the fusion of a sperm's cell membrane with an egg cell membrane, entry to the egg of the sperm nucleus but destruction of the tail and mitochondria. Also include dissolution of nuclear membranes of sperm and egg nuclei and participation of all the condensed chromosomes in a joint mitosis to produce two diploid nuclei.

**D3.1.7—Use of hormones in in vitro fertilization (IVF) treatment**

The normal secretion of hormones is suspended, and artificial doses of hormones induce superovulation.

**D3.1.8—Sexual reproduction in flowering plants**

Include production of gametes inside ovules and pollen grains, pollination, pollen development and fertilization to produce an embryo. Students should understand that reproduction in flowering plants is sexual, even if a plant species is hermaphroditic.

**D3.1.9—Features of an insect-pollinated flower**

Students should draw diagrams annotated with names of structures and their functions.

**D3.1.10—Methods of promoting cross-pollination**

Include different maturation times for pollen and stigma, separate male and female flowers or male and female plants. Also include the role of animals or wind in transferring pollen between plants.

**D3.1.11—Self-incompatibility mechanisms to increase genetic variation within a species**

Students should understand that self-pollination leads to inbreeding, which decreases genetic diversity and vigour. They should also understand that genetic mechanisms in many plant species ensure male and female gametes fusing during fertilization are from different plants.

**D3.1.12—Dispersal and germination of seeds**

Distinguish seed dispersal from pollination. Include the growth and development of the embryo and the mobilization of food reserves.

## Additional higher level

| |
|---|
| D3.1.13—Control of the developmental changes of puberty by gonadotropin-releasing hormone and steroid sex hormones |
| Limit to the increased release of gonadotropin-releasing hormone (GnRH) by the hypothalamus in childhood triggering the onset of increased luteinizing hormone (LH) and follicle-stimulating hormone (FSH) release. Ultimately the increased sex hormone production leads to the changes associated with puberty. |

| |
|---|
| D3.1.14—Spermatogenesis and oogenesis in humans |
| Include mitosis, cell growth, two divisions of meiosis and differentiation. Students should understand how gametogenesis, in typical male and female bodies, results in different numbers of sperm and eggs, and different amounts of cytoplasm. |

| |
|---|
| D3.1.15—Mechanisms to prevent polyspermy |
| The acrosome reaction allows a sperm to penetrate the zona pellucida and the cortical reaction prevents other sperm from passing through. |

| |
|---|
| D3.1.16—Development of a blastocyst and implantation in the endometrium |
| Students are not required to know the names of other stages in embryo development. |

| |
|---|
| D3.1.17—Pregnancy testing by detection of human chorionic gonadotropin secretion |
| Include the production of human chorionic gonadotropin (hCG) in the embryo or developing placenta and the use of monoclonal antibodies that bind to hCG. |

| |
|---|
| D3.1.18—Role of the placenta in foetal development inside the uterus |
| Students are not required to know details of placental structure apart from the large surface area of the placental villi. Students should understand which exchange processes occur in the placenta and that it allows the foetus to be retained in the uterus to a later stage of development than in mammals that do not develop a placenta. |

| |
|---|
| D3.1.19—Hormonal control of pregnancy and childbirth |
| Emphasize that the continuity of pregnancy is maintained by progesterone secretion initially from the corpus luteum and then from the placenta, whereas the changes during childbirth are triggered by a decrease in progesterone levels, allowing increases in oxytocin secretion due to positive feedback. |

| |
|---|
| D3.1.20—Hormone replacement therapy and the risk of coronary heart disease |
| **NOS:** In early epidemiological studies, it was argued that women undergoing hormone replacement therapy (HRT) had reduced incidence of coronary heart disease (CHD) and this was deemed to be a cause-and-effect relationship. Later randomized controlled trials showed that use of HRT led to a small increase in the risk of CHD. The correlation between HRT and decreased incidence of CHD is not actually a cause-and-effect relationship. HRT patients have a higher socioeconomic status, and this status has a causal relationship with lower risk of CHD. |

## Linking questions

- How can interspecific relationships assist in the reproductive strategies of living organisms?
- What are the roles of barriers in living systems?

# D3.2 Inheritance

Continuity and change—Organisms

**Standard level and higher level: 5 hours**

**Additional higher level: 3 hours**

## Guiding questions

- What patterns of inheritance exist in plants and animals?
- What is the molecular basis of inheritance patterns?

## SL and HL

| D3.2.1—Production of haploid gametes in parents and their fusion to form a diploid zygote as the means of inheritance |
| --- |
| Students should understand that this pattern of inheritance is common to all eukaryotes with a sexual life cycle. They should also understand that a diploid cell has two copies of each autosomal gene. |

| D3.2.2—Methods for conducting genetic crosses in flowering plants |
| --- |
| Use the terms “P generation”, “F1 generation”, “F2 generation” and “Punnett grid”. Students should understand that pollen contains male gametes and that female gametes are located in the ovary, so pollination is needed to carry out a cross. They should also understand that plants such as peas produce both male and female gametes on the same plant, allowing self-pollination and therefore self-fertilization. Mention that genetic crosses are widely used to breed new varieties of crop or ornamental plants. |

| D3.2.3—Genotype as the combination of alleles inherited by an organism |
| --- |
| Students should use and understand the terms “homozygous” and “heterozygous”, and appreciate the distinction between genes and alleles. |

| D3.2.4—Phenotype as the observable traits of an organism resulting from genotype and environmental factors |
| --- |
| Students should be able to suggest examples of traits in humans due to genotype only and due to environment only, and also traits due to interaction between genotype and environment. |

| D3.2.5—Effects of dominant and recessive alleles on phenotype |
| --- |
| Students should understand the reasons that both a homozygous-dominant genotype and a heterozygous genotype for a particular trait will produce the same phenotype. |

| D3.2.6—Phenotypic plasticity as the capacity to develop traits suited to the environment experienced by an organism, by varying patterns of gene expression |
| --- |
| Phenotypic plasticity is not due to changes in genotype, and the changes in traits may be reversible during the lifetime of an individual. |

| D3.2.7—Phenylketonuria as an example of a human disease due to a recessive allele |
| --- |
| Phenylketonuria (PKU) is a recessive genetic condition caused by mutation in an autosomal gene that codes for the enzyme needed to convert phenylalanine to tyrosine. |

| D3.2.8—Single-nucleotide polymorphisms and multiple alleles in gene pools |
| --- |

| |
|---|
| Students should understand that any number of alleles of a gene can exist in the gene pool but an individual only inherits two. |

| D3.2.9—ABO blood groups as an example of multiple alleles |
|---|
| Use $I^A$, $I^B$ and i to denote the alleles. |

| D3.2.10—Incomplete dominance and codominance |
|---|
| Students should understand the differences between these patterns of inheritance at the phenotypic level. In codominance, heterozygotes have a dual phenotype. Include the AB blood type ($I^AI^B$) as an example. In incomplete dominance, heterozygotes have an intermediate phenotype. Include four o'clock flower or marvel of Peru (*Mirabilis jalapa*) as an example.<br>*Note: When students are referring to organisms in an examination, either the common name or the scientific name is acceptable.* |

| D3.2.11—Sex determination in humans and inheritance of genes on sex chromosomes |
|---|
| Students should understand that the sex chromosome in sperm determines whether a zygote develops certain male-typical or female-typical physical characteristics and that far more genes are carried by the X chromosome than the Y chromosome. |

