Biology

First examinations 2009

Diploma Programme

Guide

IBO

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International Baccalaureate Organization

Buenos Aires Cardiff Geneva New York Singapore

Diploma Programme
Biology—guide

Published March 2007

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Printed in the United Kingdom by Antony Rowe Ltd, Chippenham, Wiltshire

4016

IBO mission statement

The International Baccalaureate Organization 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 IBO 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.

IB learners strive to be:

Inquirers	They develop their natural curiosity. They acquire the skills necessary to conduct inquiry and research and show independence in learning. They actively enjoy learning and this love of learning will be sustained throughout their lives.
Knowledgeable	They explore concepts, ideas and issues that have local and global significance. In so doing, they acquire in-depth knowledge and develop understanding across a broad and balanced range of disciplines.
Thinkers	They exercise initiative in applying thinking skills critically and creatively to recognize and approach complex problems, and make reasoned, ethical decisions.
Communicators	They understand and express ideas and information confidently and creatively in more than one language and in a variety of modes of communication. They work effectively and willingly in collaboration with others.
Principled	They act with integrity and honesty, with a strong sense of fairness, justice and respect for the dignity of the individual, groups and communities. They take responsibility for their own actions and the consequences that accompany them.
Open-minded	They understand and appreciate their own cultures and personal histories, and are open to the perspectives, values and traditions of other individuals and communities. They are accustomed to seeking and evaluating a range of points of view, and are willing to grow from the experience.
Caring	They show empathy, compassion and respect towards the needs and feelings of others. They have a personal commitment to service, and act to make a positive difference to the lives of others and to the environment.
Risk-takers	They approach unfamiliar situations and uncertainty with courage and forethought, and have the independence of spirit to explore new roles, ideas and strategies. They are brave and articulate in defending their beliefs.
Balanced	They understand the importance of intellectual, physical and emotional balance to achieve personal well-being for themselves and others.
Reflective	They give thoughtful consideration to their own learning and experience. They are able to assess and understand their strengths and limitations in order to support their learning and personal development.

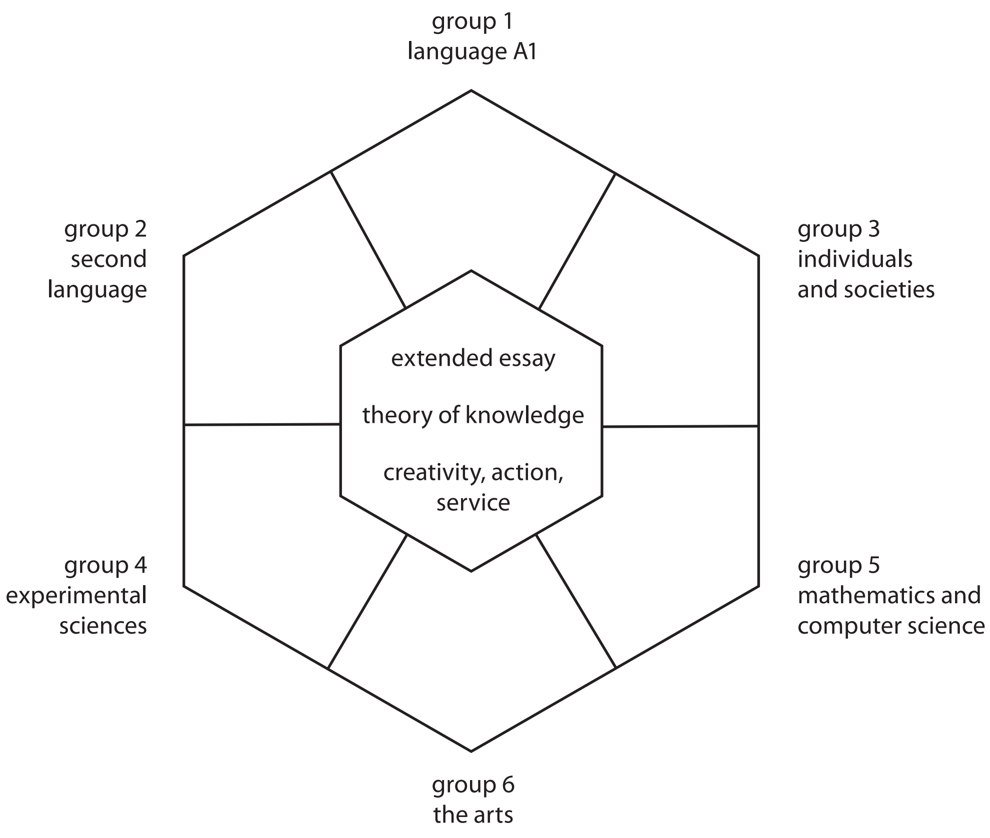
Contents

The Diploma Programme

The Diploma Programme 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 hexagon

The course is presented as six academic areas enclosing a central core. 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; one of the creative arts. It is this comprehensive range of subjects that makes the Diploma Programme 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.



Choosing the right combination

Students are required to choose one subject from each of the six academic areas, although they can choose a second subject from groups 1 to 5 instead of a group 6 subject. Normally, three subjects (and not more than four) are taken at higher level (HL), and the others are taken at standard level (SL). The IBO 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 course is available for examinations in English, French and Spanish.

The core of the hexagon

All Diploma Programme students participate in the three course requirements that make up the core of the hexagon. Reflection on all these activities is a principle that lies at the heart of the thinking behind the Diploma Programme.

The theory of knowledge (TOK) course encourages students to think about the nature of knowledge, to reflect on the process of learning in all the subjects they study as part of their Diploma Programme course, and to make connections across the academic areas. The extended essay, a substantial piece of writing of up to 4,000 words, enables students to investigate a topic of special interest that they have chosen themselves. It also encourages them to develop the skills of independent research that will be expected at university. Creativity, action, service (CAS) involves students in experiential learning through a range of artistic, sporting, physical and service activities.

The IBO mission statement and the IB learner profile

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

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Nature of group 4 subjects

Difference between SL and HL

Group 4 students at standard level (SL) and higher level (HL) undertake a common core syllabus, a common internal assessment (IA) scheme and have some overlapping elements in the options studied. They are presented with a syllabus that encourages the development of certain skills, attributes and attitudes, as described in the "Objectives" section of this guide.

While the skills and activities of group 4 science subjects are common to students at both SL and HL, students at HL are required to study some topics in greater depth, to study additional topics and to study extension material of a more demanding nature in the common options. The distinction between SL and HL is one of breadth and depth.

Group 4 subjects and prior learning

Past experience shows that students will be able to study a group 4 science subject at SL successfully with no background in, or previous knowledge of, science. Their approach to study, characterized by the specific IB learner profile attributes—inquirers, thinkers and communicators—will be significant here.

However, for most students considering the study of a group 4 subject at HL, while there is no intention to restrict access to group 4 subjects, some previous exposure to the specific group 4 subject would be necessary. Specific topic details are not specified but students who have undertaken the IB Middle Years Programme (MYP) or studied an international GCSE science subject would be well prepared. Other national science qualifications or a school-based science course would also be suitable preparation for study of a group 4 subject at HL.

Group 4 subjects and the MYP

Students who have undertaken the MYP sciences, technology and mathematics courses will be well prepared for group 4 subjects. The MYP science objectives and assessment criteria A–F are aligned with the group 4 objectives and IA criteria, and allow for a smooth transition from the MYP to Diploma Programme. In particular, the "One world" objective in MYP sciences is further developed in group 4 science with the increased emphasis on aim 8—that is, to "raise awareness of the moral, ethical, social, economic and environmental implications of using science and technology". There are specific references to aim 8 implications in assessment statements and teacher's notes in the syllabus details sections in all group 4 guides.

Group 4 subjects and TOK

In looking at the ways of knowing described in the *Theory of knowledge* guide (March 2006), scientists could legitimately claim that science encompasses all these. Driven by emotion, using sense perception, enhanced by technology and combined with reason, it communicates through language, principally the universal language of mathematics.

There is no one scientific method, in the strict Popperian sense, of gaining knowledge, of finding explanations for the behaviour of the natural world. Science works through a variety of approaches to produce these explanations, but they all rely on data from observations and experiments and have a common underpinning rigour, whether using inductive or deductive reasoning. The explanation may be in the form of a theory, sometimes requiring a model that contains elements not directly observable. Producing these theories often requires an imaginative, creative leap. Where such a predictive theoretical model is not possible, the explanation may consist of identifying a correlation between a factor and an outcome. This correlation may then give rise to a causal mechanism that can be experimentally tested, leading to an improved explanation. All these explanations require an understanding of the limitations of data, and the extent and limitations of our knowledge. Science requires freedom of thought and open-mindedness, and an essential part of the process of science is the way the international scientific community subjects the findings of scientists to intense critical scrutiny through the repetition of experiments and the peer review of results in scientific journals and at conferences. The syllabus details sections in the group 4 guides give references in teacher's notes to appropriate topics where these aspects of the scientific way of knowing can be addressed.

Group 4 subjects and the international dimension

Science itself is an international endeavour—the exchange of information and ideas across national boundaries has been essential to the progress of science. This exchange is not a new phenomenon but it has accelerated in recent times with the development of information and communication technologies. Indeed, the idea that science is a Western invention is a myth—many of the foundations of modern-day science were laid many centuries before by Arabic, Indian and Chinese civilizations, among others. Teachers are encouraged to emphasize this contribution in their teaching of various topics, perhaps through the use of time-line web sites. The scientific method in its widest sense, with its emphasis on peer review, open-mindedness and freedom of thought, transcends politics, religion and nationality. Where appropriate within certain topics, the syllabus details sections in the group 4 guides contain assessment statements and teacher's notes illustrating the international aspects of science.

On an organizational level, many international bodies now exist to promote science. United Nations bodies such as UNESCO, UNEP and WMO, where science plays a prominent part, are well known, but in addition there are hundreds of international bodies representing every branch of science. The facilities for large-scale experimental science in, for example, particle physics and the Human Genome Project, are expensive and only joint ventures involving funding from many countries allow this to take place. The data from such research is shared by scientists worldwide. Group 4 students are encouraged to access the extensive web sites of these international scientific organizations to enhance their appreciation of the international dimension.

Increasingly, however, there is a recognition that many scientific problems, from climate change to AIDS, are international in nature and this has led to a global approach to research in many areas. The reports of the intergovernmental panel on climate change are a prime example of this. Some topics in the group 4 guides are specifically written to bring out this global research.

On a practical level, the group 4 project (which all science students must undertake) mirrors the work of real scientists by encouraging collaboration between schools across the regions.

The power of scientific knowledge to transform societies is unparalleled. It has the potential to produce great universal benefits or to reinforce inequalities and cause harm to people and the environment. In line with the IBO mission statement, group 4 students need to be aware of the moral responsibility of scientists to ensure that scientific knowledge and data are available to all countries on an equitable basis and that they have the scientific capacity to use this for developing sustainable societies.

Curriculum model

A common curriculum model applies to all the Diploma Programme group 4 subjects: biology, chemistry, physics and design technology. (There are some differences in this model for design technology and these arise from the design project, which is a unique feature of this subject.) Students at both SL and HL study a core syllabus, and this is supplemented by the study of options. Students at HL also study additional higher level (AHL) material. Students at both SL and HL study two options. There are three kinds of options: those specific to SL students, those specific to HL students and those that can be taken by both SL and HL students.

Students at SL are required to spend 40 hours, and students at HL 60 hours, on practical/investigative work. This includes 10 hours for the group 4 project.

SL group 4 curriculum model

SL	Total teaching hours	150
Theory		**110**
	Core	80
	Options	30
Practical work		**40**
	Investigations	30
	Group 4 project	10

HL group 4 curriculum model

HL	Total teaching hours	240
Theory		**180**
	Core	80
	Additional higher level (AHL)	55
	Options	45
Practical work		**60**
	Investigations	50
	Group 4 project	10

Format of the syllabus details

Note: The order in which the syllabus content is presented is not intended to represent the order in which it should be taught.

The format of the syllabus details section of the group 4 guides is the same for each subject. The structure is as follows.

Topics or options

Topics are numbered and options are indicated by a letter (for example, “Topic 5: Ecology and evolution”, or “Option D: Evolution”).

Sub-topics

Sub-topics are numbered and the estimated teaching time required to cover the material is indicated (for example, “7.1 DNA structure (2 hours)”). These times are for guidance only and do not include time for practical/investigative work.

Assessment statements (AS)

Assessment statements, which are numbered, are expressed in terms of the outcomes that are expected of students at the end of the course (for example, “5.1.2 Distinguish between *autotroph* and *heterotroph*”). These are intended to prescribe to examiners what can be assessed by means of the written examinations. Each one is classified as objective 1, 2 or 3 (see the “Objectives” section) according to the command terms used (see the “Command terms” section). The objective levels are relevant for the examinations and for balance within the syllabus, while the command terms indicate the depth of treatment required for a given assessment statement. It is important that students are made aware of the meanings of the command terms because these will be used in examination questions. (When the command term “define” is used, the word(s) or phrase to be defined is in italics. When the command term “distinguish” is used, the terms or concepts to be distinguished are also in italics.)

Teacher’s notes

Teacher’s notes, which are included alongside some assessment statements, provide further guidance to teachers.

They may also suggest ideas for the promotion of aim 7, aim 8, TOK and the international dimension (Int).

Topic 2: Cells (12 hours) — Topic or option

2.1 Cell theory — Sub-topic

3 hours

	Assessment statement	Obj	Teacher's notes
2.1.1	Outline the cell theory.	2	Include the following. • Living organisms are composed of cells. • Cells are the smallest unit of life. • Cells come from pre-existing cells.
2.1.2	Discuss the evidence for the cell theory.	3	**TOK:** The nature of scientific theories could be introduced here: the accumulation of evidence that allows a hypothesis to become a theory; whether a theory should be abandoned when there is evidence that it does not offer a full explanation; and what evidence is needed for a theory to be adopted or rejected.
2.1.3	State that unicellular organisms carry out all the functions of life.	1	Include metabolism, response, homeostasis, growth, reproduction and nutrition.
2.1.4	Compare the relative sizes of molecules, cell membrane thickness, viruses, bacteria, organelles and cells, using the appropriate SI unit.	3	Appreciation of relative size is required, such as molecules (1 nm), thickness of membranes (10 nm), viruses (100 nm), bacteria (1 µm), organelles (up to 10 µm), and most cells (up to 100 µm). The three-dimensional nature/shape of cells should be emphasized. **TOK:** All the biological entities in the above list are beyond our ability to perceive directly. They must be observed through the use of technology such as the light microscope and the electron microscope. Is there any distinction to be drawn between knowledge claims dependent upon observations made directly with the senses and knowledge claims dependent upon observations assisted by technology?
2.1.5	Calculate the linear magnification of drawings and the actual size of specimens in images of known magnification.	2	Magnification could be stated (for example, ×250) or indicated by means of a scale bar, for example. 1 µm **Aim 7:** The size of objects in digital images of microscope fields could be analysed using graticule baselines and image-processing software.
2.1.6	Explain the importance of the surface area to volume ratio as a factor limiting cell size.	3	Mention the concept that the rate of heat production/waste production/resource consumption of a cell is a function of its volume, whereas the rate of exchange of materials and energy (heat) is a function of its surface area. Simple mathematical models involving cubes and the changes in the ratio that occur as the sides increase by one unit could be compared. **Aim 7:** Data logging could be carried out to measure changes in conductivity in distilled water as salt diffuses out of salt–agar cubes of different dimensions.

Assessment statement

Teacher's notes

Objective

Aims

Through studying any of the group 4 subjects, students should become aware of how scientists work and communicate with each other. While the “scientific method” may take on a wide variety of forms, it is the emphasis on a practical approach through experimental work that distinguishes the group 4 subjects from other disciplines and characterizes each of the subjects within group 4.

It is in this context that all the Diploma Programme experimental science courses should aim to:

1. provide opportunities for scientific study and creativity within a global context that will stimulate and challenge students
2. provide a body of knowledge, methods and techniques that characterize science and technology
3. enable students to apply and use a body of knowledge, methods and techniques that characterize science and technology
4. develop an ability to analyse, evaluate and synthesize scientific information
5. engender an awareness of the need for, and the value of, effective collaboration and communication during scientific activities
6. develop experimental and investigative scientific skills
7. develop and apply the students’ information and communication technology skills in the study of science
8. raise awareness of the moral, ethical, social, economic and environmental implications of using science and technology
9. develop an appreciation of the possibilities and limitations associated with science and scientists
10. encourage an understanding of the relationships between scientific disciplines and the overarching nature of the scientific method.

Objectives

The objectives for all group 4 subjects reflect those parts of the aims that will be assessed. Wherever appropriate, the assessment will draw upon environmental and technological contexts and identify the social, moral and economic effects of science.

It is the intention of all the Diploma Programme experimental science courses that students achieve the following objectives.

1. Demonstrate an understanding of:
    a. scientific facts and concepts
    b. scientific methods and techniques
    c. scientific terminology
    d. methods of presenting scientific information.
2. Apply and use:
    a. scientific facts and concepts
    b. scientific methods and techniques
    c. scientific terminology to communicate effectively
    d. appropriate methods to present scientific information.
3. Construct, analyse and evaluate:
    a. hypotheses, research questions and predictions
    b. scientific methods and techniques
    c. scientific explanations.
4. Demonstrate the personal skills of cooperation, perseverance and responsibility appropriate for effective scientific investigation and problem solving.
5. Demonstrate the manipulative skills necessary to carry out scientific investigations with precision and safety.

Command terms

These command terms indicate the depth of treatment required for a given assessment statement. These command terms will be used in examination questions, so it is important that students are familiar with the following definitions.

Objective 1

Define	Give the precise meaning of a word, phrase or physical quantity.
Draw	Represent by means of pencil lines.
Label	Add labels to a diagram.
List	Give a sequence of names or other brief answers with no explanation.
Measure	Find a value for a quantity.
State	Give a specific name, value or other brief answer without explanation or calculation.

Objective 2

Annotate	Add brief notes to a diagram or graph.
Apply	Use an idea, equation, principle, theory or law in a new situation.
Calculate	Find a numerical answer showing the relevant stages in the working (unless instructed not to do so).
Describe	Give a detailed account.
Distinguish	Give the differences between two or more different items.
Estimate	Find an approximate value for an unknown quantity.
Identify	Find an answer from a given number of possibilities.
Outline	Give a brief account or summary.

Objective 3

Analyse	Interpret data to reach conclusions.
Comment	Give a judgment based on a given statement or result of a calculation.
Compare	Give an account of similarities and differences between two (or more) items, referring to both (all) of them throughout.
Construct	Represent or develop in graphical form.
Deduce	Reach a conclusion from the information given.
Derive	Manipulate a mathematical relationship(s) to give a new equation or relationship.
Design	Produce a plan, simulation or model.
Determine	Find the only possible answer.
Discuss	Give an account including, where possible, a range of arguments for and against the relative importance of various factors, or comparisons of alternative hypotheses.
Evaluate	Assess the implications and limitations.
Explain	Give a detailed account of causes, reasons or mechanisms.
Predict	Give an expected result.
Show	Give the steps in a calculation or derivation.
Sketch	Represent by means of a graph showing a line and labelled but unscaled axes but with important features (for example, intercept) clearly indicated.
Solve	Obtain an answer using algebraic and/or numerical methods.
Suggest	Propose a hypothesis or other possible answer.

Assessment outline

SL assessment specifications

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Component	Overall weighting (%)	Approximate weighting of objectives (%) 1+2	3	Duration (hours)	Format and syllabus coverage
Paper 1	20	20		¾	30 multiple-choice questions on the core
Paper 2	32	16	16	1¼	Section A: one data-based question and several short-answer questions on the core (all compulsory) Section B: one extended-response question on the core (from a choice of three)
Paper 3	24	12	12	1	Several short-answer questions in each of the two options studied (all compulsory)

HL assessment specifications

First examinations 2009

Component	Overall weighting (%)	Approximate weighting of objectives (%) 1+2	3	Duration (hours)	Format and syllabus coverage
Paper 1	20	20		1	40 multiple-choice questions (±15 common to SL plus about five more on the core and about 20 more on the AHL)
Paper 2	36	18	18	2¼	Section A: one data-based question and several short-answer questions on the core and the AHL (all compulsory) Section B: two extended-response questions on the core and the AHL (from a choice of four)
Paper 3	20	10	10	1¼	Several short-answer questions and one extended-response question in each of the two options studied (all compulsory)

In addition to addressing objectives 1, 2 and 3, the internal assessment scheme for both SL and HL addresses objective 4 (personal skills) using the personal skills criterion to assess the group 4 project, and objective 5 (manipulative skills) using the manipulative skills criterion to assess practical work. For both SL and HL, calculators are not permitted in paper 1 but are required in papers 2 and 3.

External assessment

The external assessment consists of three written papers.

Paper 1

Paper 1 is made up of multiple-choice questions that test knowledge of the core only for students at SL and the core and AHL material for students at HL. The questions are designed to be short, one- or two-stage problems that address objectives 1 and 2 (see the "Objectives" section). No marks are deducted for incorrect responses. Calculators are not permitted, but students are expected to carry out simple calculations.