| D3.2.12—Haemophilia as an example of a sex-linked genetic disorder |
|---|
| Show alleles carried on X chromosomes as superscript letters on an uppercase X. |

| D3.2.13—Pedigree charts to deduce patterns of inheritance of genetic disorders |
|---|
| Students should understand the genetic basis for the prohibition of marriage between close relatives in many societies.<br>**NOS:** Scientists draw general conclusions by inductive reasoning when they base a theory on observations of some but not all cases. A pattern of inheritance may be deduced from parts of a pedigree chart and this theory may then allow genotypes of specific individuals in the pedigree to be deduced. Students should be able to distinguish between inductive and deductive reasoning. |

| D3.2.14—Continuous variation due to polygenic inheritance and/or environmental factors |
|---|
| Use skin colour in humans as an example.<br>**Application of skills:** Students should understand the distinction between continuous variables such as skin colour and discrete variables such as ABO blood group. They should also be able to apply measures of central tendency such as mean, median and mode. |

| D3.2.15—Box-and-whisker plots to represent data for a continuous variable such as student height |
|---|
| **Application of skills:** Students should use a box-and-whisker plot to display six aspects of data: outliers, minimum, first quartile, median, third quartile and maximum. A data point is categorized as an outlier if it is more than 1.5 × IQR (interquartile range) above the third quartile or below the first quartile. |

## Additional higher level

| D3.2.16—Segregation and independent assortment of unlinked genes in meiosis |
|---|
| Students should understand the link between the movements of chromosomes in meiosis and the outcome of dihybrid crosses involving pairs of unlinked genes. |

| D3.2.17—Punnett grids for predicting genotypic and phenotypic ratios in dihybrid crosses involving pairs of unlinked autosomal genes |
|---|
| Students should understand how the 9:3:3:1 and 1:1:1:1 ratios are derived.<br>**NOS:** 9:3:3:1 and 1:1:1:1 ratios for dihybrid crosses are based on what has been called Mendel's second law. This law only applies if genes are on different chromosomes or are far apart enough on one chromosome for recombination rates to reach 50%. Students should recognize that there are exceptions to all biological "laws" under certain conditions. |

| D3.2.18—Loci of human genes and their polypeptide products |
|---|
| **Application of skills:** Students should explore genes and their polypeptide products in databases. They should find pairs of genes with loci on different chromosomes and also in close proximity on the same chromosome. |

| D3.2.19—Autosomal gene linkage |
|---|
| In crosses involving linkage, the symbols used to denote alleles should be shown alongside vertical lines representing homologous chromosomes. Students should understand the reason that alleles of linked genes can fail to assort independently. |

| D3.2.20—Recombinants in crosses involving two linked or unlinked genes |
|---|
| Students should understand how to determine the outcomes of crosses between an individual heterozygous for both genes and an individual homozygous recessive for both genes. Identify recombinants in gametes, in genotypes of offspring and in phenotypes of offspring. |

| D3.2.21—Use of a chi-squared test on data from dihybrid crosses |
|---|
| Students should understand the concept of statistical significance, the $p = 0.05$ level, null/alternative hypothesis and the idea of observed versus expected results.<br>**NOS:** Students should recognize that statistical testing often involves using a sample to represent a population. In this case the sample is the F2 generation. In many experiments the sample is the replicated or repeated measurements. |

## Linking questions

- What are the principles of effective sampling in biological research?
- What biological processes involve doubling and halving?

# D3.3 Homeostasis

Continuity and change—Organisms

**Standard level and higher level: 2 hours**

**Additional higher level: 2 hours**

## Guiding questions

- How are constant internal conditions maintained in humans?
- What are the benefits to organisms of maintaining constant internal conditions?

## SL and HL

| D3.3.1—Homeostasis as maintenance of the internal environment of an organism |
|---|

| |
|---|
| Variables are kept within preset limits, despite fluctuations in external environment. Include body temperature, blood pH, blood glucose concentration and blood osmotic concentration as homeostatic variables in humans. |

| D3.3.2—Negative feedback loops in homeostasis |
|---|
| Students should understand the reason for use of negative rather than positive feedback control in homeostasis and also that negative feedback returns homeostatic variables to the set point from values above and below the set point. |

| D3.3.3—Regulation of blood glucose as an example of the role of hormones in homeostasis |
|---|
| Include control of secretion of insulin and glucagon by pancreatic endocrine cells, transport in blood and the effects on target cells. |

| D3.3.4—Physiological changes that form the basis of type 1 and type 2 diabetes |
|---|
| Students should understand the physiological changes, together with risk factors and methods of prevention and treatment. |

| D3.3.5—Thermoregulation as an example of negative feedback control |
|---|
| Include the roles of peripheral thermoreceptors, the hypothalamus and pituitary gland, thyroxin and also examples of muscle and adipose tissue that act as effectors of temperature change. |

| D3.3.6—Thermoregulation mechanisms in humans |
|---|
| Students should appreciate that birds and mammals regulate their body temperature by physiological and behavioural means. Students are only required to understand the details of thermoregulation for humans. Include vasodilation, vasoconstriction, shivering, sweating, uncoupled respiration in brown adipose tissue and hair erection. |

## Additional higher level

| D3.3.7—Role of the kidney in osmoregulation and excretion |
|---|
| Students should understand the distinction between excretion and osmoregulation. Osmoregulation is regulation of osmotic concentration. The units for osmotic concentration are osmoles per litre (osmol $L^{-1}$). |

| D3.3.8—Role of the glomerulus, Bowman’s capsule and proximal convoluted tubule in excretion |
|---|
| Students should appreciate how ultrafiltration remove solutes from blood plasma and how useful substances are then reabsorbed, to leave toxins and other unwanted solutes in the filtrate, which are excreted in urine. |

| D3.3.9—Role of the loop of Henle |
|---|
| Limit to active transport of sodium ions in the ascending limb to maintain high osmotic concentrations in the medulla, facilitating water reabsorption in the collecting ducts. |

| D3.3.10—Osmoregulation by water reabsorption in the collecting ducts |
|---|
| Include the roles of osmoreceptors in the hypothalamus, changes to the rate of antidiuretic hormone secretion by the pituitary gland and the resultant switches in location of aquaporins between cell membranes and intracellular vesicles in cells of the collecting ducts. |

| D3.3.11—Changes in blood supply to organs in response to changes in activity |
|---|
| As examples, use the pattern of blood supply to the skeletal muscles, gut, brain and kidneys during sleep, vigorous physical activity and wakeful rest. |

## Linking questions

- For what reasons do organisms need to distribute materials and energy?
- What biological systems are sensitive to temperature changes?

# D4.1 Natural selection

Continuity and change—Ecosystems

**Standard level and higher level: 2 hours**

**Additional higher level: 2 hours**

## Guiding questions

- What processes can cause changes in allele frequencies within a population?
- What is the role of reproduction in the process of natural selection?

## SL and HL

| D4.1.1—Natural selection as the mechanism driving evolutionary change |
|---|
| Students should appreciate that natural selection operates continuously and over billions of years, resulting in the biodiversity of life on Earth.<br>**NOS:** In Darwin's time it was widely understood that species evolved, but the mechanism was not clear. Darwin's theory provided a convincing mechanism and replaced Lamarckism. This is an example of a paradigm shift. Students should understand the meaning of the term "paradigm shift". |

| D4.1.2—Roles of mutation and sexual reproduction in generating the variation on which natural selection acts |
|---|
| Mutation generates new alleles and sexual reproduction generates new combinations of alleles. |

| D4.1.3—Overproduction of offspring and competition for resources as factors that promote natural selection |
|---|
| Include examples of food and other resources that may limit carrying capacity. |

| D4.1.4—Abiotic factors as selection pressures |
|---|
| Include examples of density-independent factors such as high or low temperatures that may affect survival of individuals in a population. |

| D4.1.5—Differences between individuals in adaptation, survival and reproduction as the basis for natural selection |
|---|
| Students are required to study natural selection due to intraspecific competition, including the concept of fitness when discussing the survival value and reproductive potential of a genotype. |

| D4.1.6—Requirement that traits are heritable for evolutionary change to occur |
|---|

| |
|---|
| Students should understand that characteristics acquired during an individual's life due to environmental factors are not encoded in the base sequence of genes and so are not heritable. |

| |
|---|
| D4.1.7—Sexual selection as a selection pressure in animal species |
| Differences in physical and behavioural traits, which can be used as signs of overall fitness, can affect success in attracting a mate and so drive the evolution of an animal population. Illustrate this using suitable examples such as the evolution of the plumage of birds of paradise. |

| |
|---|
| D4.1.8—Modelling of sexual and natural selection based on experimental control of selection pressures |
| **Application of skills:** Students should interpret data from John Endler's experiments with guppies. |

## Additional higher level

| |
|---|
| D4.1.9—Concept of the gene pool |
| A gene pool consists of all the genes and their different alleles, present in a population. |

| |
|---|
| D4.1.10—Allele frequencies of geographically isolated populations |
| **Application of skills:** Students should use databases to search allele frequencies. Use at least one human example. |

| |
|---|
| D4.1.11—Changes in allele frequency in the gene pool as a consequence of natural selection between individuals according to differences in their heritable traits |
| Darwin developed the theory of evolution by natural selection. Biologists subsequently integrated genetics with natural selection in what is now known as neo-Darwinism. |

| |
|---|
| D4.1.12—Differences between directional, disruptive and stabilizing selection |
| Students should be aware that all three types result in a change in allele frequency. |

| |
|---|
| D4.1.13—Hardy–Weinberg equation and calculations of allele or genotype frequencies |
| Use $p$ and $q$ to denote the two allele frequencies. Students should understand that $p + q = 1$ so genotype frequencies are predicted by the Hardy–Weinberg equation: $p^2 + 2pq + q^2 = 1$.<br>If one of the genotype frequencies is known, the allele frequencies can be calculated using the same equations. |

| |
|---|
| D4.1.14—Hardy–Weinberg conditions that must be maintained for a population to be in genetic equilibrium |
| Students should understand that if genotype frequencies in a population do not fit the Hardy–Weinberg equation, this indicates that one or more of the conditions is not being met, for example mating is non-random or survival rates vary between genotypes. |

| |
|---|
| D4.1.15—Artificial selection by deliberate choice of traits |
| Artificial selection is carried out in crop plants and domesticated animals by choosing individuals for breeding that have desirable traits. Unintended consequences of human actions, such as the evolution of resistance in bacteria when an antibiotic is used, are due to natural rather than artificial selection. |

## Linking questions

- How do intraspecific interactions differ from interspecific interactions?
- What mechanisms minimize competition?

# D4.2 Stability and change

Continuity and change—Ecosystems

**Standard level and higher level: 4 hours**

**Additional higher level: 2 hours**

## Guiding questions

- What features of ecosystems allow stability over unlimited time periods?
- What changes caused by humans threaten the stability of ecosystems?

## SL and HL

| D4.2.1—Stability as a property of natural ecosystems |
|---|
| Illustrate ecosystem stability with evidence of forest, desert or other ecosystems that have shown continuity over long periods. There is evidence for some ecosystems persisting for millions of years. |

| D4.2.2—Requirements for stability in ecosystems |
|---|
| Include supply of energy, recycling of nutrients, genetic diversity and climatic variables remaining within tolerance levels. |

| D4.2.3—Deforestation of Amazon rainforest as an example of a possible tipping point in ecosystem stability |
|---|
| Include the need for a large area of rainforest for the generation of atmospheric water vapour by transpiration, with consequent cooling, air flows and rainfall. Include uncertainty over the minimum area of rainforest that is sufficient to maintain these processes.<br>**Application of skills:** Students should be able to calculate percentage change. In this case the extent of deforestation can be assessed by calculating the percentage change from the original area of forest. |

| D4.2.4—Use of a model to investigate the effect of variables on ecosystem stability |
|---|
| Mesocosms can be set up in open tanks but sealed glass vessels are preferable because entry and exit of matter can be prevented but energy transfer is still possible. Aquatic or microbial ecosystems are likely to be more successful than terrestrial ones.<br>**NOS:** Care and maintenance of the mesocosms should follow IB experimental guidelines. |

| D4.2.5—Role of keystone species in the stability of ecosystems |
|---|
| Students should appreciate the disproportionate impact on community structure of keystone species and the risk of ecosystem collapse if they are removed. |

| D4.2.6—Assessing sustainability of resource harvesting from natural ecosystems |
|---|
| Sustainability depends on the rate of harvesting being lower than the rate of replacement. Include one terrestrial plant species and one species of marine fish as examples of renewable resources and how sustainability of harvesting can be assessed. |

| D4.2.7—Factors affecting the sustainability of agriculture |
|---|
| Include the need to consider soil erosion, leaching of nutrients, supply of fertilizers and other inputs, pollution due to agrochemicals, and carbon footprint. |

| D4.2.8—Eutrophication of aquatic and marine ecosystems due to leaching |
|---|
| Students should understand the effects of eutrophication resulting from leaching of nitrogen and phosphate fertilizers, including increased biochemical oxygen demand (BOD). |

| D4.2.9—Biomagnification of pollutants in natural ecosystems |
|---|
| Students should understand how increased levels of toxins accumulate in the tissues of consumers in higher trophic levels. Include DDT and mercury as examples. |

| D4.2.10—Effects of microplastic and macroplastic pollution of the oceans |
|---|
| Students should understand that plastics are persistent in the natural environment due to non-biodegradability. Include examples of the effects of plastic pollution on marine life.<br>**NOS:** Scientists can influence the actions of citizens if they provide clear information about their research findings. Popular media coverage of the effects of plastic pollution on marine life changed public perception globally, which has driven measures to address this problem. |

| D4.2.11—Restoration of natural processes in ecosystems by rewilding |
|---|
| Methods should include reintroduction of apex predators and other keystone species, re-establishment of connectivity of habitats over large areas, and minimization of human impact including by ecological management. Include the example of Hinewai Reserve in New Zealand. |

## Additional higher level

| D4.2.12—Ecological succession and its causes |
|---|
| Succession can be triggered by changes in both an abiotic environment and in biotic factors. |

| D4.2.13—Changes occurring during primary succession |
|---|
| Use any suitable terrestrial example to illustrate these general principles: increases in size of plants, amount of primary production, species diversity, complexity of food webs and amount of nutrient cycling. |

| D4.2.14—Cyclical succession in ecosystems |
|---|
| Students should appreciate that in some ecosystems there is a cycle of communities rather than a single unchanging climax community. Students should refer to an example. |

| D4.2.15—Climax communities and arrested succession |
|---|
| Given any specific environmental conditions, ecological succession tends to lead to a particular type of climax community, but human influences can prevent this from developing. Use grazing by farm livestock and drainage of wetlands as examples. |

## Linking questions

- What is the distinction between artificial and natural processes?
- Over what timescales do things change in different biological systems?