Paper 2

Paper 2 tests knowledge of the core only for students at SL and the core and AHL material for students at HL. The questions address objectives 1, 2 and 3 and the paper is divided into two sections.

In section A, there is a data-based question that requires students to analyse a given set of data. The remainder of section A is made up of short-answer questions.

In section B, students at SL are required to answer one question from a choice of three, and students at HL are required to answer two questions from a choice of four. These extended-response questions may involve writing a number of paragraphs, solving a substantial problem, or carrying out a substantial piece of analysis or evaluation. A calculator is required for this paper.

Paper 3

Paper 3 tests knowledge of the options and addresses objectives 1, 2 and 3. Students at SL are required to answer several short-answer questions in each of the two options studied. Students at HL are required to answer several short-answer questions and an extended-response question in each of the two options studied. A calculator is required for this paper.

Note: Wherever possible, teachers should use, and encourage students to use, the Système International d'Unités (International System of Units—SI units).

Practical work and internal assessment

General introduction

The internal assessment (IA) requirements are the same for all group 4 subjects, with the exception of design technology, which has an additional element. The IA, worth 24% of the final assessment (or 36% for design technology), consists of an interdisciplinary project, a mixture of short- and long-term investigations (such as practicals and subject-specific projects) and, for design technology only, the design project.

Student work is internally assessed by the teacher and externally moderated by the IBO. The performance in IA at both SL and HL is marked against assessment criteria, with each criterion having a maximum mark of 6.

Rationale for practical work

Although the requirements for IA are mainly centred on the assessment of practical skills, the different types of experimental work that a student may engage in serve other purposes, including:

- illustrating, teaching and reinforcing theoretical concepts
- developing an appreciation of the essential hands-on nature of scientific work
- developing an appreciation of the benefits and limitations of scientific methodology.

Therefore, there may be good justification for teachers to conduct further experimental work beyond that required for the IA scheme.

Practical scheme of work

The practical scheme of work (PSOW) is the practical course planned by the teacher and acts as a summary of all the investigative activities carried out by a student. Students at SL and HL in the same subject may carry out some of the same investigations.

Syllabus coverage

The range of investigations carried out should reflect the breadth and depth of the subject syllabus at each level, but it is not necessary to carry out an investigation for every syllabus topic. However, all students must participate in the group 4 project and the IA activities should ideally include a spread of content material from the core, options and, where relevant, AHL material. A minimum number of investigations to be carried out is not specified.

Choosing investigations

Teachers are free to formulate their own practical schemes of work by choosing investigations according to the requirements outlined. Their choices should be based on:

- subjects, levels and options taught
- the needs of their students
- available resources
- teaching styles.

Each scheme must include some complex investigations that make greater conceptual demands on students. A scheme made up entirely of simple experiments, such as ticking boxes or exercises involving filling in tables, will not provide an adequate range of experience for students.

Teachers are encouraged to use the online curriculum centre (OCC) to share ideas about possible investigations by joining in the discussion forums and adding resources in the subject home pages.

Note: Any investigation or part investigation that is to be used to assess students should be specifically designed to match the relevant assessment criteria.

Flexibility

The IA model is flexible enough to allow a wide variety of investigations to be carried out. These could include:

- short laboratory practicals over one or two lessons and long-term practicals or projects extending over several weeks
- computer simulations
- data-gathering exercises such as questionnaires, user trials and surveys
- data-analysis exercises
- general laboratory work and fieldwork.

The group 4 project

The group 4 project is an interdisciplinary activity in which all Diploma Programme science students must participate. The intention is that students from the different group 4 subjects analyse a common topic or problem. The exercise should be a collaborative experience where the emphasis is on the **processes** involved in scientific investigation rather than the **products** of such investigation.

In most cases all students in a school would be involved in the investigation of the same topic. Where there are large numbers of students, it is possible to divide them into several smaller groups containing representatives from each of the science subjects. Each group may investigate the same topic or different topics—that is, there may be several group 4 projects in the same school.

Practical work documentation

Details of an individual student's practical scheme of work are recorded on **form 4/PSOW** provided in section 4 of the *Vade Mecum*. Electronic versions may be used as long as they include all necessary information. In addition, the laboratory work corresponding to the best two marks achieved by each student when assessed using the internal assessment criteria (design, data collection and processing, and conclusion and evaluation) and the instructions given by the teacher for the laboratory work must be retained for possible inclusion in the sample work sent to an internal assessment moderator.

Time allocation for practical work

The recommended teaching times for all Diploma Programme courses are 150 hours at SL and 240 hours at HL. Students at SL are required to spend 40 hours, and students at HL 60 hours, on practical activities (excluding time spent writing up work). These times include 10 hours for the group 4 project. Only 2–3 hours of investigative work can be carried out after the deadline for submitting work to the moderator and still be counted in the total number of hours for the practical scheme of work.

Note: For design technology, students at SL are required to spend 55 hours, and students at HL 81 hours, on practical activities.

Only some of the 40/60 hours of practical work need be allocated to the practical work that is assessed using the IA criteria. This will normally be done during the latter part of the course when students have become more familiar with the criteria and can be assessed in complex practical work.

Guidance and authenticity

All students should be familiar with the requirements for IA. It should be made clear to them that they are entirely responsible for their own work. It is helpful if teachers encourage students to develop a sense of responsibility for their own learning so that they accept a degree of ownership and take pride in their own work.

In responding to specific questions from students concerning investigations, teachers should (where appropriate) guide students into more productive routes of inquiry rather than respond with a direct answer. As part of the learning process, teachers can give general advice to students on a first draft of their work for IA. However, constant drafting and redrafting is not allowed and the next version handed to the teacher after the first draft must be the final one. This is marked by the teacher using the IA criteria. It is useful to annotate this work with the levels awarded for each aspect—"c" for complete, "p" for partial and "n" for not at all, to assist the moderator should the work be selected as part of the sample.

In assessing student work using the IA criteria, teachers should only mark and annotate the final draft.

When completing an investigation outside the classroom, students should work independently. Teachers are required to ensure that work submitted is the student's own. If any doubt exists, authenticity may be checked by one or more of the following methods.

- Discussion with the student
- Asking the student to explain the methods used and to summarize the results
- Asking the student to repeat the investigation

Teachers are required to sign the IA coversheet to confirm that the work of each student is his or her own unaided work.

Safety

While teachers are responsible for following national or local guidelines, which may differ from country to country, attention should be given to the mission statement below, which was developed by the International Council of Associations for Science Education (ICASE) Safety Committee.

ICASE Safety Committee

Mission statement

> The mission of the ICASE Safety Committee is to promote good quality, exciting practical science, which will stimulate students and motivate their teachers, in a safe and healthy learning environment. In this way, all individuals (teachers, students, laboratory assistants, supervisors, visitors) involved in science education are entitled to work under the safest possible practicable conditions in science classrooms and laboratories. Every reasonable effort needs to be made by administrators to provide and maintain a safe and healthy learning

environment and to establish and require safe methods and practices at all times. Safety rules and regulations need to be developed and enforced for the protection of those individuals carrying out their activities in science classrooms and laboratories, and experiences in the field. Alternative science activities are encouraged in the absence of sufficiently safe conditions.

It is a basic responsibility of everyone involved to make safety and health an ongoing commitment. Any advice given will acknowledge the need to respect the local context, the varying educational and cultural traditions, the financial constraints and the legal systems of differing countries.

Internal assessment criteria

General information

The method of assessment used for internal assessment is criterion-related. That is to say, the method of assessment judges each student in relation to identified assessment criteria and not in relation to the work of other students.

The internal assessment component in all group 4 courses is assessed according to sets of assessment criteria and achievement level descriptors. The internal assessment criteria are for the use of teachers.

- For each assessment criterion, there are a number of descriptors that each describes a specific level of achievement.
- The descriptors concentrate on positive achievement, although for the lower levels failure to achieve may be included in the description.

Using the internal assessment criteria

Teachers should judge the internal assessment exercise against the descriptors for each criterion. The same internal assessment criteria are used for both SL and HL.

- The aim is to find, for each criterion, the descriptor that conveys most adequately the achievement level attained by the student. The process, therefore, is one of approximation. In the light of any one criterion, a student's work may contain features denoted by a high achievement level descriptor combined with features appropriate to a lower one. A professional judgment should be made in identifying the descriptor that approximates most closely to the work.
- Having scrutinized the work to be assessed, the descriptors for each criterion should be read, starting with level 0, until one is reached that describes an achievement level that the work being assessed does not match as well as the previous level. The work is, therefore, best described by the preceding achievement level descriptor and this level should be recorded. Only whole numbers should be used, not partial points such as fractions or decimals.
- The highest descriptors do not imply faultless performance and moderators and teachers should not hesitate to use the extremes, including zero, if they are appropriate descriptions of the work being assessed.
- Descriptors should not be considered as marks or percentages, although the descriptor levels are ultimately added together to obtain a total. It should not be assumed that there are other arithmetical relationships; for example, a level 2 performance is not necessarily twice as good as a level 1 performance.
- A student who attains a particular achievement level in relation to one criterion will not necessarily attain similar achievement levels in relation to the others. It should not be assumed that the overall assessment of the students will produce any particular distribution of scores.
- The assessment criteria should be available to students at all times.

Criteria and aspects

There are five assessment criteria that are used to assess the work of both SL and HL students.

- Design—D
- Data collection and processing—DCP
- Conclusion and evaluation—CE
- Manipulative skills—MS
- Personal skills—PS

The first three criteria—design (D), data collection and processing (DCP) and conclusion and evaluation (CE)—are each assessed twice.

Manipulative skills (MS) is assessed summatively over the whole course and the assessment should be based on a wide range of manipulative skills.

Personal skills (PS) is assessed once only and this will be during the group 4 project.

Each of the assessment criteria can be separated into three **aspects** as shown in the following sections. Descriptions are provided to indicate what is expected in order to meet the requirements of a given aspect **completely (c)** and **partially (p)**. A description is also given for circumstances in which the requirements are not satisfied, **not at all (n)**.

A **"complete"** is awarded 2 marks, a **"partial"** 1 mark and a **"not at all"** 0 marks.

The maximum mark for each criterion is 6 (representing three "completes").

D	$\times 2 = 12$
DCP	$\times 2 = 12$
CE	$\times 2 = 12$
MS	$\times 1 = 6$
PS	$\times 1 = 6$

This makes a total mark out of 48.

The marks for each of the criteria are added together to determine the final mark out of 48 for the IA component. This is then scaled at IBCA to give a total out of 24%.

General regulations and procedures relating to IA can be found in the *Vade Mecum* for the year in which the IA is being submitted.

Design

Levels/marks	Aspect 1	Aspect 2	Aspect 3
	Defining the problem and selecting variables	Controlling variables	Developing a method for collection of data
Complete/2	Formulates a focused problem/research question and identifies the relevant variables.	Designs a method for the effective control of the variables.	Develops a method that allows for the collection of sufficient relevant data.
Partial/1	Formulates a problem/research question that is incomplete **or** identifies only some relevant variables.	Designs a method that makes some attempt to control the variables.	Develops a method that allows for the collection of insufficient relevant data.
Not at all/0	Does not identify a problem/research question **and** does not identify any relevant variables.	Designs a method that does not control the variables.	Develops a method that does not allow for any relevant data to be collected.

Data collection and processing

Levels/marks	Aspect 1	Aspect 2	Aspect 3
	Recording raw data	Processing raw data	Presenting processed data
Complete/2	Records appropriate quantitative and associated qualitative raw data, including units and uncertainties where relevant.	Processes the quantitative raw data correctly.	Presents processed data appropriately and, where relevant, includes errors and uncertainties.
Partial/1	Records appropriate quantitative and associated qualitative raw data, but with some mistakes or omissions.	Processes quantitative raw data, but with some mistakes and/or omissions.	Presents processed data appropriately, but with some mistakes and/or omissions.
Not at all/0	Does not record any appropriate quantitative raw data **or** raw data is incomprehensible.	No processing of quantitative raw data is carried out **or** major mistakes are made in processing.	Presents processed data inappropriately **or** incomprehensibly.

Conclusion and evaluation

Levels/marks	Aspect 1	Aspect 2	Aspect 3
	Concluding	Evaluating procedure(s)	Improving the investigation
Complete/2	States a conclusion, with justification, based on a reasonable interpretation of the data.	Evaluates weaknesses and limitations.	Suggests realistic improvements in respect of identified weaknesses and limitations.
Partial/1	States a conclusion based on a reasonable interpretation of the data.	Identifies some weaknesses and limitations, but the evaluation is weak or missing.	Suggests only superficial improvements.
Not at all/0	States no conclusion **or** the conclusion is based on an unreasonable interpretation of the data.	Identifies irrelevant weaknesses and limitations.	Suggests unrealistic improvements.

Manipulative skills (assessed summatively)

This criterion addresses objective 5.

Levels/marks	Aspect 1	Aspect 2	Aspect 3
	Following instructions*	Carrying out techniques	Working safely
Complete/2	Follows instructions accurately, adapting to new circumstances (seeking assistance when required).	Competent and methodical in the use of a range of techniques and equipment.	Pays attention to safety issues.
Partial/1	Follows instructions but requires assistance.	Usually competent and methodical in the use of a range of techniques and equipment.	Usually pays attention to safety issues.
Not at all/0	Rarely follows instructions **or** requires constant supervision.	Rarely competent and methodical in the use of a range of techniques and equipment.	Rarely pays attention to safety issues.

*Instructions may be in a variety of forms: oral, written worksheets, diagrams, photographs, videos, flow charts, audio tapes, models, computer programs, and so on, and need not originate from the teacher.

See "The group 4 project" section for the personal skills criterion.

Clarifications of the IA criteria

Design

Aspect 1: defining the problem and selecting variables

It is essential that teachers give an open-ended problem to investigate, where there are several independent variables from which a student could choose one that provides a suitable basis for the investigation. This should ensure that a range of plans will be formulated by students and that there is sufficient scope to identify both independent and controlled variables.

Although the general aim of the investigation may be given by the teacher, students must identify a focused problem or specific research question. Commonly, students will do this by modifying the general aim provided and indicating the variable(s) chosen for investigation.

The teacher may suggest the general research question only. Asking students to investigate some property of a plant's cells, where no variables are given, would be an acceptable teacher prompt. This could be focused by the student as follows: "Does the cyclosis of chloroplasts in *Elodea* leaf cells vary with light intensity?"

Alternatively, the teacher may suggest the general research question and specify the dependent variable. An example of such a teacher prompt would be to ask the student to investigate the effect of a factor that influences enzyme activity. This could then be focused by the student as follows: "Does ethanol concentration affect the activity of bovine catalase?" It is not sufficient for the student merely to restate the research question provided by the teacher.

Variables are factors that can be measured and/or controlled. Independent variables are those that are manipulated, and the result of this manipulation leads to the measurement of the dependent variable. A controlled variable is one that should be held constant so as not to obscure the effects of the independent variable on the dependent variable.

The variables need to be explicitly identified by the student as the dependent (measured), independent (manipulated) and controlled variables (constants). Relevant variables are those that can reasonably be expected to affect the outcome. For example, in the investigation "How does the speed of movement of chloroplasts in *Elodea* cells vary with light intensity?", the student must state clearly that the independent variable is the light intensity and the dependent variable is the speed of movement. Relevant controlled variables would include temperature, preparation of *Elodea* cells, sample size and light quality (wavelength).

Students should **not** be:

- given a focused research question
- told the outcome of the investigation
- told which independent variable to select
- told which variables to hold constant.

Aspect 2: controlling variables

"Control of variables" refers to the manipulation of the independent variable and the attempt to maintain the controlled variables at a constant value. The method should include explicit reference to how the control of variables is achieved. If the control of variables is not practically possible, some effort should be made to monitor the variable(s).

A standard measurement technique may be used as part of a wider investigation but it should not be the focus of that investigation. Students should be assessed on their individual design of the wider investigation. If a standard measurement technique is used, it should be referenced. For example, while planning an investigation to study the effect of light wavelength on the rate of photosynthesis in *Cabomba*, the student may have adapted a method to measure the rate of photosynthesis taken from a textbook. A standard reference would then be expected as a footnote, for example, "Freeland, PW (1985) *Problems in Practical Advanced Level Biology*, Hodder and Stoughton." Or the student may adapt a general protocol provided by a teacher in a previous investigation. The reference may appear as: Michigan, J (2007) "Studying the rate of photosynthesis" worksheet.

Students should **not** be told:

- which apparatus to select
- the experimental method.

Aspect 3: developing a method for collection of data

The definition of "sufficient relevant data" depends on the context. The planned investigation should anticipate the collection of sufficient data so that the aim or research question can be suitably addressed and an evaluation of the reliability of the data can be made.

If error analysis involving the calculation of standard deviation is to be carried out, then a sample size of at least five is needed. The data range and amount of data in that range are also important. For example, when trying to determine the optimum pH of an enzyme, using a range of pH values between 6 and 8 would be insufficient. Using a range of values between 3 and 10 would be better, but would also be insufficient if only three different pH values were tested in that range.

Students should **not** be told:

- how to collect the data
- how much data to collect.

Data collection and processing

Ideally, students should work on their own when collecting data.

When data collection is carried out in groups, the actual recording and processing of data should be independently undertaken if this criterion is to be assessed. Recording class or group data is only appropriate if the data-sharing method does not suggest a presentation format for the students.

Pooling data from a class is permitted where the students have independently organized and presented their data. For example, they may have placed it on a real or virtual bulletin board. For assessment of aspect 1, students must clearly indicate which data is their own.

Aspect 1: recording raw data

Raw data is the actual data measured. This may include associated qualitative data. It is permissible to convert handwritten raw data into word-processed form. The term "quantitative data" refers to numerical measurements of the variables associated with the investigation. Associated qualitative data are considered to be those observations that would enhance the interpretation of results.

Uncertainties are associated with all raw data and an attempt should always be made to quantify uncertainties. For example, when students say there is an uncertainty in a stopwatch measurement because of reaction time, they must estimate the magnitude of the uncertainty. Within tables of quantitative data, columns should be clearly annotated with a heading, units and an indication of the uncertainty of measurement. The uncertainty need not be the same as the manufacturer's stated precision of the measuring device used. Significant digits in the data and the uncertainty in the data must be consistent. This applies to all measuring devices, for example, digital meters, stopwatches, and so on. The number of significant digits should reflect the precision of the measurement.

There should be no variation in the precision of raw data. For example, the same number of decimal places should be used. For data derived from processing raw data (for example, means), the level of precision should be consistent with that of the raw data.

The recording of the level of precision would be expected from the point where the student takes over the manipulation. For example, students would not be expected to state the level of precision in a solution prepared for them.

Students should **not** be told how to record the raw data. For example, they should not be given a pre-formatted table with columns, headings, units or uncertainties.

Aspect 2: processing raw data

Data processing involves, for example, combining and manipulating raw data to determine the value of a physical quantity (such as adding, subtracting, squaring, dividing), and taking the average of several measurements and transforming data into a form suitable for graphical representation. It might be that the data is already in a form suitable for graphical presentation, for example, distance travelled by woodlice against temperature. If the raw data is represented in this way and a best-fit line graph is drawn, the raw data has been processed. Plotting raw data (without a graph line) does not constitute processing data.

The recording and processing of data may be shown in one table provided they are clearly distinguishable.

Students should **not** be told:

- how to process the data
- what quantities to graph/plot.

Aspect 3: presenting processed data

Students are expected to decide upon a suitable presentation format themselves (for example, spreadsheet, table, graph, chart, flow diagram, and so on). There should be clear, unambiguous headings for calculations, tables or graphs. Graphs need to have appropriate scales, labelled axes with units, and accurately plotted data points with a suitable best-fit line or curve (not a scattergraph with data-point to data-point connecting lines). Students should present the data so that all the stages to the final result can be followed. Inclusion of metric/SI units is expected for final derived quantities, which should be expressed to the correct number of significant figures. The uncertainties associated with the raw data must be taken into account. The treatment of uncertainties in graphical analysis requires the construction of appropriate best-fit lines.

The complete fulfillment of aspect 3 does **not** require students to draw lines of minimum and maximum fit to the data points, to include error bars or to combine errors through root mean squared calculations. Although error bars on data points (for example, standard error) are not expected, they are a perfectly acceptable way of expressing the degree of uncertainty in the data.

In order to fulfill aspect 3 completely, students should include a treatment of uncertainties and errors with their processed data, where relevant.

The treatment of uncertainties should be in accordance with assessment statements 1.1.2, 1.1.3 and 1.1.4 of this guide.

Conclusion and evaluation

Aspect 1: concluding

Analysis may include comparisons of different graphs or descriptions of trends shown in graphs. The explanation should contain observations, trends or patterns revealed by the data.

When measuring an already known and accepted value of a physical quantity, students should draw a conclusion as to their confidence in their result by comparing the experimental value with the textbook or literature value. The literature consulted should be fully referenced.

Aspect 2: evaluating procedure(s)

The design and method of the investigation must be commented upon as well as the quality of the data. The student must not only list the weaknesses but must also appreciate how significant the weaknesses are. Comments about the precision and accuracy of the measurements are relevant here. When evaluating the procedure used, the student should specifically look at the processes, use of equipment and management of time.

Aspect 3: improving the investigation

Suggestions for improvements should be based on the weaknesses and limitations identified in aspect 2. Modifications to the experimental techniques and the data range can be addressed here. The modifications proposed should be realistic and clearly specified. It is not sufficient to state generally that more precise equipment should be used.

Manipulative skills

(This criterion must be assessed summatively.)

Aspect 1: following instructions

Indications of manipulative ability are the amount of assistance required in assembling equipment, the orderliness of carrying out the procedure(s) and the ability to follow the instructions accurately. The adherence to safe working practices should be apparent in all aspects of practical activities.

A wide range of complex tasks should be included in the scheme of work.

Aspect 2: carrying out techniques

It is expected that students will be exposed to a variety of different investigations during the course that enables them to experience a variety of experimental situations.

Aspect 3: working safely

The student's approach to safety during investigations in the laboratory or in the field must be assessed. Nevertheless, the teacher must not put students in situations of unacceptable risk.

The teacher should judge what is acceptable and legal under local regulations and with the facilities available. See the "Safety" section in this guide under "Guidance and authenticity".

Personal skills

Note: The personal skills criterion is assessed in the group 4 project only and is to be found in "The group 4 project" section.

The use of ICT

In accordance with aim 7—that is, to “develop and apply the students’ information and communication technology skills in the study of science”—the use of information and communication technology (ICT) is encouraged in practical work throughout the course, whether the investigations are assessed using the IA criteria or otherwise.

Section A: use of ICT in assessment

Data-logging software may be used in experiments/investigations assessed using the IA criteria provided that the following principle is applied.

The student’s contribution to the experiment must be evident so that this alone can be assessed by the teacher. This student’s contribution can be in the selection of settings used by the data-logging and graphing equipment, or can be demonstrated in subsequent stages of the experiment.

(When data logging is used, raw data is defined as any data produced by software and extracted by the student from tables or graphs to be subsequently processed by the student.)

The following categories of experiments exemplify the application of this principle.

1. Data logging within a narrowly focused task

Data-logging software may be used to perform a traditional experiment in a new way.

Use of data-logging software is appropriate with respect to assessment if the student decides and inputs most of the relevant software settings. For example, an investigation could be set up to monitor a person’s breathing capacities while on an exercise bike using a spirometer sensor linked to a calculator-based data logger in which the student controls the level of exercise (speed or workload). Data-logging software that automatically determines the various settings and generates the data tables and graphs would be inappropriate with regard to assessment because the remaining student input required to investigate the breathing capacities would be minimal.

If the experiment is suitable for assessment the following guidelines must be followed for the DCP criterion.

Data collection and processing: aspect 1

Students may present raw data collected using data logging as long as they are responsible for the majority of software settings. The numerical raw data may be presented as a table, or, where a large amount of data has been generated, by graphical means. For example, the student should set the duration and rate of the sampling, and the generated data in the form of lists of measurements from the calculator or computer could be downloaded by the student into a computer spreadsheet. Students must organize the data correctly, for example, by means of table or graph titles, columns or graph axes labelled with units, indications of uncertainties, associated qualitative observations, and so on.

The number of decimal places used in recorded data should not exceed that expressed by the sensitivity of the instrument used. In the case of electronic probes used in data logging, students will be expected to record the sensitivity of the instrument.

Data collection and processing: aspects 2 and 3

Use of software for graph drawing is appropriate as long as the student is responsible for most of the decisions, such as:

- what to graph
- selection of quantities for axes
- appropriate units
- graph title
- appropriate scale
- how to graph, for example, linear graph line and not scatter.

> Note: A computer-calculated gradient is acceptable.

In the example of the investigation to monitor breathing capacities, the student could process data by drawing a graph in the spreadsheet and measuring the breathing frequency from the data. By inspecting the graph or spreadsheet data, the maximal and minimal lung volume values could be identified and used to calculate the mean tidal volume at rest. The mean volume of air breathed per minute and recovery rate after exercise could also be calculated.

Statistical analysis carried out using calculators or calculations using spreadsheets are acceptable provided that the student selects the data to be processed and chooses the method of processing. In both cases, the student must show one example in the written text. For example, the student must quote the formula used by or entered into a calculator and define the terms used, or the student must write the formula used in a spreadsheet if it is not a standard part of the program's menu of functions (for example, mean, standard deviation).

2. Data logging in an open-ended investigation

Data-logging software can enhance data collection and transform the sort of investigations possible. In this case fully automated data-logging software is appropriate with regard to assessment **if** it is used to enable a broader, complex investigation to be undertaken where students can develop a range of responses involving independent decision-making.

For example, a task could be set to investigate a factor that affects the rate of photosynthesis. If an oxygen sensor with automatic pre-programmed software to monitor the amount of oxygen released by an aquatic plant is used, the student could use the program to develop a broader, complex investigation, for example, comparing rate of photosynthesis in different species of aquatic plants at different light intensities.

Design: aspect 1

The student must state a focused problem/research question, for example: "What is the difference in the rate of photosynthesis at different light intensities, as measured by oxygen release, between *Elodea canadensis* and *Myriophyllum spicatum*?"

Relevant variables must also be identified, for example:

- independent variable—species of aquatic plants
- dependent variable—rate of oxygen production
- controlled variables—temperature, mass of plant, leaf surface area, time, light quality (wavelength).

Design: aspect 2

The student must design a method to monitor and control the variables (for example, a water bath for control of temperature), use an electronic balance to determine the mass of the plants, and use the same light source to control light quality.

Design: aspect 3

The student must design the method for the appropriate collection of sufficient raw data. The student would select the species of aquatic plants to use, and measure the amount of dissolved oxygen in the water using the oxygen sensor program. The student would also decide on the range and number of different light intensities and the number of experimental replicates.

Data collection and processing: aspect 1

Appropriate raw data would consist of the rates of photosynthesis derived from the graphs of the experimental runs generated by the program using the oxygen sensor. These rates of photosynthesis may be calculated by the student using a function on the program that analyses the graphs. This must be done without prompting by the teacher. The derived data for rates of photosynthesis could be annotated on a series of graphs or presented in a table with an appropriate title, column headings and units. Calculation of uncertainties would not be expected in this experiment. In addition, other important data should be recorded, for example, water temperature.

Data collection and processing: aspect 2

The graphs showing changes in oxygen concentration would not be assessed, as these would have been generated automatically by the pre-programmed software on the data logger, without input from the student. However, the rates of photosynthesis derived from these graphs could be plotted against light intensity for each species using graph-plotting software where student input is possible, for example, choice of type of graph, *x* and *y* axes, range and scale.

Data collection and processing: aspect 3

The student would generate graphs of light intensity *versus* rates of photosynthesis for each species, which should have clear titles, correctly labelled axes, a legend for the data of the different species of plants, and trend lines to reveal the degree of uncertainty.

Section B: use of ICT in non-assessed practical work

It is not necessary to use ICT in assessed investigations but, in order to carry out aim 7 in practice, students will be required to use each of the following software applications at least once during the course.

- Data logging in an experiment
- Software for graph plotting
- A spreadsheet for data processing
- A database
- Computer modelling/simulation

There are many examples of the above in the ICT resources for biology, chemistry and physics on the OCC.

Apart from sensors for data logging, all the other components involve software that is free and readily available on the Internet. As students only need to use data-logging software and sensors once in the course, class sets are not required.

The use of each of the above five ICT applications by students would be authenticated by means of entries in the students' practical scheme of work, form 4/PSOW. For example, if a student used a spreadsheet in an investigation, this should be recorded on form 4/PSOW. Any other applications of ICT can also be recorded on form 4/PSOW.

The group 4 project

Summary of the group 4 project

The group 4 project is a collaborative activity where students from different group 4 subjects work together on a scientific or technological topic, allowing for concepts and perceptions from across the disciplines to be shared in line with aim 10—that is, to "encourage an understanding of the relationships between scientific disciplines and the overarching nature of the scientific method". The project can be practically or theoretically based. Collaboration between schools in different regions is encouraged.

The group 4 project allows students to appreciate the environmental, social and ethical implications of science and technology. It may also allow them to understand the limitations of scientific study, for example, the shortage of appropriate data and/or the lack of resources. The emphasis is on interdisciplinary cooperation and the processes involved in scientific investigation, rather than the products of such investigation.

The choice of scientific or technological topic is open but the project should clearly address aims 7, 8 and 10 of the group 4 subject guides.

Ideally, the project should involve students collaborating with those from other group 4 subjects at all stages. To this end, it is not necessary for the topic chosen to have clearly identifiable separate subject components. However, for logistical reasons some schools may prefer a separate subject "action" phase (see the following "Project stages" section).

Project stages

The 10 hours allocated to the group 4 project, which are part of the teaching time set aside for IA, can be divided into three stages: planning, action and evaluation.

Planning

This stage is crucial to the whole exercise and should last about two hours.

- The planning stage could consist of a single session, or two or three shorter ones.
- This stage must involve all group 4 students meeting to "brainstorm" and discuss the central topic, sharing ideas and information.
- The topic can be chosen by the students themselves or selected by the teachers.
- Where large numbers of students are involved, it may be advisable to have more than one mixed subject group.

After selecting a topic or issue, the activities to be carried out must be clearly defined before moving from the planning stage to the action and evaluation stages.

A possible strategy is that students define specific tasks for themselves, either individually or as members of groups, and investigate various aspects of the chosen topic. At this stage, if the project is to be experimentally based, apparatus should be specified so that there is no delay in carrying out the action stage. Contact with other schools, if a joint venture has been agreed, is an important consideration at this time.

Action

This stage should last around six hours and may be carried out over one or two weeks in normal scheduled class time. Alternatively, a whole day could be set aside if, for example, the project involves fieldwork.

- Students should investigate the topic in mixed subject groups or single subject groups.
- There should be collaboration during the action stage; findings of investigations should be shared with other students within the mixed/single subject group. During this stage, in any practically based activity, it is important to pay attention to safety, ethical and environmental considerations.

> Note: Students studying two group 4 subjects are not required to do two separate action phases.

Evaluation

The emphasis during this stage, for which two hours is probably necessary, is on students sharing their findings, both successes and failures, with other students. How this is achieved can be decided by the teachers, the students or jointly.

- One solution is to devote a morning, afternoon or evening to a symposium where all the students, as individuals or as groups, give brief presentations.
- Alternatively, the presentation could be more informal and take the form of a science fair where students circulate around displays summarizing the activities of each group.

The symposium or science fair could also be attended by parents, members of the school board and the press. This would be especially pertinent if some issue of local importance has been researched. Some of the findings might influence the way the school interacts with its environment or local community.

Addressing aims 7 and 8

Aim 7—“develop and apply the students’ information and communication technology skills in the study of science”.

Aim 7 may be partly addressed at the planning stage by using electronic communication within and between schools. It may be that ICT (for example, data logging, spreadsheets, databases, and so on) will be used in the action phase and certainly in the presentation/evaluation stage (for example, use of digital images, presentation software, web sites, digital video, and so on).

Aim 8—“raise awareness of the moral, ethical, social, economic and environmental implications of using science and technology”.

The choice of topic should enable one or more elements of aim 8 to be incorporated into the project.

Addressing the international dimension

There are also possibilities in the choice of topic to illustrate the international nature of the scientific endeavour and the increasing cooperation required to tackle global issues involving science and technology. An alternative way to bring an international dimension to the project is to collaborate with a school in another region.

Types of project

While addressing aims 7, 8 and 10 the project must be based on science or its applications.

The project may have a hands-on practical action phase or one involving purely theoretical aspects. It could be undertaken in a wide range of ways.

- Designing and carrying out a laboratory investigation or fieldwork.
- Carrying out a comparative study (experimental or otherwise) in collaboration with another school.
- Collating, manipulating and analysing data from other sources, such as scientific journals, environmental organizations, science and technology industries and government reports.
- Designing and using a model or simulation.
- Contributing to a long-term project organized by the school.

Logistical strategies

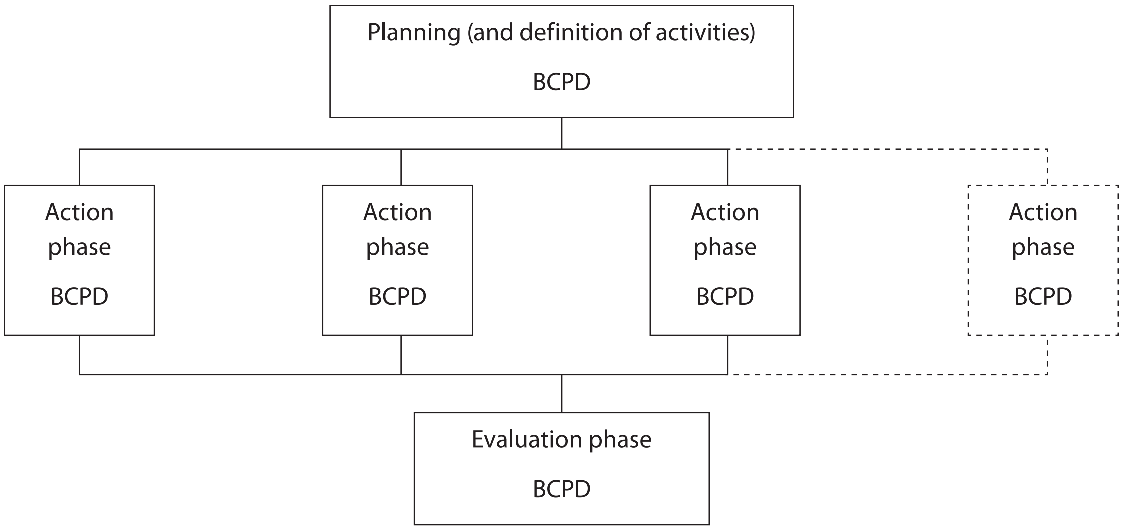
The logistical organization of the group 4 project is often a challenge to schools. The following models illustrate possible ways in which the project may be implemented.

Models A, B and C apply within a single school, and model D relates to a project involving collaboration between schools.

Model A: mixed subject groups and one topic

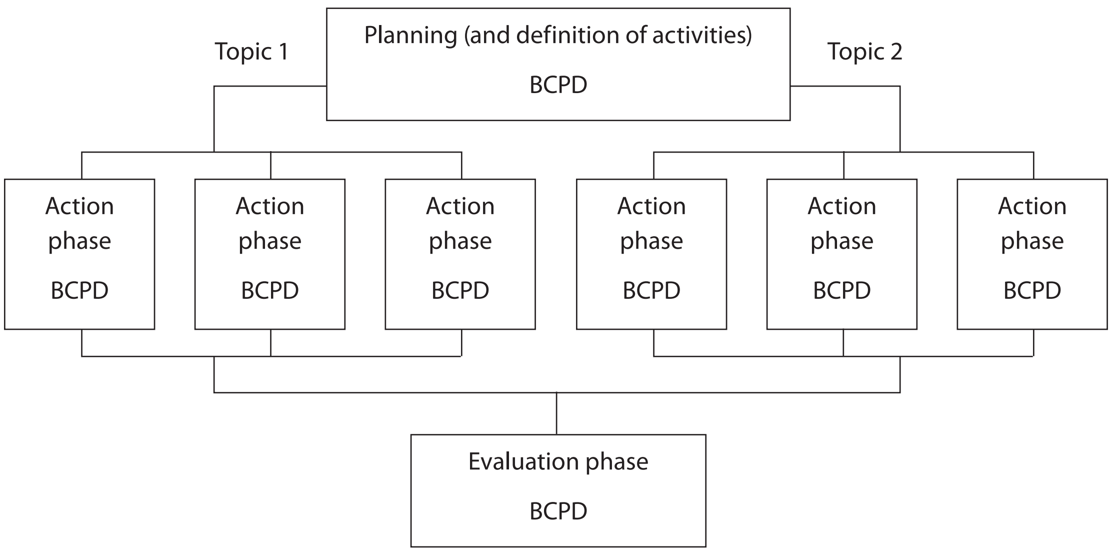
Schools may adopt mixed subject groups and choose one common topic. The number of groups will depend on the number of students. The dotted lines in the model show the addition of more groups as student numbers increase.

B—biology C—chemistry P—physics D—design technology



Model B: mixed subject groups adopting more than one topic

Schools with large numbers of students may choose to do more than one topic.



Model C: single subject groups

For schools opting for single subject groups with one or more topics in the action phase, simply replace the mixed subject groups in model A or B with single subject groups.

Model D: collaboration with another school

The collaborative model is open to any school. To this end, the IBO will provide an electronic collaboration board on the OCC where schools can post their project ideas and invite collaboration from another school. This could range from merely sharing evaluations for a common topic to a full-scale collaborative venture at all stages.

For schools with few diploma students or schools with certificate students, it is possible to work with non-Diploma Programme or non-group 4 students or undertake the project once every two years. However, these schools are encouraged to collaborate with another school. This strategy is also recommended for individual students who may not have participated in the project, for example, through illness or because they have transferred to a new school where the project has already taken place.

Timing

The 10 hours that the IBO recommends be allocated to the project may be spread over a number of weeks. The distribution of these hours needs to be taken into account when selecting the optimum time to carry out the project. However, it is possible for a group to dedicate a period of time exclusively to project work if all/most other school work is suspended.

Year 1

In the first year, students' experience and skills may be limited and it would be inadvisable to start the project too soon in the course. However, doing the project in the final part of the first year may have the advantage of reducing pressure on students later on. This strategy provides time for solving unexpected problems.

Year 1–year 2

The planning stage could start, the topic could be decided upon, and provisional discussion in individual subjects could take place at the end of the first year. Students could then use the vacation time to think about how they are going to tackle the project and would be ready to start work early in the second year.

Year 2

Delaying the start of the project until some point in the second year, particularly if left too late, increases pressure on students in many ways: the schedule for finishing the work is much tighter than for the other options; the illness of any student or unexpected problems will present extra difficulties. Nevertheless, this choice does mean students know one another and their teachers by this time, have probably become accustomed to working in a team and will be more experienced in the relevant fields than in the first year.

Combined SL and HL

Where circumstances dictate that the project is only carried out every two years, HL beginners and more experienced SL students can be combined.

Selecting a topic

Students may choose the topic or propose possible topics, with the teacher then deciding which one is the most viable based on resources, staff availability, and so on. Alternatively, the teacher selects the topic or proposes several topics from which students make a choice.

Student selection

Students are likely to display more enthusiasm and feel a greater sense of ownership for a topic that they have chosen themselves. A possible strategy for student selection of a topic, which also includes part of the planning stage, is outlined here. At this point, subject teachers may provide advice on the viability of proposed topics.

- Identify possible topics by using a questionnaire or a survey of students.
- Conduct an initial "brainstorming" session of potential topics or issues.
- Discuss, briefly, two or three topics that seem interesting.
- Select one topic by consensus.
- Students make a list of potential investigations that could be carried out. All students then discuss issues such as possible overlap and collaborative investigations.

Assessment

The group 4 project is to be assessed for the personal skills criterion only and this will be the only place where this criterion is assessed. It is up to the school how this assessment takes place.

> Note: The group 4 project is not to be used for the assessment of the other criteria.

Personal skills (for group 4 project assessment only)

This criterion addresses objective 4.

Levels/marks	Aspect 1	Aspect 2	Aspect 3
	Self-motivation and perseverance	Working within a team	Self-reflection
Complete/2	Approaches the project with self-motivation and follows it through to completion.	Collaborates and communicates in a group situation and integrates the views of others.	Shows a thorough awareness of their own strengths and weaknesses and gives thoughtful consideration to their learning experience.
Partial/1	Completes the project but sometimes lacks self-motivation.	Exchanges some views but requires guidance to collaborate with others.	Shows limited awareness of their own strengths and weaknesses and gives some consideration to their learning experience.
Not at all/0	Lacks perseverance and motivation.	Makes little or no attempt to collaborate in a group situation.	Shows no awareness of their own strengths and weaknesses and gives no consideration to their learning experience.

The assessment can be assisted by the use of a student self-evaluation form, but the use of such a form is not a requirement.

Nature of the subject

Biologists have accumulated huge amounts of information about living organisms, and it would be easy to confuse students by teaching large numbers of seemingly unrelated facts. In the Diploma Programme biology course, it is hoped that students will acquire a limited body of facts and, at the same time, develop a broad, general understanding of the principles of the subject.

Although the Diploma Programme biology course at standard level (SL) and higher level (HL) has been written as a series of discrete statements (for assessment purposes), there are four basic biological concepts that run throughout.

Structure and function

This relationship is probably one of the most important in a study of biology and operates at all levels of complexity. Students should appreciate that structures permit some functions while, at the same time, limiting others.

Universality *versus* diversity

At the factual level, it soon becomes obvious to students that some molecules (for example, enzymes, amino acids, nucleic acids and ATP) are ubiquitous, and so are processes and structures. However, these universal features exist in a biological world of enormous diversity. Species exist in a range of habitats and show adaptations that relate structure to function. At another level, students can grasp the idea of a living world in which universality means that a diverse range of organisms (including ourselves) are connected and interdependent.

Equilibrium within systems

Checks and balances exist both within living organisms and within ecosystems. The state of dynamic equilibrium is essential for the continuity of life.

Evolution

The concept of evolution draws together the other themes. It can be regarded as change leading to diversity within constraints, and this leads to adaptations of structure and function.