# D4.3 Climate change

Continuity and change—Ecosystems

**Standard level and higher level: 3 hours**

**Additional higher level: 1 hour**

## Guiding questions

- What are the drivers of climate change?
- What are the impacts of climate change on ecosystems?

## SL and HL

| D4.3.1—Anthropogenic causes of climate change |
| --- |
| Limit to anthropogenic increases in atmospheric concentrations of carbon dioxide and methane.<br>**NOS:** Students should be able to distinguish between positive and negative correlation and should also distinguish between correlation and causation. For example, data from Antarctic ice cores shows a positive correlation between global temperatures and atmospheric carbon dioxide concentrations over hundreds of thousands of years. This correlation does not prove that carbon dioxide in the atmosphere increases global temperatures, although other evidence confirms the causal link. |

| D4.3.2—Positive feedback cycles in global warming |
| --- |
| Include release of carbon dioxide from deep ocean, increases in absorption of solar radiation due to loss of reflective snow and ice, accelerating rates of decomposition of peat and previously undecomposed organic matter in permafrost, release of methane from melting permafrost and increases in droughts and forest fires. |

| D4.3.3—Change from net carbon accumulation to net loss in boreal forests as an example of a tipping point |
| --- |
| Include warmer temperatures and decreased winter snowfall leading to increased incidence of drought and reductions in primary production in taiga, with forest browning and increases in the frequency and intensity of forest fires, which result in legacy carbon combustion. |

| D4.3.4—Melting of landfast ice and sea ice as examples of polar habitat change |
| --- |
| Include potential loss of breeding grounds of the emperor penguin (*Aptenodytes forsteri*) due to early breakout of landfast ice in the Antarctic and loss of sea ice habitat for walruses in the Arctic.<br>*Note: When students are referring to organisms in an examination, either the common name or the scientific name is acceptable.* |

| D4.3.5—Changes in ocean currents altering the timing and extent of nutrient upwelling |
| --- |
| Warmer surface water can prevent nutrient upwelling to the surface, decreasing ocean primary production and energy flow through marine food chains. |

| D4.3.6—Poleward and upslope range shifts of temperate species |
| --- |
| As evidence-based examples, include upslope range shifts for tropical-zone montane bird species in New Guinea and range contraction and northward spread in North American tree species. |

| D4.3.7—Threats to coral reefs as an example of potential ecosystem collapse |
| --- |

| |
|---|
| Increased carbon dioxide concentrations are the cause of ocean acidification and suppression of calcification in corals. Increases in water temperature are a cause of coral bleaching. Loss of corals causes the collapse of reef ecosystems. |

| D4.3.8—Afforestation, forest regeneration and restoration of peat-forming wetlands as approaches to carbon sequestration |
|---|
| **NOS:** There is active scientific debate over whether plantations of non-native tree species or rewilding with native species offer the best approach to carbon sequestration. Peat formation naturally occurs in waterlogged soils in temperate and boreal zones and also very rapidly in some tropical ecosystems. |

## Additional higher level

| D4.3.9—Phenology as research into the timing of biological events |
|---|
| Students should be aware that photoperiod and temperature patterns are examples of variables that influence the timing of biological events such as flowering, budburst and bud set in deciduous trees, bird migration and nesting. |

| D4.3.10—Disruption to the synchrony of phenological events by climate change |
|---|
| Students should recognize that within an ecosystem temperature may act as the cue in one population and photoperiod may be the cue in another. Include spring growth of the Arctic mouse-ear chickweed (*Cerastium arcticum*) and arrival of migrating reindeer (*Rangifer tarandus*) as one example. Also include a suitable local example or use the breeding of the great tit (*Parus major*) and peak biomass of caterpillars in north European forests as another.<br>*Note: When students are referring to organisms in an examination, either the common name or the scientific name is acceptable.* |

| D4.3.11—Increases to the number of insect life cycles within a year due to climate change |
|---|
| Use the spruce bark beetle (*Ips typographus* or *Dendroctonus micans*) as an example.<br>*Note: When students are referring to organisms in an examination, either the common name or the scientific name is acceptable.* |

| D4.3.12—Evolution as a consequence of climate change |
|---|
| Include changes in the fitness of colour variants of the tawny owl (*Strix aluco*) as a consequence of changes in snow cover.<br>*Note: When students are referring to organisms in an examination, either the common name or the scientific name is acceptable.* |

## Linking questions

- What are the impacts of climate change at each level of biological organization?
- What processes determine the distribution of organisms on Earth?

# Assessment in the Diploma Programme

## General

Assessment is an integral part of teaching and learning. The most important aims of assessment in the Diploma Programme (DP) are that it should support curricular goals and encourage appropriate student learning. Both external and internal assessments are used in the DP. IB examiners mark work produced for external assessment, while work produced for internal assessment is marked by teachers and externally moderated by the IB.

There are two types of assessment identified by the IB.

- Formative assessment informs both teaching and learning. It is concerned with providing accurate and helpful feedback to students and teachers on the kind of learning taking place and the nature of students' strengths and weaknesses in order to help develop students' understanding and capabilities. Formative assessment can also help to improve teaching quality, as it can provide information to monitor progress towards meeting the course aims and objectives (0404-01).
- Summative assessment gives an overview of previous learning and is concerned with measuring student achievement at, or towards the end, of the course of study (0404-04).

A comprehensive assessment policy is viewed as being integral with teaching, learning and course organization. For further information, see the IB *Programme standards and practices* publication.

The approach to assessment used by the IB is criterion-related, not norm-referenced. This approach to assessment judges students' work by their performance in relation to identified levels of attainment, and not in relation to the work of other students. For further information on assessment within the DP, please refer to the publication *Assessment principles and practices—Quality assessments in a digital age.*

To support teachers in the planning, delivery and assessment of the DP courses, a variety of resources can be found on the Programme Resource Centre or purchased from the IB store (store.ibo.org). Additional publications such as specimen papers and markschemes, teacher support material (TSM), subject reports and grade descriptors can also be found on the Programme Resource Centre. Past examination papers as well as markschemes can be purchased from the IB store.

## Methods of assessment

The IB uses several methods to assess work produced by students.

### Assessment criteria

Assessment criteria are used when the assessment task is open-ended. Each criterion concentrates on a particular skill that students are expected to demonstrate. An assessment objective describes what students should be able to do, and assessment criteria describe how well they should be able to do it. Using assessment criteria allows discrimination between different answers and encourages a variety of responses. Each criterion comprises a set of hierarchically ordered level descriptors. Each level descriptor is worth one or more marks. Each criterion is applied independently using a best-fit model. The maximum marks for each criterion may differ according to the criterion's importance. The marks awarded for each criterion are added together to give the total mark for the piece of work.

### Markbands

Markbands are a comprehensive statement of expected performance against which responses are judged. They represent a single holistic criterion divided into level descriptors. Each level descriptor corresponds to a range of marks to differentiate student performance. A best-fit approach is used to ascertain which particular mark to use from the possible range for each level descriptor.

### Analytic markschemes

Analytic markschemes are prepared for those examination questions that expect a particular kind of response and/or a given final answer from students. They give detailed instructions to examiners on how to break down the total mark for each question for different parts of the response.

### Marking notes

For some assessment components marked using assessment criteria, marking notes are provided. Marking notes give guidance on how to apply assessment criteria to the particular requirements of a question.