These four concepts serve as themes that unify the various topics that make up the three sections of the course: the core, the additional higher level (AHL) material and the options.

The order in which the syllabus is arranged is **not** the order in which it should be taught, and it is up to individual teachers to decide on an arrangement that suits their circumstances. Option material may be taught within the core or the AHL material, if desired.

Syllabus overview

The syllabus for the Diploma Programme biology course is divided into three parts: the core, the AHL material and the options. A syllabus overview is provided below.

		Teaching hours
Core		**80**
Topic 1:	Statistical analysis	2
Topic 2:	Cells	12
Topic 3:	The chemistry of life	15
Topic 4:	Genetics	15
Topic 5:	Ecology and evolution	16
Topic 6:	Human health and physiology	20
AHL		**55**
Topic 7:	Nucleic acids and proteins	11
Topic 8:	Cell respiration and photosynthesis	10
Topic 9:	Plant science	11
Topic 10:	Genetics	6
Topic 11:	Human health and physiology	17
Options		**15/22**
Options SL		
Option A:	Human nutrition and health	15
Option B:	Physiology of exercise	15
Option C:	Cells and energy	15
Options SL and HL		
Option D:	Evolution	15/22
Option E:	Neurobiology and behaviour	15/22
Option F:	Microbes and biotechnology	15/22
Option G:	Ecology and conservation	15/22
Options HL		
Option H:	Further human physiology	22

Students at SL are required to study any **two** options from A–G.
The duration of each option is 15 hours.

Students at HL are required to study any **two** options from D–H.
The duration of each option is 22 hours.

Syllabus outline

		Teaching hours
Core		**80**
Topic 1: Statistical analysis		**2**
Topic 2: Cells		**12**
2.1	Cell theory	3
2.2	Prokaryotic cells	1
2.3	Eukaryotic cells	3
2.4	Membranes	3
2.5	Cell division	2
Topic 3: The chemistry of life		**15**
3.1	Chemical elements and water	2
3.2	Carbohydrates, lipids and proteins	2
3.3	DNA structure	1
3.4	DNA replication	1
3.5	Transcription and translation	2
3.6	Enzymes	2
3.7	Cell respiration	2
3.8	Photosynthesis	3
Topic 4: Genetics		**15**
4.1	Chromosomes, genes, alleles and mutations	2
4.2	Meiosis	3
4.3	Theoretical genetics	5
4.4	Genetic engineering and biotechnology	5
Topic 5: Ecology and evolution		**16**
5.1	Communities and ecosystems	5
5.2	The greenhouse effect	3
5.3	Populations	2
5.4	Evolution	3
5.5	Classification	3
Topic 6: Human health and physiology		**20**
6.1	Digestion	3
6.2	The transport system	3
6.3	Defence against infectious disease	3
6.4	Gas exchange	2
6.5	Nerves, hormones and homeostasis	6
6.6	Reproduction	3

		Teaching hours
AHL		**55**
Topic 7: Nucleic acids and proteins		**11**
7.1	DNA structure	2
7.2	DNA replication	2
7.3	Transcription	2
7.4	Translation	2
7.5	Proteins	1
7.6	Enzymes	2
Topic 8: Cell respiration and photosynthesis		**10**
8.1	Cell respiration	5
8.2	Photosynthesis	5
Topic 9: Plant science		**11**
9.1	Plant structure and growth	4
9.2	Transport in angiospermophytes	4
9.3	Reproduction in angiospermophytes	3
Topic 10: Genetics		**6**
10.1	Meiosis	2
10.2	Dihybrid crosses and gene linkage	3
10.3	Polygenic inheritance	1
Topic 11: Human health and physiology		**17**
11.1	Defence against infectious disease	4
11.2	Muscles and movement	4
11.3	The kidney	4
11.4	Reproduction	5

Options SL — 15

These options are available at SL only.

Option A: Human nutrition and health		**15**
A1	Components of the human diet	5
A2	Energy in human diets	4
A3	Special issues in human nutrition	6
Option B: Physiology of exercise		**15**
B1	Muscles and movement	4
B2	Training and the pulmonary system	2
B3	Training and the cardiovascular system	3
B4	Exercise and respiration	3
B5	Fitness and training	2
B6	Injuries	1
Option C: Cells and energy		**15**
C1	Proteins	1
C2	Enzymes	2
C3	Cell respiration	6
C4	Photosynthesis	6

		Teaching hours
Options SL and HL		**15/22**

Options SL and HL — 15/22

Students at SL study the core of these options, and students at HL study the whole option (that is, the core and the extension material).

Option D: Evolution		**15/22**
Core (SL and HL)		**15**
D1	Origin of life on Earth	4
D2	Species and speciation	5
D3	Human evolution	6
Extension (HL only)		**7**
D4	The Hardy–Weinberg principle	2
D5	Phylogeny and systematics	5
Option E: Neurobiology and behaviour		**15/22**
Core (SL and HL)		**15**
E1	Stimulus and response	2
E2	Perception of stimuli	4
E3	Innate and learned behaviour	4
E4	Neurotransmitters and synapses	5
Extension (HL only)		**7**
E5	The human brain	4
E6	Further studies of behaviour	3
Option F: Microbes and biotechnology		**15/22**
Core (SL and HL)		**15**
F1	Diversity of microbes	5
F2	Microbes and the environment	4
F3	Microbes and biotechnology	3
F4	Microbes and food production	3
Extension (HL only)		**7**
F5	Metabolism of microbes	2
F6	Microbes and disease	5
Option G: Ecology and conservation		**15/22**
Core (SL and HL)		**15**
G1	Community ecology	5
G2	Ecosystems and biomes	4
G3	Impacts of humans on ecosystems	6
Extension (HL only)		**7**
G4	Conservation of biodiversity	3
G5	Population ecology	4

Options HL — 22

This option is available at HL only.

Option H: Further human physiology		**22**
H1	Hormonal control	3
H2	Digestion	4
H3	Absorption of digested foods	2
H4	Functions of the liver	3
H5	The transport system	5
H6	Gas exchange	5

Syllabus details—Core

Topic 1: Statistical analysis (2 hours)

	Assessment statement	Obj	Teacher's notes
1.1.1	State that error bars are a graphical representation of the variability of data.	1	Error bars can be used to show either the range of the data or the standard deviation.
1.1.2	Calculate the mean and standard deviation of a set of values.	2	Students should specify the standard deviation (*s*), not the population standard deviation. Students will not be expected to know the formulas for calculating these statistics. They will be expected to use the standard deviation function of a graphic display or scientific calculator. **Aim 7:** Students could also be taught how to calculate standard deviation using a spreadsheet computer program.
1.1.3	State that the term standard deviation is used to summarize the spread of values around the mean, and that 68% of the values fall within one standard deviation of the mean.	1	For normally distributed data, about 68% of all values lie within ±1 standard deviation (*s* or σ) of the mean. This rises to about 95% for ±2 standard deviations.
1.1.4	Explain how the standard deviation is useful for comparing the means and the spread of data between two or more samples.	3	A small standard deviation indicates that the data is clustered closely around the mean value. Conversely, a large standard deviation indicates a wider spread around the mean.
1.1.5	Deduce the significance of the difference between two sets of data using calculated values for *t* and the appropriate tables.	3	For the *t*-test to be applied, the data must have a normal distribution and a sample size of at least 10. The *t*-test can be used to compare two sets of data and measure the amount of overlap. Students will not be expected to calculate values of *t*. Only a two-tailed, unpaired *t*-test is expected. **Aim 7:** While students are not expected to calculate a value for the *t*-test, students could be shown how to calculate such values using a spreadsheet program or the graphic display calculator. **TOK:** The scientific community defines an objective standard by which claims about data can be made.
1.1.6	Explain that the existence of a correlation does not establish that there is a causal relationship between two variables.	3	**Aim 7:** While calculations of such values are not expected, students who want to use r and r_2 values in their practical work could be shown how to determine such values using a spreadsheet program.

Topic 2: Cells (12 hours)

2.1 Cell theory

3 hours

	Assessment statement	Obj	Teacher's notes
2.1.1	Outline the cell theory.	2	Include the following. • Living organisms are composed of cells. • Cells are the smallest unit of life. • Cells come from pre-existing cells.
2.1.2	Discuss the evidence for the cell theory.	3	**TOK:** The nature of scientific theories could be introduced here: the accumulation of evidence that allows a hypothesis to become a theory; whether a theory should be abandoned when there is evidence that it does not offer a full explanation; and what evidence is needed for a theory to be adopted or rejected.
2.1.3	State that unicellular organisms carry out all the functions of life.	1	Include metabolism, response, homeostasis, growth, reproduction and nutrition.
2.1.4	Compare the relative sizes of molecules, cell membrane thickness, viruses, bacteria, organelles and cells, using the appropriate SI unit.	3	Appreciation of relative size is required, such as molecules (1 nm), thickness of membranes (10 nm), viruses (100 nm), bacteria (1 μm), organelles (up to 10 μm), and most cells (up to 100 μm). The three-dimensional nature/shape of cells should be emphasized. **TOK:** All the biological entities in the above list are beyond our ability to perceive directly. They must be observed through the use of technology such as the light microscope and the electron microscope. Is there any distinction to be drawn between knowledge claims dependent upon observations made directly with the senses and knowledge claims dependent upon observations assisted by technology?
2.1.5	Calculate the linear magnification of drawings and the actual size of specimens in images of known magnification.	2	Magnification could be stated (for example, ×250) or indicated by means of a scale bar, for example: 1 μm **Aim 7:** The size of objects in digital images of microscope fields could be analysed using graticule baselines and image-processing software.
2.1.6	Explain the importance of the surface area to volume ratio as a factor limiting cell size.	3	Mention the concept that the rate of heat production/waste production/resource consumption of a cell is a function of its volume, whereas the rate of exchange of materials and energy (heat) is a function of its surface area. Simple mathematical models involving cubes and the changes in the ratio that occur as the sides increase by one unit could be compared. **Aim 7:** Data logging could be carried out to measure changes in conductivity in distilled water as salt diffuses out of salt–agar cubes of different dimensions.

	Assessment statement	Obj	Teacher's notes
2.1.7	State that multicellular organisms show emergent properties.	1	Emergent properties arise from the interaction of component parts: the whole is greater than the sum of its parts. **TOK:** The concept of emergent properties has many implications in biology, and this is an opportunity to introduce them. Life itself can be viewed as an emergent property, and the nature of life could be discussed in the light of this, including differences between living and non-living things and problems about defining death in medical decisions.
2.1.8	Explain that cells in multicellular organisms differentiate to carry out specialized functions by expressing some of their genes but not others.	3	
2.1.9	State that stem cells retain the capacity to divide and have the ability to differentiate along different pathways.	1	
2.1.10	Outline one therapeutic use of stem cells.	2	This is an area of rapid development. In 2005, stem cells were used to restore the insulation tissue of neurons in laboratory rats, resulting in subsequent improvements in their mobility. Any example of the therapeutic use of stem cells in humans or other animals can be chosen. **Aim 8:** There are ethical issues involved in stem cell research, whether humans or other animals are used. Use of embryonic stem cells involves the death of early-stage embryos, but if therapeutic cloning is successfully developed the suffering of patients with a wide variety of conditions could be reduced. **Int:** Stem cell research has depended on the work of teams of scientists in many countries, who share results and so speed up the rate of progress. However, ethical concerns about the procedures have led to restrictions on research in some countries. National governments are influenced by local, cultural and religious traditions, which vary greatly, and these, therefore, have an impact on the work of scientists. **TOK:** This is an opportunity to discuss balancing the huge opportunities of therapeutic cloning against the considerable risks—for example, stem cells developing into tumours. Another issue is how the scientific community conveys information about its work to the wider community in such a way that informed decisions about research can be made.

2.2 Prokaryotic cells

1 hour

	Assessment statement	Obj	Teacher's notes
2.2.1	Draw and label a diagram of the ultrastructure of *Escherichia coli* (*E. coli*) as an example of a prokaryote.	1	The diagram should show the cell wall, plasma membrane, cytoplasm, pili, flagella, ribosomes and nucleoid (region containing naked DNA).
2.2.2	Annotate the diagram from 2.2.1 with the functions of each named structure.	2	
2.2.3	Identify structures from 2.2.1 in electron micrographs of *E. coli*.	2	
2.2.4	State that prokaryotic cells divide by binary fission.	1	

2.3 Eukaryotic cells

3 hours

	Assessment statement	Obj	Teacher's notes
2.3.1	Draw and label a diagram of the ultrastructure of a liver cell as an example of an animal cell.	1	The diagram should show free ribosomes, rough endoplasmic reticulum (rER), lysosome, Golgi apparatus, mitochondrion and nucleus. The term Golgi apparatus will be used in place of Golgi body, Golgi complex or dictyosome.
2.3.2	Annotate the diagram from 2.3.1 with the functions of each named structure.	2	
2.3.3	Identify structures from 2.3.1 in electron micrographs of liver cells.	2	
2.3.4	Compare prokaryotic and eukaryotic cells.	3	Differences should include: • naked DNA *versus* DNA associated with proteins • DNA in cytoplasm *versus* DNA enclosed in a nuclear envelope • no mitochondria *versus* mitochondria • 70S *versus* 80S ribosomes • eukaryotic cells have internal membranes that compartmentalize their functions.
2.3.5	State three differences between plant and animal cells.	1	
2.3.6	Outline two roles of extracellular components.	2	The plant cell wall maintains cell shape, prevents excessive water uptake, and holds the whole plant up against the force of gravity. Animal cells secrete glycoproteins that form the extracellular matrix. This functions in support, adhesion and movement.

2.4 Membranes

3 hours

	Assessment statement	Obj	Teacher's notes
2.4.1	Draw and label a diagram to show the structure of membranes.	1	The diagram should show the phospholipid bilayer, cholesterol, glycoproteins, and integral and peripheral proteins. Use the term plasma membrane, not cell surface membrane, for the membrane surrounding the cytoplasm. Integral proteins are embedded in the phospholipid of the membrane, whereas peripheral proteins are attached to its surface. Variations in composition related to the type of membrane are not required. **Aim 7:** Data logging to measure the changes in membrane permeability using colorimeter probes can be used.
2.4.2	Explain how the hydrophobic and hydrophilic properties of phospholipids help to maintain the structure of cell membranes.	3	
2.4.3	List the functions of membrane proteins.	1	Include the following: hormone binding sites, immobilized enzymes, cell adhesion, cell-to-cell communication, channels for passive transport, and pumps for active transport.
2.4.4	Define *diffusion* and *osmosis*.	1	Diffusion is the passive movement of particles from a region of high concentration to a region of low concentration. Osmosis is the passive movement of water molecules, across a partially permeable membrane, from a region of lower solute concentration to a region of higher solute concentration.
2.4.5	Explain passive transport across membranes by simple diffusion and facilitated diffusion.	3	
2.4.6	Explain the role of protein pumps and ATP in active transport across membranes.	3	
2.4.7	Explain how vesicles are used to transport materials within a cell between the rough endoplasmic reticulum, Golgi apparatus and plasma membrane.	3	
2.4.8	Describe how the fluidity of the membrane allows it to change shape, break and re-form during endocytosis and exocytosis.	2	

2.5 Cell division

2 hours

	Assessment statement	Obj	Teacher's notes
2.5.1	Outline the stages in the cell cycle, including interphase (G_1, S, G_2), mitosis and cytokinesis.	2	
2.5.2	State that tumours (cancers) are the result of uncontrolled cell division and that these can occur in any organ or tissue.	1	
2.5.3	State that interphase is an active period in the life of a cell when many metabolic reactions occur, including protein synthesis, DNA replication and an increase in the number of mitochondria and/or chloroplasts.	1	
2.5.4	Describe the events that occur in the four phases of mitosis (prophase, metaphase, anaphase and telophase).	2	Include supercoiling of chromosomes, attachment of spindle microtubules to centromeres, splitting of centromeres, movement of sister chromosomes to opposite poles, and breakage and re-formation of nuclear membranes. Textbooks vary in the use of the terms chromosome and chromatid. In this course, the two DNA molecules formed by DNA replication are considered to be sister chromatids until the splitting of the centromere at the start of anaphase; after this, they are individual chromosomes. The term kinetochore is not expected. **Aim 7:** Students could determine mitotic index and fraction of cells in each phase of mitosis. Individual groups could paste data into a database. Pie charts could be constructed with a graphing computer program. If a graphing computer program is used in DCP for internal assessment, it should be according to the IA and ICT clarifications.
2.5.5	Explain how mitosis produces two genetically identical nuclei.	3	
2.5.6	State that growth, embryonic development, tissue repair and asexual reproduction involve mitosis.	1	

Topic 3: The chemistry of life (15 hours)

3.1 Chemical elements and water

2 hours

	Assessment statement	Obj	Teacher's notes
3.1.1	State that the most frequently occurring chemical elements in living things are carbon, hydrogen, oxygen and nitrogen.	1	
3.1.2	State that a variety of other elements are needed by living organisms, including sulfur, calcium, phosphorus, iron and sodium.	1	
3.1.3	State one role for each of the elements mentioned in 3.1.2.	1	Refer to the roles in plants, animals and prokaryotes.
3.1.4	Draw and label a diagram showing the structure of water molecules to show their polarity and hydrogen bond formation.	1	
3.1.5	Outline the thermal, cohesive and solvent properties of water.	2	**Aim 7:** Data logging could be carried out to compare the thermal properties of water with those of other liquids. **TOK:** Claims about the "memory of water" have been categorized as pseudoscientific. By what criteria can a claim be judged to be pseudoscientific?
3.1.6	Explain the relationship between the properties of water and its uses in living organisms as a coolant, medium for metabolic reactions and transport medium.	3	Limit the properties to those outlined in 3.1.5.

3.2 Carbohydrates, lipids and proteins

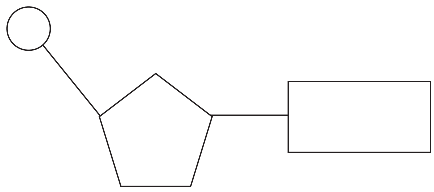
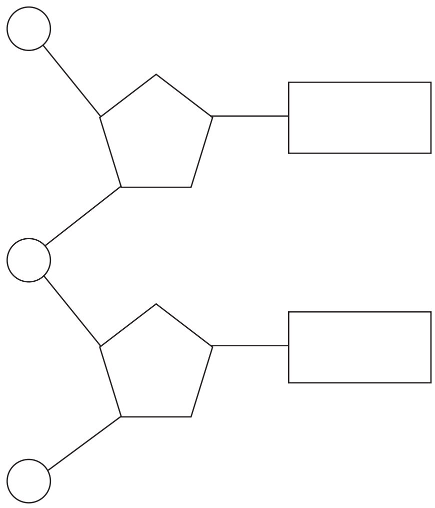
2 hours

	Assessment statement	Obj	Teacher's notes
3.2.1	Distinguish between *organic* and *inorganic* compounds.	2	Compounds containing carbon that are found in living organisms (except hydrogencarbonates, carbonates and oxides of carbon) are regarded as organic.
3.2.2	Identify amino acids, glucose, ribose and fatty acids from diagrams showing their structure.	2	Specific names of amino acids and fatty acids are not expected.
3.2.3	List three examples each of monosaccharides, disaccharides and polysaccharides.	1	The examples used should be: • glucose, galactose and fructose • maltose, lactose and sucrose • starch, glycogen and cellulose.

	Assessment statement	Obj	Teacher's notes
3.2.4	State one function of glucose, lactose and glycogen in animals, and of fructose, sucrose and cellulose in plants.	1	
3.2.5	Outline the role of condensation and hydrolysis in the relationships between monosaccharides, disaccharides and polysaccharides; between fatty acids, glycerol and triglycerides; and between amino acids and polypeptides.	2	This can be dealt with using equations with words or chemical formulas.
3.2.6	State three functions of lipids.	1	Include energy storage and thermal insulation.
3.2.7	Compare the use of carbohydrates and lipids in energy storage.	3	

3.3 DNA structure

1 hour

	Assessment statement	Obj	Teacher's notes
3.3.1	Outline DNA nucleotide structure in terms of sugar (deoxyribose), base and phosphate.	2	Chemical formulas and the purine/pyrimidine subdivision are not required. Simple shapes can be used to represent the component parts. Only the relative positions are required. 
3.3.2	State the names of the four bases in DNA.	1	
3.3.3	Outline how DNA nucleotides are linked together by covalent bonds into a single strand.	2	Only the relative positions are required. 

	Assessment statement	Obj	Teacher's notes
3.3.4	Explain how a DNA double helix is formed using complementary base pairing and hydrogen bonds.	3	
3.3.5	Draw and label a simple diagram of the molecular structure of DNA.	1	An extension of the diagram in 3.3.3 is sufficient to show the complementary base pairs of A–T and G–C, held together by hydrogen bonds and the sugar–phosphate backbones. The number of hydrogen bonds between pairs and details of purine/pyrimidines are not required. **TOK:** The story of the elucidation of the structure of DNA illustrates that cooperation and collaboration among scientists exists alongside competition between research groups. To what extent was Watson and Crick's "discovery" of the three-dimensional structure of DNA dependent on the use of data generated by Rosalind Franklin, which was shared without her knowledge or consent?

3.4 DNA replication

1 hour

	Assessment statement	Obj	Teacher's notes
3.4.1	Explain DNA replication in terms of unwinding the double helix and separation of the strands by helicase, followed by formation of the new complementary strands by DNA polymerase.	3	It is not necessary to mention that there is more than one DNA polymerase.
3.4.2	Explain the significance of complementary base pairing in the conservation of the base sequence of DNA.	3	
3.4.3	State that DNA replication is semi-conservative.	1	

3.5 Transcription and translation

2 hours

	Assessment statement	Obj	Teacher's notes
3.5.1	Compare the structure of RNA and DNA.	3	Limit this to the names of sugars, bases and the number of strands.
3.5.2	Outline DNA transcription in terms of the formation of an RNA strand complementary to the DNA strand by RNA polymerase.	2	
3.5.3	Describe the genetic code in terms of codons composed of triplets of bases.	2	
3.5.4	Explain the process of translation, leading to polypeptide formation.	3	Include the roles of messenger RNA (mRNA), transfer RNA (tRNA), codons, anticodons, ribosomes and amino acids.

	Assessment statement	Obj	Teacher's notes
3.5.5	Discuss the relationship between one gene and one polypeptide.	3	Originally, it was assumed that one gene would invariably code for one polypeptide, but many exceptions have been discovered. **TOK:** The way in which theories are modified as related evidence accumulates could be discussed, and whether contrary evidence should cause a theory to be discarded immediately if there are exceptions to it. Where a theory is suddenly and totally abandoned, to be replaced by a different theory, this is known as a paradigm shift.

3.6 Enzymes

2 hours

	Assessment statement	Obj	Teacher's notes
3.6.1	Define *enzyme* and *active site*.	1	
3.6.2	Explain enzyme–substrate specificity.	3	The lock-and-key model can be used as a basis for the explanation. Refer to the three-dimensional structure. The induced-fit model is not expected at SL.
3.6.3	Explain the effects of temperature, pH and substrate concentration on enzyme activity.	3	**Aim 7:** Enzyme activity could be measured using data loggers such as pressure sensors, pH sensors or colorimeters. **Aim 8:** The effects of environmental acid rain could be discussed.
3.6.4	Define *denaturation*.	1	Denaturation is a structural change in a protein that results in the loss (usually permanent) of its biological properties. Refer only to heat and pH as agents.
3.6.5	Explain the use of lactase in the production of lactose-free milk.	3	**Aim 8:** Production of lactose-free milk is an example of an industrial process depending on biological methods (biotechnology). These methods are of huge and increasing economic importance. **Int/TOK:** Development of some techniques benefits particular human populations and not others because of the natural variation in human characteristics. Lactose intolerance is found in a high proportion of the human population (for example, in Asia) but more rarely among those of European origin. Sometimes a transfer of biotechnology is needed when techniques are developed in one part of the world that are more applicable in another.

3.7 Cell respiration

2 hours

	Assessment statement	Obj	Teacher's notes
3.7.1	Define *cell respiration*.	1	Cell respiration is the controlled release of energy from organic compounds in cells to form ATP.
3.7.2	State that, in cell respiration, glucose in the cytoplasm is broken down by glycolysis into pyruvate, with a small yield of ATP.	1	
3.7.3	Explain that, during anaerobic cell respiration, pyruvate can be converted in the cytoplasm into lactate, or ethanol and carbon dioxide, with no further yield of ATP.	3	Mention that ethanol and carbon dioxide are produced in yeast, whereas lactate is produced in humans. **Aim 7:** Data logging using gas sensors, oxygen, carbon dioxide or pH probes could be used.
3.7.4	Explain that, during aerobic cell respiration, pyruvate can be broken down in the mitochondrion into carbon dioxide and water with a large yield of ATP.	3	

3.8 Photosynthesis

3 hours

	Assessment statement	Obj	Teacher's notes
3.8.1	State that photosynthesis involves the conversion of light energy into chemical energy.	1	
3.8.2	State that light from the Sun is composed of a range of wavelengths (colours).	1	Reference to actual wavelengths or frequencies is not expected.
3.8.3	State that chlorophyll is the main photosynthetic pigment.	1	
3.8.4	Outline the differences in absorption of red, blue and green light by chlorophyll.	2	Students should appreciate that pigments absorb certain colours of light. The remaining colours of light are reflected. It is not necessary to mention wavelengths or the structure responsible for the absorption. **Aim 7:** Data logging using colorimeters or light sensors could be used.
3.8.5	State that light energy is used to produce ATP, and to split water molecules (photolysis) to form oxygen and hydrogen.	1	
3.8.6	State that ATP and hydrogen (derived from the photolysis of water) are used to fix carbon dioxide to make organic molecules.	1	

	Assessment statement	Obj	Teacher's notes
3.8.7	Explain that the rate of photosynthesis can be measured directly by the production of oxygen or the uptake of carbon dioxide, or indirectly by an increase in biomass.	3	The recall of details of specific experiments to indicate that photosynthesis has occurred or to measure the rate of photosynthesis is not expected.
3.8.8	Outline the effects of temperature, light intensity and carbon dioxide concentration on the rate of photosynthesis.	2	The shape of the graphs is required. The concept of limiting factors is not expected. **Aim 7:** Data logging using gas sensors, oxygen, carbon dioxide or pH probes could be used.

Topic 4: Genetics (15 hours)

4.1 Chromosomes, genes, alleles and mutations

2 hours

	Assessment statement	Obj	Teacher's notes
4.1.1	State that eukaryote chromosomes are made of DNA and proteins.	1	The names of the proteins (histones) are not required, nor is the structural relationship between DNA and the proteins.
4.1.2	Define *gene*, *allele* and *genome*.	1	Gene: a heritable factor that controls a specific characteristic. (The differences between structural genes, regulator genes and genes coding for tRNA and rRNA are not expected at SL). Allele: one specific form of a gene, differing from other alleles by one or a few bases only and occupying the same gene locus as other alleles of the gene. Genome: the whole of the genetic information of an organism.
4.1.3	Define *gene mutation*.	1	The terms point mutation or frameshift mutation will not be used.

	Assessment statement	Obj	Teacher's notes
4.1.4	Explain the consequence of a base substitution mutation in relation to the processes of transcription and translation, using the example of sickle-cell anemia.	3	GAG has mutated to GTG causing glutamic acid to be replaced by valine, and hence sickle-cell anemia. **Aim 8:** There is a variety of social issues associated with sickle-cell anemia, including the suffering due to anemia, personal feelings if one has either inherited or passed on the sickle-cell allele, questions relating to the desirability of genetic screening for the sickle-cell allele before having children, and the genetic counselling of carriers of the allele. There are also ethical issues relating to screening of fetuses and abortion of those found to have a genetic disease. **TOK:** Where a correlation is found, a causal link may or may not be present. The frequency of the sickle-cell allele is correlated with the prevalence of malaria in many parts of the world. In this case, there is a clear causal link. Other cases where there is no causal link could be described as a contrast. There has clearly been natural selection in favour of the sickle-cell allele in malarial areas, despite it causing severe anemia in the homozygous condition. Natural selection has led to particular frequencies of the sickle-cell and the normal hemoglobin alleles, to balance the twin risks of anemia and malaria.

4.2 Meiosis

3 hours

	Assessment statement	Obj	Teacher's notes
4.2.1	State that meiosis is a reduction division of a diploid nucleus to form haploid nuclei.	1	
4.2.2	Define *homologous chromosomes*.	1	
4.2.3	Outline the process of meiosis, including pairing of homologous chromosomes and crossing over, followed by two divisions, which results in four haploid cells.	2	Limit crossing over to the exchange of genetic material between non-sister chromatids during prophase I. Names of the stages are required.
4.2.4	Explain that non-disjunction can lead to changes in chromosome number, illustrated by reference to Down syndrome (trisomy 21).	3	The characteristics of Down syndrome are not required.
4.2.5	State that, in karyotyping, chromosomes are arranged in pairs according to their size and structure.	1	

	Assessment statement	Obj	Teacher's notes
4.2.6	State that karyotyping is performed using cells collected by chorionic villus sampling or amniocentesis, for pre-natal diagnosis of chromosome abnormalities.	1	**Aim 8:** There are ethical and social issues associated with karyotyping of unborn fetuses because this procedure allows parents to abort fetuses with a chromosome abnormality. There is also evidence that, in some parts of the world, abortion on the basis of gender is carried out. **TOK:** Various questions relating to karyotyping could be raised, including balancing the risks of side-effects (for example, miscarriage) against the possibility of identifying and aborting a fetus with an abnormality. There are questions about decision-making: who should make the decision about whether to perform karyotyping and allow a subsequent abortion—parents or health-care professionals or both groups? There are also questions about whether or not national governments should interfere with personal freedoms, and whether or not they should be able to ban procedures within the country and possibly also ban citizens travelling to foreign countries where the procedures are permitted.
4.2.7	Analyse a human karyotype to determine gender and whether non-disjunction has occurred.	3	Karyotyping can be done by using enlarged photographs of chromosomes. **Aim 7:** Online simulations of karyotyping activities are available.

4.3 Theoretical genetics

5 hours

	Assessment statement	Obj	Teacher's notes
4.3.1	Define *genotype*, *phenotype*, *dominant allele*, *recessive allele*, *codominant alleles*, *locus*, *homozygous*, *heterozygous*, *carrier* and *test cross*.	1	Genotype: the alleles of an organism. Phenotype: the characteristics of an organism. Dominant allele: an allele that has the same effect on the phenotype whether it is present in the homozygous or heterozygous state. Recessive allele: an allele that only has an effect on the phenotype when present in the homozygous state. Codominant alleles: pairs of alleles that both affect the phenotype when present in a heterozygote. (The terms incomplete and partial dominance are no longer used.) Locus: the particular position on homologous chromosomes of a gene. Homozygous: having two identical alleles of a gene. Heterozygous: having two different alleles of a gene. Carrier: an individual that has one copy of a recessive allele that causes a genetic disease in individuals that are homozygous for this allele. Test cross: testing a suspected heterozygote by crossing it with a known homozygous recessive. (The term backcross is no longer used.)

	Assessment statement	Obj	Teacher's notes
4.3.2	Determine the genotypes and phenotypes of the offspring of a monohybrid cross using a Punnett grid.	3	The grid should be labelled to include parental genotypes, gametes, and both offspring genotype and phenotype. **Aim 7:** Genetics simulation software is available.
4.3.3	State that some genes have more than two alleles (multiple alleles).	1	
4.3.4	Describe ABO blood groups as an example of codominance and multiple alleles.	2	Phenotype — Genotype O — ii A — I^AI^A or I^Ai B — I^BI^B or I^Bi AB — I^AI^B
4.3.5	Explain how the sex chromosomes control gender by referring to the inheritance of X and Y chromosomes in humans.	3	
4.3.6	State that some genes are present on the X chromosome and absent from the shorter Y chromosome in humans.	1	
4.3.7	Define *sex linkage*.	1	
4.3.8	Describe the inheritance of colour blindness and hemophilia as examples of sex linkage.	2	Both colour blindness and hemophilia are produced by a recessive sex-linked allele on the X chromosome. X^b and X^h is the notation for the alleles concerned. The corresponding dominant alleles are X^B and X^H.
4.3.9	State that a human female can be homozygous or heterozygous with respect to sex-linked genes.	1	
4.3.10	Explain that female carriers are heterozygous for X-linked recessive alleles.	3	
4.3.11	Predict the genotypic and phenotypic ratios of offspring of monohybrid crosses involving any of the above patterns of inheritance.	3	**Aim 8:** Statisticians are convinced that Mendel's results are too close to exact ratios to be genuine. We shall never know how this came about, but it offers an opportunity to discuss the need for scientists to be truthful about their results, whether it is right to discard results that do not fit a theory as Louis Pasteur is known to have done, and the danger of publishing results only when they show statistically significant differences. **TOK:** Reasons for Mendel's theories not being accepted by the scientific community for a long time could be considered. Other cases of paradigm shifts taking a long time to be accepted could be considered. Ways in which individual scientists are most likely to be able to convince the scientific community could be considered, and also the need always to consider the evidence rather than the views of individual scientists, however distinguished.

	Assessment statement	Obj	Teacher's notes
4.3.12	Deduce the genotypes and phenotypes of individuals in pedigree charts.	3	For dominant and recessive alleles, upper-case and lower-case letters, respectively, should be used. Letters representing alleles should be chosen with care to avoid confusion between upper and lower case. For codominance, the main letter should relate to the gene and the suffix to the allele, both upper case. For example, red and white codominant flower colours should be represented as C^R and C^W, respectively. For sickle-cell anemia, Hb^A is normal and Hb^S is sickle cell. **Aim 8:** There are many social issues in families in which there is a genetic disease, including decisions for carriers about whether to have children, personal feelings for those who have inherited or passed on alleles for the disease, and potential problems in finding partners, employment and health or life insurance. There are ethical questions about whether personal details about genes should be disclosed to insurance companies or employers. Decisions may have to be made about whether or not to have screening. These are particularly acute in the case of Huntington disease.

4.4 Genetic engineering and biotechnology

5 hours

	Assessment statement	Obj	Teacher's notes
4.4.1	Outline the use of polymerase chain reaction (PCR) to copy and amplify minute quantities of DNA.	2	Details of methods are not required.
4.4.2	State that, in gel electrophoresis, fragments of DNA move in an electric field and are separated according to their size.	1	
4.4.3	State that gel electrophoresis of DNA is used in DNA profiling.	1	
4.4.4	Describe the application of DNA profiling to determine paternity and also in forensic investigations.	2	**Aim 8:** There is a variety of social implications stemming from DNA profiling, such as identity issues for a child who learns unexpectedly who his or her biological father is, self-esteem problems for someone who learns he is not a father, problems in relationships where the male partner learns that he did not father a child, but also relief for crime victims when those responsible for the crime are identified and convicted, sometimes decades later. **TOK:** A comparison could be made between blood groups and DNA profiles in their potential for determining paternity. The difficulty in assessing the chance of two individuals having the same profile could be discussed, and also the success of DNA profiling in securing convictions in some of the high-profile legal cases of recent years.

	Assessment statement	Obj	Teacher's notes
4.4.5	Analyse DNA profiles to draw conclusions about paternity or forensic investigations.	3	The outcomes of this analysis could include knowledge of the number of human genes, the location of specific genes, discovery of proteins and their functions, and evolutionary relationships. **Aim 7:** Online bioinformatics simulations are available. **Aim 8:** We can either emphasize the large shared content of the human genome, which is common to all of us and should give us a sense of unity, or we can emphasize the small but significant allelic differences that create the biodiversity within our species, which should be treasured. Differences in the success of human races in coping with the modern world and the threat to some small human tribes could be mentioned. It is important to stress parity of esteem of all humans, whatever their genome. **TOK:** The Human Genome Project was an international endeavour, with laboratories throughout the world collaborating. However, there were also efforts in some parts of the world to gain commercial benefits from the outcomes of the project. The data from the Human Genome Project can be viewed in different ways: it could be seen as a complete account of what makes up a human, if one takes a reductionist view of life, or, alternatively, as merely the chemical instructions that have allowed a huge range of more significant human characteristics to develop. This could lead to a discussion about the essential nature of humanity.
4.4.6	Outline three outcomes of the sequencing of the complete human genome.	2	
4.4.7	State that, when genes are transferred between species, the amino acid sequence of polypeptides translated from them is unchanged because the genetic code is universal.	1	**Aim 8:** There is an ethical or moral question here: whether it is right to change the genetic integrity of a species by transferring genes to it from another species. The discussion could include the wider question of selective breeding of animals, and whether this is distinctively different and always acceptable. The possibility of animals suffering as a result of genetic modification could be considered.
4.4.8	Outline a basic technique used for gene transfer involving plasmids, a host cell (bacterium, yeast or other cell), restriction enzymes (endonucleases) and DNA ligase.	2	The use of *E. coli* in gene technology is well documented. Most of its DNA is in one circular chromosome, but it also has plasmids (smaller circles of DNA). These plasmids can be removed and cleaved by restriction enzymes at target sequences. DNA fragments from another organism can also be cleaved by the same restriction enzyme, and these pieces can be added to the open plasmid and spliced together by ligase. The recombinant plasmids formed can be inserted into new host cells and cloned.

	Assessment statement	Obj	Teacher's notes
4.4.9	State two examples of the current uses of genetically modified crops or animals.	1	Examples include salt tolerance in tomato plants, synthesis of beta-carotene (vitamin A precursor) in rice, herbicide resistance in crop plants and factor IX (human blood clotting) in sheep milk. **Aim 8:** The economic benefits of genetic modification to biotechnology companies that perform it could be considered. Also mention the possibility that harmful changes to local economies could result, and the danger that wealth could become more concentrated in a smaller percentage of the population if expensive but profitable new techniques are introduced. In this respect, inequalities in wealth may become greater.
4.4.10	Discuss the potential benefits and possible harmful effects of one example of genetic modification.	3	**Aim 8:** There are ethical questions here about how far it is acceptable for humans to change other species, as well as other ecosystems, in order to gain benefit for humans. **TOK:** This is an opportunity to discuss how we can assess whether risks are great enough to justify banning techniques and how the scientific community can inform communities generally about potential risks. Informed decisions need to be made but irrational fears should not be propagated. Consideration could be given to the paradox that careful research is needed to assess the risks, but performing this research in itself could be risky. Do protesters who destroy trials of GM crops make the world safer?
4.4.11	Define *clone*.	1	Clone: a group of genetically identical organisms or a group of cells derived from a single parent cell.
4.4.12	Outline a technique for cloning using differentiated animal cells.	2	**Aim 8:** Ethical questions about cloning should be separated into questions about reproductive cloning and therapeutic cloning. Some groups are vehemently opposed to both types.
4.4.13	Discuss the ethical issues of therapeutic cloning in humans.	3	Therapeutic cloning is the creation of an embryo to supply embryonic stem cells for medical use.

Topic 5: Ecology and evolution (16 hours)

5.1 Communities and ecosystems

5 hours

	Assessment statement	Obj	Teacher's notes
5.1.1	Define *species*, *habitat*, *population*, *community*, *ecosystem* and *ecology*.	1	Species: a group of organisms that can interbreed and produce fertile offspring. Habitat: the environment in which a species normally lives or the location of a living organism. Population: a group of organisms of the same species who live in the same area at the same time. Community: a group of populations living and interacting with each other in an area. Ecosystem: a community and its abiotic environment. Ecology: the study of relationships between living organisms and between organisms and their environment.
5.1.2	Distinguish between *autotroph* and *heterotroph*.	2	Autotroph: an organism that synthesizes its organic molecules from simple inorganic substances. Heterotroph: an organism that obtains organic molecules from other organisms.
5.1.3	Distinguish between *consumers*, *detritivores* and *saprotrophs*.	2	Consumer: an organism that ingests other organic matter that is living or recently killed. Detritivore: an organism that ingests non-living organic matter. Saprotroph: an organism that lives on or in non-living organic matter, secreting digestive enzymes into it and absorbing the products of digestion.
5.1.4	Describe what is meant by a food chain, giving three examples, each with at least three linkages (four organisms).	2	Only real examples should be used from natural ecosystems. A $\rightarrow$ B indicates that A is being "eaten" by B (that is, the arrow indicates the direction of energy flow). Each food chain should include a producer and consumers, but not decomposers. Named organisms at either species or genus level should be used. Common species names can be used instead of binomial names. General names such as "tree" or "fish" should not be used.
5.1.5	Describe what is meant by a food web.	2	
5.1.6	Define *trophic level*.	1	
5.1.7	Deduce the trophic level of organisms in a food chain and a food web.	3	Students should be able to place an organism at the level of producer, primary consumer, secondary consumer, and so on, as the terms herbivore and carnivore are not always applicable.
5.1.8	Construct a food web containing up to 10 organisms, using appropriate information.	3	
5.1.9	State that light is the initial energy source for almost all communities.	1	No reference to communities where food chains start with chemical energy is required.

	Assessment statement	Obj	Teacher's notes
5.1.10	Explain the energy flow in a food chain.	3	Energy losses between trophic levels include material not consumed or material not assimilated, and heat loss through cell respiration.
5.1.11	State that energy transformations are never 100% efficient.	1	Reference to the second law of thermodynamics is not expected.
5.1.12	Explain reasons for the shape of pyramids of energy.	3	A pyramid of energy shows the flow of energy from one trophic level to the next in a community. The units of pyramids of energy are, therefore, energy per unit area per unit time, for example, kJ m^{-2} yr^{-1}.
5.1.13	Explain that energy enters and leaves ecosystems, but nutrients must be recycled.	3	
5.1.14	State that saprotrophic bacteria and fungi (decomposers) recycle nutrients.	1	

5.2 The greenhouse effect

3 hours

	Assessment statement	Obj	Teacher's notes
5.2.1	Draw and label a diagram of the carbon cycle to show the processes involved.	1	The details of the carbon cycle should include the interaction of living organisms and the biosphere through the processes of photosynthesis, cell respiration, fossilization and combustion. Recall of specific quantitative data is not required. **TOK:** What difference might it make to scientific work if nature were to be regarded as a machine, for example, as a clockwork mechanism, or as an organism, that is, the Gaia hypothesis? How useful are these metaphors?
5.2.2	Analyse the changes in concentration of atmospheric carbon dioxide using historical records.	3	Data from the Mauna Loa, Hawaii, or Cape Grim, Tasmania, monitoring stations may be used.
5.2.3	Explain the relationship between rises in concentrations of atmospheric carbon dioxide, methane and oxides of nitrogen and the enhanced greenhouse effect.	3	Students should be aware that the greenhouse effect is a natural phenomenon. Reference should be made to transmission of incoming shorter-wave radiation and re-radiated longer-wave radiation. Knowledge that other gases, including methane and oxides of nitrogen, are greenhouse gases is expected.