## Inclusive access arrangements

Inclusive access arrangements are available for candidates with access requirements. Standard assessment conditions may put candidates with assessment access requirements at a disadvantage by preventing them from demonstrating their attainment level. Inclusive access arrangements enable candidates to demonstrate their ability under assessment conditions that are as fair as possible.

The IB document *Access and inclusion policy* provides details on all the inclusive access arrangements available to candidates. The IB document *Learning diversity and inclusion in IB programmes: Removing barriers to learning* outlines the position of the IB with regard to candidates with diverse learning needs in the IB programmes. For candidates affected by adverse circumstances, the publication *Diploma Programme Assessment procedures* (updated annually), which includes the general regulations, provides details on access consideration.

## Responsibilities of the school

The school is required to ensure that equal access arrangements and reasonable adjustments are provided to candidates with learning support requirements that are in line with the IB documents *Access and inclusion policy* and *Learning diversity and inclusion in IB programmes: Removing barriers to learning*.

# Assessment outline—SL

| First assessment 2025 |
| --- |

| Assessment component | Weighting |
| --- | --- |
| **External assessment (3 hours)** | **80%** |
| **Paper 1 (1 hour and 30 minutes)**<br>Paper 1A—Multiple-choice questions<br>Paper 1B—Data-based questions (four questions that are syllabus related, addressing all themes)<br>(Total 55 marks) | **36%** |
| **Paper 2 (1 hour and 30 minutes)**<br>Section A—Data-based and short answer questions<br>Section B—Extended-response questions<br>(Total 50 marks) | **44%** |
| **Internal assessment (10 hours)** | **20%** |
| The internal assessment consists of one task: the scientific investigation.<br>This component is internally assessed by the teacher and externally moderated by the IB at the end of the course.<br>(Total 24 marks) | |

# Assessment outline—HL

| First assessment 2025 |
|---|

| Assessment component | Weighting |
|---|---|
| **External assessment (4 hours 30 minutes)** | **80%** |
| **Paper 1 (2 hours)**<br>Paper 1A—Multiple-choice questions<br>Paper 1B—Data-based questions (four questions that are syllabus related, addressing all themes)<br>(Total 75 marks) | **36%** |
| **Paper 2 (2 hour and 30 minutes)**<br>Section A—Data-based and short answer questions<br>Section B—Extended-response questions<br>(Total 80 marks) | **44%** |
| **Internal assessment (10 hours)** | **20%** |
| The internal assessment consists of one task: the scientific investigation.<br>This component is internally assessed by the teacher and externally moderated by the IB at the end of the course.<br>(Total 24 marks) | |

# External assessment

Detailed markschemes specific to each examination paper (paper 1 and paper 2) are used to assess students.

Examinations may require a general understanding and application of the nature of science (NOS).

## External assessment details—SL

### Paper 1

**Duration: 1 hour and 30 minutes**

**Weighting: 36%**

**Marks: 55**

**Paper 1 is presented as two separate booklets**

Paper 1A—30 marks

- 30 multiple-choice questions on standard level material.

  No marks are deducted for incorrect answers.

Paper 1B—25 marks

- Four data-based questions related to experimental work and the syllabus.

Paper 1A and Paper 1B are to be completed together without interruptions.

The questions on paper 1 test assessment objectives 1, 2 and 3.

The use of calculators is permitted. See the *Calculators guidance for examinations booklet* on the Programme Resource Centre.

### Paper 2

**Duration: 1 hour and 30 minutes**

**Weighting: 44%**

**Marks: 50**

**Section A—34 marks**

- Data-based question.
- Short-answer questions on standard level material.

**Section B—16 marks**

- Extended-response questions on standard level material.

  One of two extended-response questions to be attempted by candidates.

The questions on paper 2 test assessment objectives 1, 2 and 3.

The use of calculators is permitted. See the *Calculators guidance for examinations booklet* on the Programme Resource Centre.

# External assessment details—HL

## Paper 1

**Duration: 2 hours**

**Weighting: 36%**

**Marks: 75**

**Paper 1 is presented as two separate booklets**

Paper 1A—40 marks

- 40 multiple-choice questions on standard level and additional higher level material.

  No marks are deducted for incorrect answers.

Paper 1B—35 marks

- Four data-based questions related to experimental work and the syllabus.

| Paper 1A and Paper 1B are to be completed together without interruptions. |
| --- |

The questions on paper 1 test assessment objectives 1, 2 and 3.

The use of calculators is permitted. See the *Calculators guidance for examinations booklet* on the Programme Resource Centre.

## Paper 2

**Duration: 2 hours and 30 minutes**

**Weighting: 44%**

**Marks: 80**

**Section A—48 marks**

- Data-based question.
- Short-answer questions on standard level and additional higher level material.

**Section B—32 marks**

- Extended-response questions on standard level and additional higher level material.

  Two of three extended-response questions to be attempted by candidates.

The questions on paper 2 test assessment objectives 1, 2 and 3.

The use of calculators is permitted. See the *Calculators guidance for examinations booklet* on the Programme Resource Centre.

# Internal assessment

## Purpose of internal assessment

Internal assessment is an integral part of the course and is compulsory for both SL and HL students. It enables students to demonstrate the application of their skills and knowledge, and to pursue their personal interests, without the time limitations and other constraints that are associated with written examinations. The internal assessment should, as far as possible, be woven into normal classroom teaching and not be a separate activity conducted after a course has been taught.

The internal assessment requirements at SL and at HL are the same.

## Guidance and authenticity

The scientific investigation (SL and HL) submitted for internal assessment must be the student's own work. However, it is not the intention that students should decide upon a title or topic and be left to work on the internal assessment component without any further support from the teacher. The teacher should play an important role during both the planning stage and the period when the student is working on the internally assessed work. It is the responsibility of the teacher to ensure that students are familiar with:

- the requirements of the type of work to be internally assessed
- the *Sciences experimentation guidelines* publication
- the assessment criteria. Students must understand that the work submitted for assessment must address these criteria effectively.

Teachers and students must discuss the internally assessed work. Students should be encouraged to initiate discussions with the teacher to obtain advice and information, and students must not be penalized for seeking guidance. As part of the learning process, teachers should read and give advice to students on one draft of the work. The teacher should provide oral or written advice on how the work could be improved, but not edit the draft. The next version handed to the teacher must be the final version for submission.

It is the responsibility of teachers to ensure that all students understand the basic meaning and significance of concepts that relate to academic integrity, especially authenticity and intellectual property. Teachers must ensure that all student work for assessment is prepared according to the requirements and must explain clearly to students that the internally assessed work must be entirely their own. Where collaboration between students is permitted, it must be clear to all students what the difference is between collaboration and collusion.

All work submitted to the IB for moderation or assessment must be authenticated by a teacher, and must not include any known instances of suspected or confirmed malpractice. Each student must confirm that the work is their authentic work and constitutes the final version of that work. Once a student has officially submitted the final version of the work, it cannot be retracted. The requirement to confirm the authenticity of work applies to the work of all students, not just the sample work that will be submitted to the IB for the purpose of moderation. For further details, refer to the IB publications *Academic integrity*, *Diploma Programme: From principles into practice* and the relevant general regulations (in *Diploma Programme Assessment procedures*).

Authenticity may be checked by discussion with the student on the content of the work, and by scrutiny of one or more of the following.