	Assessment statement	Obj	Teacher's notes
5.2.4	Outline the precautionary principle.	2	The precautionary principle holds that, if the effects of a human-induced change would be very large, perhaps catastrophic, those responsible for the change must prove that it will **not do harm** before proceeding. This is the reverse of the normal situation, where those who are concerned about the change would have to prove that it will **do harm** in order to prevent such changes going ahead. **TOK:** Parallels could be drawn here between success in deterring crime by increasing the severity of the punishment or by increasing the chance of detection. If the possible consequences of rapid global warming are devastating enough, preventive measures are justified even if it is far from certain that rapid global warming will result from current human activities.
5.2.5	Evaluate the precautionary principle as a justification for strong action in response to the threats posed by the enhanced greenhouse effect.	3	**Aim 8:** Consider whether the economic harm of measures taken now to limit global warming could be balanced against the potentially much greater harm for future generations of taking no action now. There are also ethical questions about whether the health and wealth of future human generations should be jeopardized, and whether it is right to knowingly damage the habitat of, and possibly drive to extinction, species other than humans. The environmental angle here is that the issue of global warming is, by definition, a genuinely global one in terms of causes, consequences and remedies. Only through international cooperation will a solution be found. There is an inequality between those in the world who are contributing most to the problem and those who will be most harmed.
5.2.6	Outline the consequences of a global temperature rise on arctic ecosystems.	2	Effects include increased rates of decomposition of detritus previously trapped in permafrost, expansion of the range of habitats available to temperate species, loss of ice habitat, changes in distribution of prey species affecting higher trophic levels, and increased success of pest species, including pathogens.

5.3 Populations

2 hours

	Assessment statement	Obj	Teacher's notes
5.3.1	Outline how population size is affected by natality, immigration, mortality and emigration.	2	**Aim 7:** Simulation exercises can be performed.
5.3.2	Draw and label a graph showing a sigmoid (S-shaped) population growth curve.	1	

	Assessment statement	Obj	Teacher's notes
5.3.3	Explain the reasons for the exponential growth phase, the plateau phase and the transitional phase between these two phases.	3	
5.3.4	List three factors that set limits to population increase.	1	

5.4 Evolution

3 hours

	Assessment statement	Obj	Teacher's notes
5.4.1	Define *evolution*.	1	Evolution is the cumulative change in the heritable characteristics of a population. If we accept not only that species can evolve, but also that new species arise by evolution from pre-existing ones, then the whole of life can be seen as unified by its common origins. Variation within our species is the result of different selection pressures operating in different parts of the world, yet this variation is not so vast to justify a construct such as race having a biological or scientific basis.
5.4.2	Outline the evidence for evolution provided by the fossil record, selective breeding of domesticated animals and homologous structures.	2	
5.4.3	State that populations tend to produce more offspring than the environment can support.	1	
5.4.4	Explain that the consequence of the potential overproduction of offspring is a struggle for survival.	3	
5.4.5	State that the members of a species show variation.	1	
5.4.6	Explain how sexual reproduction promotes variation in a species.	3	
5.4.7	Explain how natural selection leads to evolution.	3	Greater survival and reproductive success of individuals with favourable heritable variations can lead to change in the characteristics of a population. **Aim 7:** Computer simulations can be performed.
5.4.8	Explain two examples of evolution in response to environmental change; one must be antibiotic resistance in bacteria.	3	Other examples could include: the changes in size and shape of the beaks of Galapagos finches; pesticide resistance, industrial melanism or heavy-metal tolerance in plants.

5.5 Classification

3 hours

	Assessment statement	Obj	Teacher's notes
5.5.1	Outline the binomial system of nomenclature.	2	**TOK:** The adoption of a system of binomial nomenclature is largely due to Swedish botanist and physician Carolus Linnaeus (1707–1778). Linnaeus also defined four groups of humans, and the divisions were based on both physical and social traits. By 21st-century standards, his descriptions can be regarded as racist. How does the social context of scientific work affect the methods and findings of research? Is it necessary to consider the social context when evaluating ethical aspects of knowledge claims?
5.5.2	List seven levels in the hierarchy of taxa—kingdom, phylum, class, order, family, genus and species—using an example from two different kingdoms for each level.	1	
5.5.3	Distinguish between the following phyla of plants, using simple external recognition features: *bryophyta, filicinophyta*, *coniferophyta* and *angiospermophyta*.	2	
5.5.4	Distinguish between the following phyla of animals, using simple external recognition features: *porifera, cnidaria, platyhelminthes, annelida, mollusca* and *arthropoda*.	2	
5.5.5	Apply and design a key for a group of up to eight organisms.	3	A dichotomous key should be used.

Topic 6: Human health and physiology (20 hours)

6.1 Digestion

3 hours

	Assessment statement	Obj	Teacher's notes
6.1.1	Explain why digestion of large food molecules is essential.	3	
6.1.2	Explain the need for enzymes in digestion.	3	The need for increasing the rate of digestion at body temperature should be emphasized.
6.1.3	State the source, substrate, products and optimum pH conditions for one amylase, one protease and one lipase.	1	Any human enzymes can be selected. Details of structure or mechanisms of action are not required. **Aim 7:** Data logging with pH sensors and lipase, and data logging with colorimeters and amylase can be used.

	Assessment statement	Obj	Teacher's notes
6.1.4	Draw and label a diagram of the digestive system.	1	The diagram should show the mouth, esophagus, stomach, small intestine, large intestine, anus, liver, pancreas and gall bladder. The diagram should clearly show the interconnections between these structures.
6.1.5	Outline the function of the stomach, small intestine and large intestine.	2	
6.1.6	Distinguish between *absorption* and *assimilation*.	2	
6.1.7	Explain how the structure of the villus is related to its role in absorption and transport of the products of digestion.	3	

6.2 The transport system

3 hours

	Assessment statement	Obj	Teacher's notes
6.2.1	Draw and label a diagram of the heart showing the four chambers, associated blood vessels, valves and the route of blood through the heart.	1	Care should be taken to show the relative wall thickness of the four chambers. Neither the coronary vessels nor the conductive system are required.
6.2.2	State that the coronary arteries supply heart muscle with oxygen and nutrients.	1	
6.2.3	Explain the action of the heart in terms of collecting blood, pumping blood, and opening and closing of valves.	3	A basic understanding is required, limited to the collection of blood by the atria, which is then pumped out by the ventricles into the arteries. The direction of flow is controlled by atrio-ventricular and semilunar valves.
6.2.4	Outline the control of the heartbeat in terms of myogenic muscle contraction, the role of the pacemaker, nerves, the medulla of the brain and epinephrine (adrenaline).	2	Histology of the heart muscle, names of nerves or transmitter substances are not required. **Aim 7:** Simulation and data logging involving heart rate monitors, or data logging involving an EKG sensor to measure electrical signals produced during muscle contractions, can be used.
6.2.5	Explain the relationship between the structure and function of arteries, capillaries and veins.	3	
6.2.6	State that blood is composed of plasma, erythrocytes, leucocytes (phagocytes and lymphocytes) and platelets.	1	
6.2.7	State that the following are transported by the blood: nutrients, oxygen, carbon dioxide, hormones, antibodies, urea and heat.	1	No chemical details are required.

6.3 Defence against infectious disease

3 hours

	Assessment statement	Obj	Teacher's notes
6.3.1	Define *pathogen*.	1	Pathogen: an organism or virus that causes a disease.
6.3.2	Explain why antibiotics are effective against bacteria but not against viruses.	3	Antibiotics block specific metabolic pathways found in bacteria. Viruses reproduce using the host cell's metabolic pathways, which are not affected by antibiotics. **Aim 8:** The great benefits to people throughout the world in the control of bacterial diseases using antibiotics should be stressed. Examples of diseases that often proved fatal before the advent of antibiotics could be named.
6.3.3	Outline the role of skin and mucous membranes in defence against pathogens.	2	A diagram of the skin is not required.
6.3.4	Outline how phagocytic leucocytes ingest pathogens in the blood and in body tissues.	2	Details of the subdivisions and classifications of phagocytes are not required.
6.3.5	Distinguish between *antigens* and *antibodies*.	2	
6.3.6	Explain antibody production.	3	Many different types of lymphocyte exist. Each type recognizes one specific antigen and responds by dividing to form a clone. This clone then secretes a specific antibody against the antigen. No other details are required.
6.3.7	Outline the effects of HIV on the immune system.	2	The effects of HIV should be limited to a reduction in the number of active lymphocytes and a loss of the ability to produce antibodies.
6.3.8	Discuss the cause, transmission and social implications of AIDS.	3	**Aim 8:** The social implications of AIDS are well known. Cases of AIDS are not evenly distributed in the world, and consideration could be given to the severe problems in southern Africa. Cultural and economic reasons for differences in the prevalence of AIDS could be considered. The moral obligation of those with the technology and the wealth to help others lacking these things could be discussed. **TOK:** The different methods of transmission of HIV each carry their own risk. The extent to which individuals in different societies can minimize or eliminate each of these risks could be considered.

6.4 Gas exchange

2 hours

	Assessment statement	Obj	Teacher's notes
6.4.1	Distinguish between *ventilation*, *gas exchange* and *cell respiration*.	2	
6.4.2	Explain the need for a ventilation system.	3	A ventilation system is needed to maintain high concentration gradients in the alveoli.
6.4.3	Describe the features of alveoli that adapt them to gas exchange.	2	This should include a large total surface area, a wall consisting of a single layer of flattened cells, a film of moisture and a dense network of capillaries.
6.4.4	Draw and label a diagram of the ventilation system, including trachea, lungs, bronchi, bronchioles and alveoli.	1	Students should draw the alveoli in an inset diagram at a higher magnification.
6.4.5	Explain the mechanism of ventilation of the lungs in terms of volume and pressure changes caused by the internal and external intercostal muscles, the diaphragm and abdominal muscles.	3	**Aim 7:** Data logging involving spirometers or ventilation rate monitors is possible here.

6.5 Nerves, hormones and homeostasis

6 hours

	Assessment statement	Obj	Teacher's notes
6.5.1	State that the nervous system consists of the central nervous system (CNS) and peripheral nerves, and is composed of cells called neurons that can carry rapid electrical impulses.	1	No other structural or functional divisions of the nervous system are required.
6.5.2	Draw and label a diagram of the structure of a motor neuron.	1	Include dendrites, cell body with nucleus, axon, myelin sheath, nodes of Ranvier and motor end plates.
6.5.3	State that nerve impulses are conducted from receptors to the CNS by sensory neurons, within the CNS by relay neurons, and from the CNS to effectors by motor neurons.	1	
6.5.4	Define *resting potential* and *action potential* (depolarization and repolarization).	1	
6.5.5	Explain how a nerve impulse passes along a non-myelinated neuron.	3	Include the movement of Na^+ and K^+ ions to create a resting potential and an action potential.
6.5.6	Explain the principles of synaptic transmission.	3	Include the release, diffusion and binding of the neurotransmitter, initiation of an action potential in the post-synaptic membrane, and subsequent removal of the neurotransmitter. **Aim 7:** Data logging can be used to measure changes in conductivity in distilled water as Na^+ and K^+ diffuse out of salt–agar cubes or dialysing tubing.

	Assessment statement	Obj	Teacher's notes
6.5.7	State that the endocrine system consists of glands that release hormones that are transported in the blood.	1	The nature and action of hormones or direct comparisons between nerve and endocrine systems are not required.
6.5.8	State that homeostasis involves maintaining the internal environment between limits, including blood pH, carbon dioxide concentration, blood glucose concentration, body temperature and water balance.	1	The internal environment consists of blood and tissue fluid.
6.5.9	Explain that homeostasis involves monitoring levels of variables and correcting changes in levels by negative feedback mechanisms.	3	
6.5.10	Explain the control of body temperature, including the transfer of heat in blood, and the roles of the hypothalamus, sweat glands, skin arterioles and shivering.	3	**Aim 7:** Data logging using a surface temperature sensor to investigate the warming by nasal passages could be carried out here.
6.5.11	Explain the control of blood glucose concentration, including the roles of glucagon, insulin and α and β cells in the pancreatic islets.	3	The effects of adrenaline are not required here.
6.5.12	Distinguish between *type I* and *type II* diabetes.	2	**Aim 8:** Diabetes is having an increasing effect on human societies around the world, including personal suffering due to ill health from the diabetes directly but also from side-effects such as kidney failure. There are economic consequences relating to the health-care costs of treating diabetics. **TOK:** The causes of the variation in rates of type II diabetes in different human populations could be analysed. Rates can be particularly high when individuals consume a diet very different to the traditional one of their ancestors, for example, when having migrated to a new country. There are genetic differences in our capacity to cope with high levels of refined sugar and fat in the diet. Humans also vary considerably in how prone they are to become obese.

6.6 Reproduction

3 hours

	Assessment statement	Obj	Teacher's notes
6.6.1	Draw and label diagrams of the adult male and female reproductive systems.	1	The relative positions of the organs is important. Do not include any histological details, but include the bladder and urethra.
6.6.2	Outline the role of hormones in the menstrual cycle, including FSH (follicle stimulating hormone), LH (luteinizing hormone), estrogen and progesterone.	2	

	Assessment statement	Obj	Teacher's notes
6.6.3	Annotate a graph showing hormone levels in the menstrual cycle, illustrating the relationship between changes in hormone levels and ovulation, menstruation and thickening of the endometrium.	2	
6.6.4	List three roles of testosterone in males.	1	Limit this to pre-natal development of male genitalia, development of secondary sexual characteristics and maintenance of sex drive.
6.6.5	Outline the process of *in vitro* fertilization (IVF).	2	
6.6.6	Discuss the ethical issues associated with IVF.	3	**Aim 8:** There is great variation between human societies around the world in the views held on IVF. This is the result of cultural and religious diversity. There is little evidence to suggest that children born as a result of standard IVF protocols are different in any way from children conceived naturally. It is important that there is parity of esteem for all children, however they were conceived. **TOK:** There are potential risks in the drug treatments that the woman is given, and there are concerns about the artificial selection of sperm and the injection of them into the eggs that occurs with some IVF protocols. The natural selection of sperm with consequent elimination of unhealthy ones is bypassed, and there is evidence that there are higher rates of abnormality in the offspring as a result.

Syllabus details—AHL

Topic 7: Nucleic acids and proteins (11 hours)

7.1 DNA structure

2 hours

	Assessment statement	Obj	Teacher's notes
7.1.1	Describe the structure of DNA, including the antiparallel strands, 3′–5′ linkages and hydrogen bonding between purines and pyrimidines.	2	Major and minor grooves, direction of the "twist", alternative B and Z forms, and details of the dimensions are not required.
7.1.2	Outline the structure of nucleosomes.	2	Limit this to the fact that a nucleosome consists of DNA wrapped around eight histone proteins and held together by another histone protein.
7.1.3	State that nucleosomes help to supercoil chromosomes and help to regulate transcription.	1	
7.1.4	Distinguish between *unique or single-copy genes* and *highly repetitive sequences* in nuclear DNA.	2	Highly repetitive sequences (satellite DNA) constitutes 5–45% of the genome. The sequences are typically between 5 and 300 base pairs per repeat, and may be duplicated as many as 10^5 times per genome. **TOK:** Highly repetitive sequences were once classified as "junk DNA", showing a degree of confidence that it had no role. This addresses the question: To what extent do the labels and categories used in the pursuit of knowledge affect the knowledge we obtain?
7.1.5	State that eukaryotic genes can contain exons and introns.	1	

7.2 DNA replication

2 hours

	Assessment statement	Obj	Teacher's notes
7.2.1	State that DNA replication occurs in a $5' \rightarrow 3'$ direction.	1	The 5′ end of the free DNA nucleotide is added to the 3′ end of the chain of nucleotides that is already synthesized.
7.2.2	Explain the process of DNA replication in prokaryotes, including the role of enzymes (helicase, DNA polymerase, RNA primase and DNA ligase), Okazaki fragments and deoxynucleoside triphosphates.	3	The explanation of Okazaki fragments in relation to the direction of DNA polymerase III action is required. DNA polymerase III adds nucleotides in the $5' \rightarrow 3'$ direction. DNA polymerase I excises the RNA primers and replaces them with DNA.
7.2.3	State that DNA replication is initiated at many points in eukaryotic chromosomes.	1	

7.3 Transcription

2 hours

	Assessment statement	Obj	Teacher's notes
7.3.1	State that transcription is carried out in a 5′ → 3′ direction.	1	The 5′ end of the free RNA nucleotide is added to the 3′ end of the RNA molecule that is already synthesized.
7.3.2	Distinguish between the *sense* and *antisense* strands of DNA.	2	The sense strand (coding strand) has the same base sequence as mRNA with uracil instead of thymine. The antisense (template) strand is transcribed.
7.3.3	Explain the process of transcription in prokaryotes, including the role of the promoter region, RNA polymerase, nucleoside triphosphates and the terminator.	3	The following details are not required: there is more than one type of RNA polymerase; features of the promoter region; the need for transcription protein factors for RNA polymerase binding; TATA boxes (and other repetitive sequences); and the exact sequence of the bases that act as terminators.
7.3.4	State that eukaryotic RNA needs the removal of introns to form mature mRNA.	1	Further details of the process of post-transcriptional modification of RNA are not required.

7.4 Translation

2 hours

	Assessment statement	Obj	Teacher's notes
7.4.1	Explain that each tRNA molecule is recognized by a tRNA-activating enzyme that binds a specific amino acid to the tRNA, using ATP for energy.	3	Each amino acid has a specific tRNA-activating enzyme (the name aminoacyl-tRNA synthetase is not required). The shape of tRNA and CCA at the 3′ end should be included.
7.4.2	Outline the structure of ribosomes, including protein and RNA composition, large and small subunits, three tRNA binding sites and mRNA binding sites.	2	
7.4.3	State that translation consists of initiation, elongation, translocation and termination.	1	
7.4.4	State that translation occurs in a 5′ → 3′ direction.	1	During translation, the ribosome moves along the mRNA towards the 3′ end. The start codon is nearer to the 5′ end.
7.4.5	Draw and label a diagram showing the structure of a peptide bond between two amino acids.	1	
7.4.6	Explain the process of translation, including ribosomes, polysomes, start codons and stop codons.	3	Use of methionine for initiation, details of the T factor and recall of actual stop codons are not required.
7.4.7	State that free ribosomes synthesize proteins for use primarily within the cell, and that bound ribosomes synthesize proteins primarily for secretion or for lysosomes.	1	

7.5 Proteins

1 hour

	Assessment statement	Obj	Teacher's notes
7.5.1	Explain the four levels of protein structure, indicating the significance of each level.	3	Quaternary structure may involve the binding of a prosthetic group to form a conjugated protein. **Aim 7:** Simulation exercises showing three-dimensional molecular models of proteins are available.
7.5.2	Outline the difference between fibrous and globular proteins, with reference to two examples of each protein type.	2	
7.5.3	Explain the significance of polar and non-polar amino acids.	3	Limit this to controlling the position of proteins in membranes, creating hydrophilic channels through membranes, and the specificity of active sites in enzymes.
7.5.4	State four functions of proteins, giving a named example of each.	1	Membrane proteins should not be included.

7.6 Enzymes

2 hours

	Assessment statement	Obj	Teacher's notes
7.6.1	State that metabolic pathways consist of chains and cycles of enzyme-catalysed reactions.	1	
7.6.2	Describe the induced-fit model.	2	This is an extension of the lock-and-key model. Its importance in accounting for the ability of some enzymes to bind to several substrates should be mentioned. **TOK:** Scientific truths are often pragmatic. We accept them as true because they give us predictive power, that is, they work. The German scientist Emil Fischer introduced the lock-and-key model for enzymes and their substrates in 1890. It was not until 1958 that Daniel Koshland in the United States suggested that the binding of the substrate to the active site caused a conformational change, hence the induced-fit model. This is an example of one model or theory, accepted for many years, being superseded by another that offers a fuller explanation of a process.
7.6.3	Explain that enzymes lower the activation energy of the chemical reactions that they catalyse.	3	Only exothermic reactions should be considered. Specific energy values do not need to be recalled.