- The student's initial proposal
- The first draft of the written work
- The references cited

- The style of writing compared with work known to be that of the student
- The analysis of the work by a web-based plagiarism detection service such as www.turnitin.com

The same piece of work cannot be submitted to meet the requirements of both the IA and the EE.

# Time allocation

Internal assessment is an integral part of the biology course, contributing 20% to the final assessment in the SL and the HL courses. This weighting should be reflected in the time that is allocated to teaching the knowledge, skills and understanding required to undertake the work, as well as the total time allocated to carry out the work.

It is recommended that a total of approximately 10 hours (SL and HL) of teaching time should be allocated to the work. This should include:

- time for the teacher to explain to students the requirements of the internal assessment
- class time for students to work on the internal assessment component and ask questions
- time for consultation between the teacher and each student
- time to review and monitor progress, and to check authenticity.

# Safety requirements and recommendations

It is the responsibility of everyone involved in science education to make an ongoing commitment to safe and healthy practical work.

The working practices and protocols should be effective in safeguarding students and protecting the environment. Schools are responsible for following national or local guidelines, which differ from country to country. The *Biology teacher support material* provides some further guidance.

# Using assessment criteria for internal assessment

For internal assessment, a number of assessment criteria have been identified. Each assessment criterion has level descriptors describing specific achievement levels, together with an appropriate range of marks. The level descriptors concentrate on positive achievement, although for the lower levels failure to achieve may be included in the description.

Teachers must judge the internally assessed work at SL and at HL against the criteria using the level descriptors.

- The same assessment criteria are provided for SL and HL.
- The aim is to find, for each criterion, the descriptor that conveys most accurately the level attained by the student, using the best-fit model. A best-fit approach means that compensation should be made when a piece of work matches different aspects of a criterion at different levels. The mark awarded should be one that most fairly reflects the balance of achievement against the criterion. It is not necessary for every single aspect of a level descriptor to be met for that mark to be awarded.
- When assessing a student's work, teachers should read the level descriptors for each criterion until they reach a descriptor that most appropriately describes the level of the work being assessed. If a piece of work seems to fall between two descriptors, both descriptors should be read again and the one that more appropriately describes the student's work should be chosen.
- Where there are two marks available within a level, teachers should award the upper marks if the student's work demonstrates the qualities described to a great extent; the work may be close to achieving marks in the level above. Teachers should award the lower marks if the student's work demonstrates the qualities described to a lesser extent; the work may be close to achieving marks in the level below.
- Only whole numbers should be recorded; partial marks (fractions and decimals) are not acceptable.

- Teachers should not think in terms of a pass or fail boundary but should concentrate on identifying the appropriate descriptor for each assessment criterion.
- The highest level descriptors do not imply faultless performance but should be achievable by a student. Teachers should not hesitate to use the extremes if they are appropriate descriptions of the work being assessed.
- A student who attains a high achievement level in relation to one criterion will not necessarily attain high achievement levels in relation to the other criteria. Similarly, a student who attains a low achievement level for one criterion will not necessarily attain low achievement levels for the other criteria. Teachers should not assume that the overall assessment of the students will produce any particular distribution of marks.
- It is recommended that the assessment criteria be made available to students.

# Internal assessment details—SL and HL

## The scientific investigation

**Duration: 10 hours**

**Weighting: 20%**

The IA requirement is the same for biology, chemistry and physics. The IA, worth 20% of the final assessment, consists of one task—the scientific investigation.

The scientific investigation is an open-ended task in which the student gathers and analyses data in order to answer their own formulated research question.

The outcome of the scientific investigation will be assessed through the form of a written report. The maximum overall word count for the report is 3,000 words.

The following are not included in the word count.

- Charts and diagrams
- Data tables
- Equations, formulas and calculations
- Citations/references (whether parenthetical, numbered, footnotes or endnotes)
- Bibliography
- Headers

The following details should be stated at the start of the report.

- Title of the investigation
- IB candidate code (alphanumeric, for example, xyz123)
- IB candidate code for all group members (if applicable)
- Number of words

There is no requirement to include a cover page or a contents page.

### Facilitating the scientific investigation

The research question should be of interest to the student, but it is not necessary that it encompasses concepts beyond those described by the understandings within the guide.

The scientific investigation undertaken must have sufficient extent and depth to allow for all the descriptors of the assessment criteria to be meaningfully addressed.

The investigation of the research question must involve the collection and analysis of quantitative data that should be supported by qualitative observations where appropriate.

The scientific investigation allows a wide range of techniques for data gathering and analysis to be employed. The approaches that could be used in isolation or in conjunction with each other are as follows.

- Hands-on practical laboratory work

- Fieldwork
- Use of a spreadsheet for analysis and modelling
- Extraction and analysis of data from a database
- Use of a simulation.

The *Biology teacher support material* contains further guidance on these possible approaches.

Teachers must:

- ensure that students are familiar with the assessment criteria
- ensure that students are able to investigate their individual research question
- counsel the students on whether their proposed methodology is feasible in consideration of available time and resources
- ensure that students have given appropriate consideration to safety, ethical and environmental factors before undertaking the action phase
- remind students of the requirements for academic integrity and the consequences of academic malpractice. The difference between collaboration and collusion must be made clear.

### Developing the research question

Each student is expected to formulate, investigate and answer a unique research question, seeking advice from their teacher.

A student must not present the same set of raw data as another student.

### Methodology for individual work

Each student develops their own methodology to answer their individual research question. The student investigates by:

- manipulating an independent variable

**or**

- selecting variables during fieldwork

**or**

- selecting different data from external databases.

The student might seek support from peers when collecting data.

### Methodology for collaborative work

Collaborative work is optional and where it is facilitated the groups formed must be no larger than three students. Students may organize their own groups. The teacher must provide guidance to ensure that all students are fully engaged in the collaborative activity. Students must clearly understand the requirement to conduct an individual investigation.

The methodology developed to answer their individual research question may be in part the outcome of collaborative activity. A student within the group investigates their individual research question by manipulating:

- a different independent variable from those selected by other group members

**or**

- the same independent variable with a different dependent variable from those selected by other group members

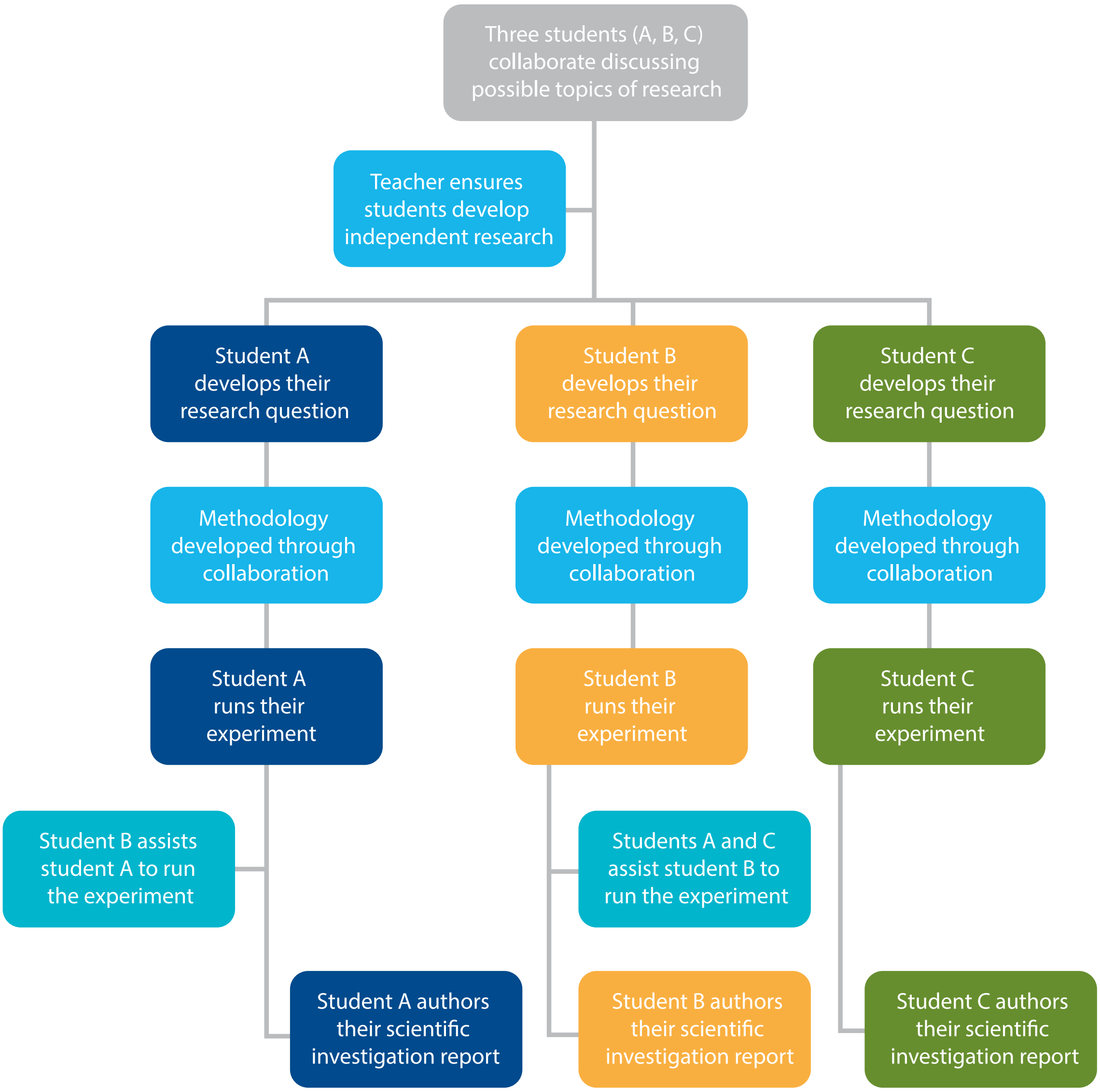
**or**

- different data from those selected by other group members from within a larger communally acquired data set.

In this context, collaborative work is permitted under the understanding that the final report presented for assessment is that of the individual student. A report by the group is not permitted. All authoring, including the description of the methodology, must be done individually. This diagram illustrates a possible route through the IA process where students collaborate.

*Figure 3*

*A possible route through collaborative work*




## Class collaboration to set up a database

A school may take part in a large-scale activity collecting data to generate a database using standardized protocols. If a student decides to utilize this database in order to answer their research question, then the investigation must be treated as a database investigation. In such a case the methodology should be focused on the way the data is filtered and sampled from the whole database in the same way as if the data was wholly acquired from an external source.

## Assessing the scientific investigation

The performance in IA at both SL and HL is marked against common assessment criteria, with a total mark out of 24. Student work is internally assessed by the teacher and externally moderated by the IB.

The four assessment criteria are as follows.

- Research design

- Data analysis
- Conclusion
- Evaluation

Each assessment criterion has level descriptors describing specific achievement levels, together with an appropriate range of marks. The level descriptors concentrate on positive achievement, although for the lower levels failure to achieve may be included in the description.

Teachers must judge the internally assessed work at SL and at HL against the same criteria using the level descriptors and aided by the clarifications. The criteria must be applied systematically using a best-fit approach—when a piece of work matches different aspects of a criterion at different levels the mark awarded should be one that most fairly reflects the balance of achievement against the criterion. It is not necessary for every single aspect of a level descriptor to be met for that mark to be awarded. The highest level descriptors do not imply faultless performance.

Where there are two or more marks available within a level, teachers should award the upper mark if the student's work largely satisfies the qualities described; the work may be close to achieving marks in the level above. Teachers should award the lower marks if the student's work demonstrates the qualities described to a lesser extent; the work may be close to achieving marks in the level below.

Only whole numbers must be recorded; partial marks (fractions and decimals) are not acceptable.

The criteria should be considered independently. A student who attains a high achievement level in relation to one criterion will not necessarily attain high achievement levels in relation to the other criteria. Similarly, a student who attains a low achievement level for one criterion will not necessarily attain low achievement levels for the other criteria. Teachers should not assume that the overall assessment of the students will produce any particular distribution of marks.

Where command terms are used in the level descriptors, they are to be interpreted as indicated in the "Glossary of command terms" section of this guide. These command terms indicate the depth of treatment required. Command terms used within the descriptors are provided in the following table.

| Assessment objective | Command term | Descriptor |
|---|---|---|
| AO1 | State | Give a specific name, value or other brief answer without explanation or calculation. |
| AO2 | Identify | Provide an answer from a number of possibilities. |
| AO2 | Outline | Give a brief account or summary. |
| AO2 | Describe | Give a detailed account. |
| AO3 | Explain | Give a detailed account including reasons or causes. |
| AO3 | Justify | Give valid reasons or evidence to support an answer or conclusion. |

### Referencing and academic integrity

Appropriate referencing to sourced information used in the report of the scientific investigation is expected. Omitted or improper referencing will be considered to be academic malpractice.

Students must ensure their assessment work adheres to the IB's academic integrity policy and that all sources are appropriately referenced. A student's failure to appropriately acknowledge a source will be investigated by the IB as a potential breach of regulations that may result in a penalty imposed by the IB Final Award Committee. See the "Academic integrity" section of this guide for full details.

# Internal assessment criteria—SL and HL

**Download:** Internal assessment criteria—SL and HL (PDF)

There are four IA criteria for the scientific investigation. The marks and weightings are as follows.

| Criterion | Maximum number of marks available | Weighting (%) |
| --- | --- | --- |
| Research design | 6 | 25 |
| Data analysis | 6 | 25 |
| Conclusion | 6 | 25 |
| Evaluation | 6 | 25 |
| **Total** | **24** | **100** |

## Research design

This criterion assesses the extent to which the student effectively communicates the methodology (purpose and practice) used to address the research question.

| Marks | Level descriptor |
| --- | --- |
| 0 | The report does not reach the standard described by the descriptors below. |
| 1–2 | • The research question is stated without context.<br>• Methodological considerations associated with collecting data relevant to the research question are stated.<br>• The description of the methodology for collecting or selecting data lacks the detail to allow for the investigation to be reproduced. |
| 3–4 | • The research question is outlined within a broad context.<br>• Methodological considerations associated with collecting relevant and sufficient data to answer the research question are described.<br>• The description of the methodology for collecting or selecting data allows for the investigation to be reproduced with few ambiguities or omissions. |
| 5–6 | • The research question is described within a specific and appropriate context.<br>• Methodological considerations associated with collecting relevant and sufficient data to answer the research question are explained.<br>• The description of the methodology for collecting or selecting data allows for the investigation to be reproduced. |

| Clarifications for research design |
| --- |
| A research question with context should contain reference to the dependent and independent variables or two correlated variables, include a concise description of the system in which the research question is embedded, and include background theory of direct relevance.<br>Methodological considerations include:<br>• the selection of the methods for measuring the dependent and independent variables<br>• the selection of the databases or model and the sampling of data<br>• the decisions regarding the scope, quantity and quality of measurements (e.g. the range, interval or frequency of the independent variable, repetition and precision of measurements)<br>• the identification of control variables and the choice of method of their control<br>• the recognition of any safety, ethical or environmental issues that needed to be taken into account.<br>The description of the methodology refers to presenting sufficiently detailed information (such as specific materials used and precise procedural steps) while avoiding unnecessary or repetitive information, so that |

| Clarifications for research design |
|---|
| the reader may readily understand how the methodology was implemented and could in principle repeat the investigation. |