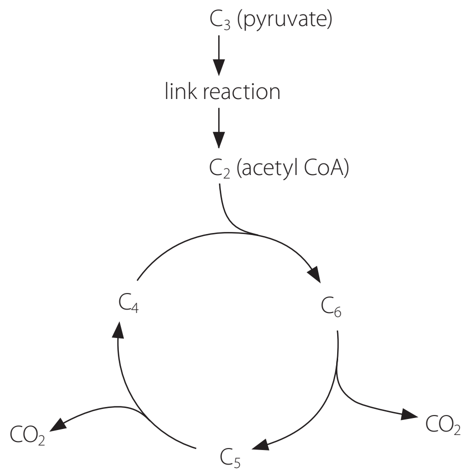
	Assessment statement	Obj	Teacher's notes
7.6.4	Explain the difference between competitive and non-competitive inhibition, with reference to one example of each.	3	Competitive inhibition is the situation when an inhibiting molecule that is structurally similar to the substrate molecule binds to the active site, preventing substrate binding. Limit non-competitive inhibition to an inhibitor binding to an enzyme (not to its active site) that causes a conformational change in its active site, resulting in a decrease in activity. Reversible inhibition, as compared to irreversible inhibition, is not required.
7.6.5	Explain the control of metabolic pathways by end-product inhibition, including the role of allosteric sites.	3	

Topic 8: Cell respiration and photosynthesis (10 hours)

8.1 Cell respiration

5 hours

	Assessment statement	Obj	Teacher's notes
8.1.1	State that oxidation involves the loss of electrons from an element, whereas reduction involves a gain of electrons; and that oxidation frequently involves gaining oxygen or losing hydrogen, whereas reduction frequently involves losing oxygen or gaining hydrogen.	1	
8.1.2	Outline the process of glycolysis, including phosphorylation, lysis, oxidation and ATP formation.	2	In the cytoplasm, one hexose sugar is converted into two three-carbon atom compounds (pyruvate) with a net gain of two ATP and two NADH + H^+.
8.1.3	Draw and label a diagram showing the structure of a mitochondrion as seen in electron micrographs.	1	

	Assessment statement	Obj	Teacher's notes
8.1.4	Explain aerobic respiration, including the link reaction, the Krebs cycle, the role of NADH + H^+, the electron transport chain and the role of oxygen.	3	In aerobic respiration (in mitochondria in eukaryotes), each pyruvate is decarboxylated (CO_2 removed). The remaining two-carbon molecule (acetyl group) reacts with reduced coenzyme A, and, at the same time, one NADH + H^+ is formed. This is known as the link reaction.  In the Krebs cycle, each acetyl group (CH_3CO) formed in the link reaction yields two CO_2. The names of the intermediate compounds in the cycle are not required. Thus it would be acceptable to note: $C_2 + C_4 = C_6 \longrightarrow C_5 \longrightarrow$, and so on.
8.1.5	Explain oxidative phosphorylation in terms of chemiosmosis.	3	
8.1.6	Explain the relationship between the structure of the mitochondrion and its function.	3	Limit this to cristae forming a large surface area for the electron transport chain, the small space between inner and outer membranes for accumulation of protons, and the fluid matrix containing enzymes of the Krebs cycle.

8.2 Photosynthesis

5 hours

	Assessment statement	Obj	Teacher's notes
8.2.1	Draw and label a diagram showing the structure of a chloroplast as seen in electron micrographs.	1	
8.2.2	State that photosynthesis consists of light-dependent and light-independent reactions.	1	These should not be called "light" and "dark" reactions.
8.2.3	Explain the light-dependent reactions.	3	Include the photoactivation of photosystem II, photolysis of water, electron transport, cyclic and non-cyclic photophosphorylation, photoactivation of photosystem I, and reduction of $NADP^+$.
8.2.4	Explain photophosphorylation in terms of chemiosmosis.	3	

	Assessment statement	Obj	Teacher's notes
8.2.5	Explain the light-independent reactions.	3	Include the roles of ribulose bisphosphate (RuBP) carboxylase, reduction of glycerate 3-phosphate (GP) to triose phosphate (TP), NADPH + H^+, ATP, regeneration of RuBP, and subsequent synthesis of more complex carbohydrates. **TOK:** The lollipop apparatus used to work out the biochemical details of the Calvin cycle shows considerable creativity. To what extent is the creation of an elegant protocol similar to the creation of a work of art?
8.2.6	Explain the relationship between the structure of the chloroplast and its function.	3	Limit this to the large surface area of thylakoids for light absorption, the small space inside thylakoids for accumulation of protons, and the fluid stroma for the enzymes of the Calvin cycle.
8.2.7	Explain the relationship between the action spectrum and the absorption spectrum of photosynthetic pigments in green plants.	3	A separate spectrum for each pigment (chlorophyll a, chlorophyll b, and so on) is not required.
8.2.8	Explain the concept of limiting factors in photosynthesis, with reference to light intensity, temperature and concentration of carbon dioxide.	3	**TOK:** This is an opportunity to discuss the need for very carefully controlled experiments. If we want to investigate the effect of one factor, all other factors that could have an influence must be controlled. In photosynthesis, the situation is relatively simple, and we can ensure that factors other than the one we are investigating are maintained at a constant and optimal level. In other areas, there are much greater problems. In the many investigations of human health, there are almost always complicating factors. For example, vegetarians have a longer life expectancy than meat eaters. We would be wrong to conclude that eating meat lowers life expectancy unless we could show that the only difference between the vegetarians and the meat eaters in our trial was the meat eating.

Topic 9: Plant science (11 hours)

9.1 Plant structure and growth

4 hours

	Assessment statement	Obj	Teacher's notes
9.1.1	Draw and label plan diagrams to show the distribution of tissues in the stem and leaf of a dicotyledonous plant.	1	Either sunflower, bean or another dicotyledonous plant with similar tissue distribution should be used. Note that plan diagrams show distribution of tissues (for example, xylem, phloem) and do not show individual cells. They are sometimes called "low-power" diagrams.

	Assessment statement	Obj	Teacher's notes
9.1.2	Outline three differences between the structures of dicotyledonous and monocotyledonous plants.	2	Teachers should emphasize three differences between monocotyledonous and dicotyledonous plants (examples include: parallel *versus* net-like venation in leaves, distribution of vascular tissue in stems, number of cotyledons, floral organs in multiples of 3 in monocotyledonous *versus* 4 or 5 in dicotyledonous, fibrous adventitious roots in monocotyledonous *versus* tap root with lateral branches in dicotyledonous).
9.1.3	Explain the relationship between the distribution of tissues in the leaf and the functions of these tissues.	3	This should be restricted to dicotyledonous plants. The functions should include: absorption of light, gas exchange, support, water conservation, and the transport of water and products of photosynthesis.
9.1.4	Identify modifications of roots, stems and leaves for different functions: bulbs, stem tubers, storage roots and tendrils.	2	
9.1.5	State that dicotyledonous plants have apical and lateral meristems.	1	Apical meristems are sometimes referred to as primary meristems, and lateral meristems as cambium. Meristems generate new cells for growth of the plant.
9.1.6	Compare growth due to apical and lateral meristems in dicotyledonous plants.	3	
9.1.7	Explain the role of auxin in phototropism as an example of the control of plant growth.	3	

9.2 Transport in angiospermophytes

4 hours

	Assessment statement	Obj	Teacher's notes
9.2.1	Outline how the root system provides a large surface area for mineral ion and water uptake by means of branching and root hairs.	2	
9.2.2	List ways in which mineral ions in the soil move to the root.	1	There are three processes: diffusion of mineral ions, fungal hyphae (mutualism), and mass flow of water in the soil carrying ions.
9.2.3	Explain the process of mineral ion absorption from the soil into roots by active transport.	3	
9.2.4	State that terrestrial plants support themselves by means of thickened cellulose, cell turgor and lignified xylem.	1	

	Assessment statement	Obj	Teacher's notes
9.2.5	Define *transpiration*.	1	Transpiration is the loss of water vapour from the leaves and stems of plants. **Aim 7:** Data logging with pressure sensors, humidity, light or temperature probes to measure rates of transpiration can be performed.
9.2.6	Explain how water is carried by the transpiration stream, including the structure of xylem vessels, transpiration pull, cohesion, adhesion and evaporation.	3	Limit the structure of xylem vessels to one type of primary xylem.
9.2.7	State that guard cells can regulate transpiration by opening and closing stomata.	1	
9.2.8	State that the plant hormone abscisic acid causes the closing of stomata.	1	
9.2.9	Explain how the abiotic factors light, temperature, wind and humidity, affect the rate of transpiration in a typical terrestrial plant.	3	
9.2.10	Outline four adaptations of xerophytes that help to reduce transpiration.	2	These could include: reduced leaves, rolled leaves, spines, deep roots, thickened waxy cuticle, reduced number of stomata, stomata in pits surrounded by hairs, water storage tissue, low growth form, CAM (crassulacean acid metabolism) and C_4 physiology.
9.2.11	Outline the role of phloem in active translocation of sugars (sucrose) and amino acids from source (photosynthetic tissue and storage organs) to sink (fruits, seeds, roots).	2	No detail of the mechanism of translocation or the structure of phloem is required.

9.3 Reproduction in angiospermophytes

3 hours

	Assessment statement	Obj	Teacher's notes
9.3.1	Draw and label a diagram showing the structure of a dicotyledonous animal-pollinated flower.	1	Limit the diagram to sepal, petal, anther, filament, stigma, style and ovary.
9.3.2	Distinguish between *pollination*, *fertilization* and *seed dispersal*.	2	
9.3.3	Draw and label a diagram showing the external and internal structure of a named dicotyledonous seed.	1	The named seed should be non-endospermic. The structure in the diagram should be limited to testa, micropyle, embryo root, embryo shoot and cotyledons.
9.3.4	Explain the conditions needed for the germination of a typical seed.	3	Seeds vary in their light requirements and, therefore, this factor need not be included.

	Assessment statement	Obj	Teacher's notes
9.3.5	Outline the metabolic processes during germination of a starchy seed.	2	Absorption of water precedes the formation of gibberellin in the embryo's cotyledon. This stimulates the production of amylase, which catalyses the breakdown of starch to maltose. This subsequently diffuses to the embryo for energy release and growth. No further details are expected.
9.3.6	Explain how flowering is controlled in long-day and short-day plants, including the role of phytochrome.	3	Limit this to the conversion of P_r (red absorbing) to P_{fr} (far-red absorbing) in red or white light, the gradual reversion of P_{fr} to P_r in darkness, and the action of P_{fr} as a promoter of flowering in long-day plants and an inhibitor of flowering in short-day plants.

Topic 10: Genetics (6 hours)

10.1 Meiosis

2 hours

	Assessment statement	Obj	Teacher's notes
10.1.1	Describe the behaviour of the chromosomes in the phases of meiosis.	2	
10.1.2	Outline the formation of chiasmata in the process of crossing over.	2	
10.1.3	Explain how meiosis results in an effectively infinite genetic variety in gametes through crossing over in prophase I and random orientation in metaphase I.	3	
10.1.4	State Mendel's law of independent assortment.	1	**TOK:** There are some interesting aspects of Mendel's work, including those mentioned in 4.3.11. The law of independent assortment was soon found to have exceptions when pairs of genes are linked on a chromosome, but the law that Mendel discovered in the 19th century does operate for the majority of pairs of genes.
10.1.5	Explain the relationship between Mendel's law of independent assortment and meiosis.	3	

10.2 Dihybrid crosses and gene linkage

3 hours

	Assessment statement	Obj	Teacher's notes
10.2.1	Calculate and predict the genotypic and phenotypic ratio of offspring of dihybrid crosses involving unlinked autosomal genes.	3	

	Assessment statement	Obj	Teacher's notes
10.2.2	Distinguish between *autosomes* and *sex chromosomes*.	2	
10.2.3	Explain how crossing over between non-sister chromatids of a homologous pair in prophase I can result in an exchange of alleles.	3	
10.2.4	Define *linkage group*.	1	
10.2.5	Explain an example of a cross between two linked genes.	3	Alleles are usually shown side by side in dihybrid crosses, for example, TtBb. In representing crosses involving linkage, it is more common to show them as vertical pairs, for example $\frac{T\ B}{t\ b}$ This format will be used in examination papers, or students will be given sufficient information to allow them to deduce which alleles are linked.
10.2.6	Identify which of the offspring are recombinants in a dihybrid cross involving linked genes.	2	In a test cross of $\frac{T\ B}{t\ b}$ the recombinants will be $\frac{T\ b}{t\ b}$ and $\frac{t\ B}{t\ b}$

10.3 Polygenic inheritance

1 hour

	Assessment statement	Obj	Teacher's notes
10.3.1	Define *polygenic inheritance*.	1	
10.3.2	Explain that polygenic inheritance can contribute to continuous variation using two examples, one of which must be human skin colour.	3	**Aim 8:** This is one of the most obvious opportunities to develop the theme of parity of esteem for all humans. The selective advantage of dark skin to protect against ultraviolet light and light skin to allow vitamin D production could be mentioned. The correlation between skin colour and intensity of sunlight is clear, though the selective advantages of particular skin colours can now be overcome by the use of sun-block creams and vitamin D supplements.

Topic 11: Human health and physiology (17 hours)

11.1 Defence against infectious disease

4 hours

	Assessment statement	Obj	Teacher's notes
11.1.1	Describe the process of blood clotting.	2	Limit this to the release of clotting factors from platelets and damaged cells resulting in the formation of thrombin. Thrombin catalyses the conversion of soluble fibrinogen into the fibrous protein fibrin, which captures blood cells.
11.1.2	Outline the principle of challenge and response, clonal selection and memory cells as the basis of immunity.	2	This is intended to be a simple introduction to the complex topic of immunity. The idea of a polyclonal response can be introduced here.
11.1.3	Define *active* and *passive* immunity.	1	Active immunity is immunity due to the production of antibodies by the organism itself after the body's defence mechanisms have been stimulated by antigens. Passive immunity is immunity due to the acquisition of antibodies from another organism in which active immunity has been stimulated, including via the placenta, colostrum, or by injection of antibodies.
11.1.4	Explain antibody production.	3	Limit the explanation to antigen presentation by macrophages and activation of helper T-cells leading to activation of B-cells which divide to form clones of antibody-secreting plasma cells and memory cells.
11.1.5	Describe the production of monoclonal antibodies and their use in diagnosis and in treatment.	2	Production should be limited to the fusion of tumour and B-cells, and their subsequent proliferation and production of antibodies. Limit the uses to one example of diagnosis and one of treatment. Detection of antibodies to HIV is one example in diagnosis. Others are detection of a specific cardiac isoenzyme in suspected cases of heart attack and detection of human chorionic gonadotrophin (HCG) in pregnancy test kits. Examples of the use of these antibodies for treatment include targeting of cancer cells with drugs attached to monoclonal antibodies, emergency treatment of rabies, blood and tissue typing for transplant compatibility, and purification of industrially made interferon. **Aim 8:** Production of monoclonal antibodies is certain to be a growth area in biotechnology, with many potential applications and consequent economic opportunities. Some of the applications will be of most use in developing countries, raising the question of how they will be paid for, whether commercial companies should be expected to carry out *pro bono* research and development, or whether national governments should provide funds for it through aid budgets. Historically, the development of treatments for tropical diseases and parasites has lagged far behind those for the diseases prevalent in wealthier countries.

	Assessment statement	Obj	Teacher's notes
11.1.6	Explain the principle of vaccination.	3	Emphasize the role of memory cells. The primary and secondary responses can be clearly illustrated by a graph. Precise details of all the types of vaccine (attenuated virus, inactivated toxins, and so on) for specific diseases are not required.
11.1.7	Discuss the benefits and dangers of vaccination.	3	The benefits should include total elimination of diseases, prevention of pandemics and epidemics, decreased health-care costs and prevention of harmful side-effects of diseases. The dangers should include the possible toxic effects of mercury in vaccines, possible overload of the immune system and possible links with autism. **Aim 8:** For parents there are ethical decisions to be made, to minimize risk for one's own child, but also to help to prevent epidemics that could affect other children. **Int:** The international dimension could be addressed here, given that some diseases have the potential to become pandemics and that the example of smallpox shows how effective international cooperation can be in combating infectious diseases. **TOK:** This is an area where it is important to estimate accurately the size of risks, using good scientific data. The use of double-blind trials for vaccines or for drug treatments could be discussed. The placebo effect could also be considered, together with the complex interplay between mind and body in feelings of illness and health. Does the patient or the doctor decide whether the patient is well or not? There are also questions about the relationship between the scientific community and the general public. How can the general public be given clear information about the benefits and risks of vaccination? What went wrong in the recent case of misplaced fears about the measles, mumps and rubella (MMR) vaccine in the UK? There are ethical questions here about who should decide vaccination policy in a country, and whether it is ethically acceptable to have a compulsory vaccination programme.

11.2 Muscles and movement

4 hours

	Assessment statement	Obj	Teacher's notes
11.2.1	State the roles of bones, ligaments, muscles, tendons and nerves in human movement.	1	
11.2.2	Label a diagram of the human elbow joint, including cartilage, synovial fluid, joint capsule, named bones and antagonistic muscles (biceps and triceps).	1	

	Assessment statement	Obj	Teacher's notes
11.2.3	Outline the functions of the structures in the human elbow joint named in 11.2.2.	2	
11.2.4	Compare the movements of the hip joint and the knee joint.	3	**Aim 7:** Video analysis of motion is possible here.
11.2.5	Describe the structure of striated muscle fibres, including the myofibrils with light and dark bands, mitochondria, the sarcoplasmic reticulum, nuclei and the sarcolemma.	2	
11.2.6	Draw and label a diagram to show the structure of a sarcomere, including Z lines, actin filaments, myosin filaments with heads, and the resultant light and dark bands.	1	No other terms for parts of the sarcomere are expected.
11.2.7	Explain how skeletal muscle contracts, including the release of calcium ions from the sarcoplasmic reticulum, the formation of cross-bridges, the sliding of actin and myosin filaments, and the use of ATP to break cross-bridges and re-set myosin heads.	3	Details of the roles of troponin and tropomyosin are not expected. **Aim 7:** Data logging could be carried out using a grip sensor to study muscle fatigue and muscle strength.
11.2.8	Analyse electron micrographs to find the state of contraction of muscle fibres.	3	Muscle fibres can be fully relaxed, slightly contracted, moderately contracted and fully contracted.

11.3 The kidney

4 hours

	Assessment statement	Obj	Teacher's notes
11.3.1	Define *excretion*.	1	Excretion is the removal from the body of the waste products of metabolic pathways.
11.3.2	Draw and label a diagram of the kidney.	1	Include the cortex, medulla, pelvis, ureter and renal blood vessels.
11.3.3	Annotate a diagram of a glomerulus and associated nephron to show the function of each part.	2	
11.3.4	Explain the process of ultrafiltration, including blood pressure, fenestrated blood capillaries and basement membrane.	3	
11.3.5	Define *osmoregulation*.	1	Osmoregulation is the control of the water balance of the blood, tissue or cytoplasm of a living organism. **Aim 7:** Data logging using colorimeters to measure the response of blood cells to changing salt concentrations is possible.

	Assessment statement	Obj	Teacher's notes
11.3.6	Explain the reabsorption of glucose, water and salts in the proximal convoluted tubule, including the roles of microvilli, osmosis and active transport.	3	
11.3.7	Explain the roles of the loop of Henle, medulla, collecting duct and ADH (vasopressin) in maintaining the water balance of the blood.	3	Details of the control of ADH secretion are only required in option H (see H.1.5).
11.3.8	Explain the differences in the concentration of proteins, glucose and urea between blood plasma, glomerular filtrate and urine.	3	
11.3.9	Explain the presence of glucose in the urine of untreated diabetic patients.	3	

11.4 Reproduction

5 hours

	Assessment statement	Obj	Teacher's notes
11.4.1	Annotate a light micrograph of testis tissue to show the location and function of interstitial cells (Leydig cells), germinal epithelium cells, developing spermatozoa and Sertoli cells.	2	
11.4.2	Outline the processes involved in spermatogenesis within the testis, including mitosis, cell growth, the two divisions of meiosis and cell differentiation.	2	The names of the intermediate stages in spermatogenesis are not required.
11.4.3	State the role of LH, testosterone and FSH in spermatogenesis.	1	
11.4.4	Annotate a diagram of the ovary to show the location and function of germinal epithelium, primary follicles, mature follicle and secondary oocyte.	2	
11.4.5	Outline the processes involved in oogenesis within the ovary, including mitosis, cell growth, the two divisions of meiosis, the unequal division of cytoplasm and the degeneration of polar body.	2	The terms oogonia and primary oocyte are not required.
11.4.6	Draw and label a diagram of a mature sperm and egg.	1	
11.4.7	Outline the role of the epididymis, seminal vesicle and prostate gland in the production of semen.	2	

	Assessment statement	Obj	Teacher's notes
11.4.8	Compare the processes of spermatogenesis and oogenesis, including the number of gametes and the timing of the formation and release of gametes.	3	
11.4.9	Describe the process of fertilization, including the acrosome reaction, penetration of the egg membrane by a sperm and the cortical reaction.	2	
11.4.10	Outline the role of HCG in early pregnancy.	2	
11.4.11	Outline early embryo development up to the implantation of the blastocyst.	2	Limit this to several mitotic divisions resulting in a hollow ball of cells called the blastocyst.
11.4.12	Explain how the structure and functions of the placenta, including its hormonal role in secretion of estrogen and progesterone, maintain pregnancy.	3	
11.4.13	State that the fetus is supported and protected by the amniotic sac and amniotic fluid.	1	Embryonic details of the fetus and the structure of amniotic membranes are not required.
11.4.14	State that materials are exchanged between the maternal and fetal blood in the placenta.	1	
11.4.15	Outline the process of birth and its hormonal control, including the changes in progesterone and oxytocin levels and positive feedback.	2	

Syllabus details—Options SL

These options are available at SL only.