## Data analysis

This criterion assesses the extent to which the student's report provides evidence that the student has recorded, processed and presented the data in ways that are relevant to the research question.

| Marks | Level descriptor |
|---|---|
| 0 | The report does not reach a standard described by the descriptors below. |
| 1–2 | • The recording and processing of the data is communicated but is neither clear nor precise.<br>• The recording and processing of data shows limited evidence of the consideration of uncertainties.<br>• Some processing of data relevant to addressing the research question is carried out but with major omissions, inaccuracies or inconsistencies. |
| 3–4 | • The communication of the recording and processing of the data is either clear or precise.<br>• The recording and processing of data shows evidence of a consideration of uncertainties but with some significant omissions or inaccuracies.<br>• The processing of data relevant to addressing the research question is carried out but with some significant omissions, inaccuracies or inconsistencies. |
| 5–6 | • The communication of the recording and processing of the data is both clear and precise.<br>• The recording and processing of data shows evidence of an appropriate consideration of uncertainties.<br>• The processing of data relevant to addressing the research question is carried out appropriately and accurately. |

| Clarifications for data analysis |
|---|
| Data refers to quantitative data or a combination of both quantitative and qualitative data.<br>**Communication**<br>• Clear communication means that the method of processing can be understood easily.<br>• Precise communication refers to following conventions correctly, such as those relating to the annotation of graphs and tables or the use of units, decimal places and significant figures.<br>Consideration of uncertainties is subject specific and further guidance is given in the *Biology teacher support material*.<br>Major omissions, inaccuracies or inconsistencies impede the possibility of drawing a valid conclusion that addresses the research question.<br>Significant omissions, inaccuracies or inconsistencies allow the possibility of drawing a conclusion that addresses the research question but with some limit to its validity or detail. |

## Conclusion

This criterion assesses the extent to which the student successfully answers their research question with regard to their analysis and the accepted scientific context.

| Marks | Level descriptor |
|---|---|
| 0 | The report does not reach a standard described by the descriptors below. |
| 1–2 | • A conclusion is stated that is relevant to the research question but is not supported by the analysis presented.<br>• The conclusion makes superficial comparison to the accepted scientific context. |
| 3–4 | • A conclusion is described that is relevant to the research question but is not fully consistent with the analysis presented.<br>• A conclusion is described that makes some relevant comparison to the accepted scientific context. |
| 5–6 | • A conclusion is justified that is relevant to the research question and fully consistent with the analysis presented.<br>• A conclusion is justified through relevant comparison to the accepted scientific context. |

| Clarifications for conclusion |
|---|
| A conclusion that is fully consistent requires the interpretation of processed data including associated uncertainties.<br>Scientific context refers to information that could come from published material (paper or online), published values, course notes, textbooks or other outside sources. The citation of published materials must be sufficiently detailed to allow these sources to be traceable. |

## Evaluation

This criterion assesses the extent to which the student's report provides evidence of evaluation of the investigation methodology and has suggested improvements.

| Marks | Level descriptor |
|---|---|
| 0 | The report does not reach a standard described by the descriptors below. |
| 1–2 | • The report states generic methodological weaknesses or limitations.<br>• Realistic improvements to the investigation are stated. |
| 3–4 | • The report describes specific methodological weaknesses or limitations.<br>• Realistic improvements to the investigation that are relevant to the identified weaknesses or limitations, are described. |
| 5–6 | • The report explains the relative impact of specific methodological weaknesses or limitations.<br>• Realistic improvements to the investigation, that are relevant to the identified weaknesses or limitations, are explained. |

| Clarifications for evaluation |
|---|
| Generic is general to many methodologies and not specifically relevant to the methodology of the investigation being evaluated.<br>Methodological refers to the overall approach to the investigation of the research question as well as procedural steps.<br>Weaknesses could relate to issues regarding the control of variables, the precision of measurement or the variation in the data. |

| Clarifications for evaluation |
| --- |
| Limitations could refer to how the conclusion is limited in scope by the range of the data collected, the confines of the system or the applicability of assumptions made. |

# Glossary of command terms

## Command terms for biology

Students must be familiar with the following key terms and phrases used in examination questions, which are to be understood as described in this section. Although these terms will be used frequently in examination questions, other terms may be used to direct students to present an argument in a specific way. These command terms indicate the depth of treatment required.

### Assessment objective 1

| Command term | Definition |
|---|---|
| Define | Give the precise meaning of a word, phrase, concept or physical quantity. |
| Draw | Represent by means of a labelled, accurate diagram or graph, using a pencil. A ruler (straight edge) should be used for straight lines. Diagrams should be drawn to scale. Graphs should have points correctly plotted (if appropriate) and joined in a straight line or smooth curve. |
| Label | Add labels to a diagram. |
| List | Give a sequence of brief answers with no explanation. |
| Measure | Obtain a value for a quantity. |
| State | Give a specific name, value or other brief answer without explanation or calculation. |

### Assessment objective 2

| Command term | Definition |
|---|---|
| Annotate | Add brief notes to a diagram or graph. |
| Calculate | Obtain a numerical answer showing the relevant stages in the working. |
| Describe | Give a detailed account. |
| Distinguish | Make clear the differences between two or more concepts or items. |
| Estimate | Obtain an approximate value. |
| Identify | Provide an answer from a number of possibilities. |
| Outline | Give a brief account or summary. |

### Assessment objective 3

| Command term | Definition |
|---|---|
| Analyse | Break down in order to bring out the essential elements or structure. |
| Comment | Give a judgement based on a given statement or result of a calculation. |
| Compare | Give an account of the similarities between two (or more) items or situations, referring to both (all) of them throughout. |

| Command term | Definition |
|---|---|
| Compare and contrast | Give an account of similarities and differences between two (or more) items or situations, referring to both (all) of them throughout. |
| Construct | Display information in a diagrammatic or logical form. |
| Deduce | Reach a conclusion from the information given. |
| Design | Produce a plan, simulation or model. |
| Determine | Obtain the only possible answer. |
| Discuss | Offer a considered and balanced review that includes a range of arguments, factors or hypotheses. Opinions or conclusions should be presented clearly and supported by appropriate evidence. |
| Evaluate | Make an appraisal by weighing up the strengths and limitations. |
| Explain | Give a detailed account including reasons or causes. |
| Justify | Give valid reasons or evidence to support an answer or conclusion. |
| Predict | Give an expected result. |
| Sketch | Represent by means of a diagram or graph (labelled as appropriate). The sketch should give a general idea of the required shape or relationship, and should include relevant features. |
| Suggest | Propose a solution, hypothesis or other possible answer. |

# Bibliography

This bibliography lists the principal works used to inform the curriculum review. It is not an exhaustive list and does not include all the literature available: judicious selection was made in order to better advise and guide teachers. This bibliography is not a list of recommended textbooks.

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