B1 is identical to 11.2.

C1 is identical to 7.5.

C2 is identical to 7.6.

C.3.1–C.3.6 are identical to 8.1.1–8.1.6.

C.4.1–C.4.8 are identical to 8.2.1–8.2.8.

Option A: Human nutrition and health (15 hours)

A1 Components of the human diet

5 hours

	Assessment statement	Obj	Teacher's notes
A.1.1	Define *nutrient*.	1	Nutrient: a chemical substance found in foods that is used in the human body.
A.1.2	List the type of nutrients that are essential in the human diet, including amino acids, fatty acids, minerals, vitamins and water.	1	Essential nutrients are those that cannot be synthesized by the body. Carbohydrates are not included because in certain traditional human diets energy is obtained from other sources without ill effect.
A.1.3	State that non-essential amino acids can be synthesized in the body from other nutrients.	1	
A.1.4	Outline the consequences of protein deficiency malnutrition.	2	Protein deficiency is shortage of one or more essential amino acids. The consequences are lack of blood plasma proteins and subsequent tissue fluid retention, with swelling of the abdomen. Development of children is likely to be both mentally and physically retarded. **Aim 8:** Patterns of global malnutrition could be looked at, both over time and over geopolitical areas, using data downloaded from the Internet.
A.1.5	Explain the causes and consequences of phenylketonuria (PKU) and how early diagnosis and a special diet can reduce the consequences.	3	The name of the gene and enzyme concerned are not required. Limit the causes to a mutation of a gene for an enzyme that converts the essential amino acid phenylalanine to tyrosine.

	Assessment statement	Obj	Teacher's notes
A.1.6	Outline the variation in the molecular structure of fatty acids, including saturated fatty acids, *cis* and *trans* unsaturated fatty acids, monounsaturated and polyunsaturated fatty acids.	2	Include omega-3 fatty acids as an example.
A.1.7	Evaluate the health consequences of diets rich in the different types of fatty acid.	3	**Aim 8:** There are marked differences in the traditional diets of human societies around the world, and also differences in the rates of coronary heart disease and other diseases that have been linked to diet. This is a chance to compare human societies—the Maasai, for example, are a striking example of people with a low rate of heart disease. **TOK:** The distinction between correlation and cause could be made here and the need for carefully controlled experiments to test whether a correlation is due to a causal link. Epidemiological data could be examined and the problems in interpreting it discussed. The link between consumption of saturated fatty acids and coronary heart disease is not a simple correlation and genetic factors are also important.
A.1.8	Distinguish between *minerals* and *vitamins* in terms of their chemical nature.	2	Limit this to minerals being elements in ionic form and vitamins being organic compounds.
A.1.9	Outline two of the methods that have been used to determine the recommended daily intake of vitamin C.	2	Include brief details of one method involving human subjects and another involving small mammals. **Aim 8:** Some of the experiments used to determine necessary levels of vitamin consumption were done using conscientious objectors during the second world war. This raises ethical questions about trials in which the experimental subjects could be harmed or suffer. **TOK:** Recommended intakes of nutrients have been published in some countries. The recommendations vary, and this raises questions about how the levels are decided by scientists or doctors.
A.1.10	Discuss the amount of vitamin C that an adult should consume per day, including the level needed to prevent scurvy, claims that higher intakes give protection against upper respiratory tract infections, and the danger of rebound malnutrition.	3	Rebound malnutrition can occur when a normally adequate intake of a vitamin follows a period of excessive intake and excretion. **TOK:** Linus Pauling, a Nobel prize-winning American chemist, famously advocated consuming 1,000 mg of vitamin C per day to avoid catching colds, without strong evidence. Many followed his advice, perhaps because he was such a distinguished scientist. This raises questions about the status of individuals who are seen as authoritative, and how others without such status can question their views on the basis of the evidence.
A.1.11	List the sources of vitamin D in human diets.	1	

	Assessment statement	Obj	Teacher's notes
A.1.12	Discuss how the risk of vitamin D deficiency from insufficient exposure to sunlight can be balanced against the risk of contracting malignant melanoma.	3	**Aim 8:** The issue of cancer and its social consequences could be raised, with malignant melanoma as a starting point. **TOK:** This is an interesting case illustrating the inevitability of risk.
A.1.13	Explain the benefits of artificial dietary supplementation as a means of preventing malnutrition, using iodine as an example.	3	
A.1.14	Outline the importance of fibre as a component of a balanced diet.	2	

A2 Energy in human diets

4 hours

	Assessment statement	Obj	Teacher's notes
A.2.1	Compare the energy content per 100 g of carbohydrate, fat and protein.	3	Students should know that carbohydrates contain approximately 1,760 kJ per 100 g, protein 1,720 kJ per 100 g and fats 4,000 kJ per 100 g.
A.2.2	Compare the main dietary sources of energy in different ethnic groups.	3	Include ethnic groups using rice, wheat, cassava, maize, fish and meat as their staple energy source. **Aim 8:** This is another opportunity to look at diversity in human societies.
A.2.3	Explain the possible health consequences of diets rich in carbohydrates, fats and proteins.	3	The consequences of an excess of each of the three types of nutrient should be explained separately. **Aim 8:** Especially in the developed world, there are social issues relating to inappropriate diets and highly effective marketing of unhealthy foods by profit-making companies. **TOK:** This is another case where correlation and cause need to be very carefully distinguished. Examples of bad advice based on flawed science can easily be found, with newspapers on an almost daily basis drawing conclusions based on loose correlation rather than on carefully controlled trials.
A.2.4	Outline the function of the appetite control centre in the brain.	2	Only a simple account is expected. Hormones are produced by the pancreas and small intestine after eating and by adipose tissue in response to fat storage. These pass to an appetite control centre in the brain, which makes the person feel that they have eaten enough.
A.2.5	Calculate body mass index (BMI) from the body mass and height of a person.	2	BMI = (mass in kg)/(height in m)^2
A.2.6	Distinguish, using the body mass index, between being *underweight, normal weight, overweight* and *obese*.	2	BMI — Status below 18.5 — underweight 18.5–24.9 — normal weight 25.0–29.9 — overweight 30.0 and above — obese

	Assessment statement	Obj	Teacher's notes
A.2.7	Outline the reasons for increasing rates of clinical obesity in some countries, including availability of cheap high-energy foods, large portion sizes, increasing use of vehicles for transport, and a change from active to sedentary occupations.	2	
A.2.8	Outline the consequences of anorexia nervosa.	2	**Aim 8:** The social issues relating to this condition need to be handled delicately as it may affect students in the class, but discussion of them could prove very worthwhile.

A3 Special issues in human nutrition

6 hours

	Assessment statement	Obj	Teacher's notes
A.3.1	Distinguish between the composition of *human milk* and *artificial milk* used for bottle-feeding babies.	2	Include lactose *versus* glucose, human milk protein *versus* other proteins, differences in fatty acid composition, and lack of antibodies in artificial milk. **Aim 8:** There is an ethical issue involved here, as profit-making companies produce artificial milk. There are concerns that restrictions on the advertising of artificial milk in the developed world have led to a greater marketing of it in developing countries, with health consequences for these babies.
A.3.2	Discuss the benefits of breastfeeding.	3	**Aim 8:** The bonding between mother and child, and social attitudes to breastfeeding in public could be discussed. **TOK:** This is an example of the need for research findings to be passed on effectively from the scientific community to mothers worldwide.
A.3.3	Outline the causes and symptoms of type II diabetes.	2	Include differences in susceptibility between ethnic groups. **TOK:** The nature of risk factors and the difficulties of making decisions about the relative influence of nature and nurture could be discussed. There are clear differences in susceptibility to type II diabetes, with some populations of Native Australians (Aboriginal Australians) and Maoris having higher rates of incidence. This could lead to a wider consideration and appreciation of the diversity in human societies combined with the need for parity of esteem.
A.3.4	Explain the dietary advice that should be given to a patient who has developed type II diabetes.	3	
A.3.5	Discuss the ethical issues concerning the eating of animal products, including honey, eggs, milk and meat.	3	

	Assessment statement	Obj	Teacher's notes
A.3.6	Evaluate the benefits of reducing dietary cholesterol in lowering the risk of coronary heart disease.	3	**TOK:** As in A.1.7, this is where the distinction between correlation and cause can be drawn.
A.3.7	Discuss the concept of food miles and the reasons for consumers choosing foods to minimize food miles.	3	Food miles are simply a measure of how far a food item has been transported from its site of production to its site of consumption. Transport of food causes air pollution, traffic congestion and greenhouse gas emissions. Transport of food also allows continuity of supply and increased choice for consumers. **Aim 7:** Databases and spreadsheets could be used. **Aim 8:** A discussion of the conflicts between responsibility as global citizens and the right to exert personal freedoms might be appropriate. **TOK:** Some concepts or theories offer a new perspective, which can change our attitudes significantly. Here, food miles allow us to assess how much we, as individuals, are contributing to global warming by our selection of foods.

Option B: Physiology of exercise (15 hours)

B1 Muscles and movement

4 hours

	Assessment statement	Obj	Teacher's notes
B.1.1	State the roles of bones, ligaments, muscles, tendons and nerves in human movement.	1	
B.1.2	Label a diagram of the human elbow joint, including cartilage, synovial fluid, joint capsule, named bones and antagonistic muscles (biceps and triceps).	1	
B.1.3	Outline the functions of the structures in the human elbow joint named in B.1.2.	2	
B.1.4	Compare the movements of the hip joint and the knee joint.	3	**Aim 7:** Video analysis of motion is possible here.
B.1.5	Describe the structure of striated muscle fibres, including the myofibrils with light and dark bands, mitochondria, the sarcoplasmic reticulum, nuclei and the sarcolemma.	2	
B.1.6	Draw and label a diagram to show the structure of a sarcomere, including Z lines, actin filaments, myosin filaments with heads, and the resultant light and dark bands.	1	No other terms for parts of the sarcomere are expected.

	Assessment statement	Obj	Teacher's notes
B.1.7	Explain how skeletal muscle contracts, including the release of calcium ions from the sarcoplasmic reticulum, the formation of cross-bridges, the sliding of actin and myosin filaments, and the use of ATP to break cross-bridges and re-set myosin heads.	3	Details of the roles of troponin and tropomyosin are not expected. **Aim 7:** Data logging could be carried out using a grip sensor to study muscle fatigue and muscle strength.
B.1.8	Analyse electron micrographs to find the state of contraction of muscle fibres.	3	Muscle fibres can be fully relaxed, slightly contracted, moderately contracted and fully contracted.

B2 Training and the pulmonary system

2 hours

	Assessment statement	Obj	Teacher's notes
B.2.1	Define *total lung capacity*, *vital capacity*, *tidal volume* and *ventilation rate*.	1	Total lung capacity: volume of air in the lungs after a maximum inhalation. Vital capacity: maximum volume of air that can be exhaled after a maximum inhalation. Tidal volume: volume of air taken in or out with each inhalation or exhalation. Ventilation rate: number of inhalations or exhalations per minute (this term is used, not breathing rate). **Aim 7:** Data logging using a spirometer could be used.
B.2.2	Explain the need for increases in tidal volume and ventilation rate during exercise.	3	
B.2.3	Outline the effects of training on the pulmonary system, including changes in ventilation rate at rest, maximum ventilation rate and vital capacity.	2	Ventilation rate at rest can be reduced from about 14 to 12 bpm. Maximum ventilation rate can be increased from about 40 to 45 bpm or more. Vital capacity may increase slightly. **Aim 7:** Data logging using a gas pressure sensor and a ventilation rate monitor belt can be performed.

B3 Training and the cardiovascular system

3 hours

	Assessment statement	Obj	Teacher's notes
B.3.1	Define *heart rate*, *stroke volume*, *cardiac output* and *venous return*.	1	Heart rate: number of contractions of the heart per minute. Stroke volume: volume of blood pumped out with each contraction of the heart. Cardiac output: volume of blood pumped out by the heart per minute. Venous return: volume of blood returning to the heart via the veins per minute.

	Assessment statement	Obj	Teacher's notes
B.3.2	Explain the changes in cardiac output and venous return during exercise.	3	Detection of lowered blood pH causes impulses to be sent by the brain to the pacemaker, increasing cardiac output. Contraction of muscles used during exercise squeezes blood in adjacent veins, increasing venous return.
B.3.3	Compare the distribution of blood flow at rest and during exercise.	3	Blood flow to the brain is unchanged during exercise. Blood flow to the heart wall, skeletal muscles and skin is increased, but blood flow to the kidneys, stomach, intestines and other abdominal organs is reduced.
B.3.4	Explain the effects of training on heart rate and stroke volume, both at rest and during exercise.	3	
B.3.5	Evaluate the risks and benefits of using EPO (erythropoietin) and blood transfusions to improve performance in sports.	3	**Aim 8:** There are clear ethical issues involved in the use of performance-enhancing drugs. **TOK:** Decisions about what constitutes an acceptable level of risk could be discussed, together with differences between different groups and their views—scientists, sportsmen, doctors and spectators.

B4 Exercise and respiration

3 hours

	Assessment statement	Obj	Teacher's notes
B.4.1	Define VO_2 and VO_2 *max*.	1	
B.4.2	Outline the roles of glycogen and myoglobin in muscle fibres.	2	Limit the role of glycogen to glucose storage, and the role of myoglobin to oxygen storage, for use during exercise.
B.4.3	Outline the method of ATP production used by muscle fibres during exercise of varying intensity and duration.	2	Creatine phosphate can be used to regenerate ATP for 8–10 seconds of intense exercise. Beyond 10 seconds, ATP is produced entirely by cell respiration. As the intensity of exercise decreases and the duration increases, the percentage of anaerobic cell respiration decreases and aerobic cell respiration increases.
B.4.4	Evaluate the effectiveness of dietary supplements containing creatine phosphate in enhancing performance.	3	
B.4.5	Outline the relationship between the intensity of exercise, VO_2 and the proportions of carbohydrate and fat used in respiration.	2	As the intensity of exercise increases, VO_2 rises until it reaches VO_2 max. Use of fat in respiration falls and use of carbohydrate rises until it reaches 100%.
B.4.6	State that lactate produced by anaerobic cell respiration is passed to the liver and creates an oxygen debt.	1	
B.4.7	Outline how oxygen debt is repaid.	2	Lactate is turned into pyruvate, which is converted to glucose or used in aerobic respiration in the mitochondrion, using oxygen taken in during deep ventilations after exercise.

B5 Fitness and training

2 hours

	Assessment statement	Obj	Teacher's notes
B.5.1	Define *fitness*.	1	
B.5.2	Discuss speed and stamina as measures of fitness.	3	
B.5.3	Distinguish between *fast* and *slow* muscle fibres.	2	Fast muscle fibres (typical of sprinters) have greater oxygen needs, low myoglobin levels and provide a maximum work rate over shorter periods (strength). Slow muscle fibres (typical of marathon athletes) have a very good blood supply, plenty of myoglobin and are capable of sustained activity (stamina) and high rates of aerobic respiration.
B.5.4	Distinguish between the effects of *moderate-intensity* and *high-intensity* exercise on fast and slow muscle fibres.	2	Moderate-intensity exercise stimulates the development of slow muscle fibres. High-intensity exercise stimulates the development of fast muscle fibres.
B.5.5	Discuss the ethics of using performance-enhancing substances, including anabolic steroids.	3	

B6 Injuries

1 hour

	Assessment statement	Obj	Teacher's notes
B.6.1	Discuss the need for warm-up routines.	3	**TOK:** There is almost universal belief in the need for warm-up and sometimes also warm-down routines, but much of the evidence for these theories is at best anecdotal and at worst non-existent. The difficulty of conducting controlled trials without a placebo effect could be discussed. The willingness of athletes to believe what they are told, without questioning it, could also be considered.
B.6.2	Describe injuries to muscles and joints, including sprains, torn muscles, torn ligaments, dislocation of joints and intervertebral disc damage.	2	

Option C: Cells and energy (15 hours)

C1 Proteins

1 hour

	Assessment statement	Obj	Teacher's notes
C.1.1	Explain the four levels of protein structure, indicating the significance of each level.	3	Quaternary structure may involve the binding of a prosthetic group to form a conjugated protein. **Aim 7:** Simulation exercises showing three-dimensional molecular models of proteins are available.

	Assessment statement	Obj	Teacher's notes
C.1.2	Outline the difference between fibrous and globular proteins, with reference to two examples of each protein type.	2	
C.1.3	Explain the significance of polar and non-polar amino acids.	3	Limit this to controlling the position of proteins in membranes, creating hydrophilic channels through membranes, and the specificity of active sites in enzymes.
C.1.4	State four functions of proteins, giving a named example of each.	1	Membrane proteins should not be included.

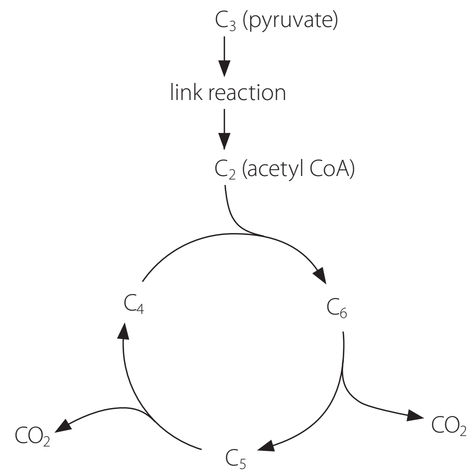
C2 Enzymes

2 hours

	Assessment statement	Obj	Teacher's notes
C.2.1	State that metabolic pathways consist of chains and cycles of enzyme-catalysed reactions.	1	
C.2.2	Describe the induced-fit model.	2	This is an extension of the lock-and-key model. Its importance in accounting for the ability of some enzymes to bind to several substrates should be mentioned. **TOK:** Scientific truths are often pragmatic. We accept them as true because they give us predictive power, that is, they work. The German scientist Emil Fischer introduced the lock-and-key model for enzymes and their substrates in 1890. It was not until 1958 that Daniel Koshland in the United States suggested that the binding of the substrate to the active site caused a conformational change, hence the induced-fit model. This is an example of one model or theory, accepted for many years, being superseded by another that offers a fuller explanation of a process.
C.2.3	Explain that enzymes lower the activation energy of the chemical reactions that they catalyse.	3	Only exothermic reactions should be considered. Specific energy values do not need to be recalled.
C.2.4	Explain the difference between competitive and non-competitive inhibition, with reference to one example of each.	3	Competitive inhibition is the situation where an inhibiting molecule that is structurally similar to the substrate molecule binds to the active site, preventing substrate binding. Limit non-competitive inhibition to an inhibitor binding to an enzyme (not to its active site) that causes a conformational change in its active site, resulting in a decrease in activity. Reversible inhibition, as compared to irreversible inhibition, is not required.
C.2.5	Explain the control of metabolic pathways by end-product inhibition, including the role of allosteric sites.	3	

C3 Cell respiration

6 hours

	Assessment statement	Obj	Teacher's notes
C.3.1	State that oxidation involves the loss of electrons from an element, whereas reduction involves a gain of electrons; and that oxidation frequently involves gaining oxygen or losing hydrogen, whereas reduction frequently involves losing oxygen or gaining hydrogen.	1	
C.3.2	Outline the process of glycolysis, including phosphorylation, lysis, oxidation and ATP formation.	2	In the cytoplasm, one hexose sugar is converted into two three-carbon atom compounds (pyruvate) with a net gain of two ATP and two NADH + H^+.
C.3.3	Draw and label a diagram showing the structure of a mitochondrion as seen in electron micrographs.	1	
C.3.4	Explain aerobic respiration, including the link reaction, the Krebs cycle, the role of NADH + H^+, the electron transport chain and the role of oxygen.	3	In aerobic respiration (in mitochondria in eukaryotes), each pyruvate is decarboxylated (CO_2 removed). The remaining two-carbon molecule (acetyl group) reacts with reduced coenzyme A, and, at the same time, one NADH + H^+ is formed. This is known as the link reaction.  In the Krebs cycle, each acetyl group (CH_3CO) formed in the link reaction yields two CO_2. The names of the intermediate compounds in the cycle are not required. Thus it would be acceptable to note: $C_2 + C_4 = C_6 \longrightarrow C_5 \longrightarrow$, and so on.
C.3.5	Explain oxidative phosphorylation in terms of chemiosmosis.	3	
C.3.6	Explain the relationship between the structure of the mitochondrion and its function.	3	Limit this to cristae forming a large surface area for the electron transport chain, the small space between inner and outer membranes for accumulation of protons, and the fluid matrix containing enzymes of the Krebs cycle.
C.3.7	Analyse data relating to respiration.	3	

C4 Photosynthesis

6 hours

	Assessment statement	Obj	Teacher's notes
C.4.1	Draw and label a diagram showing the structure of a chloroplast as seen in electron micrographs.	1	
C.4.2	State that photosynthesis consists of light-dependent and light-independent reactions.	1	These should not be called "light" and "dark" reactions.
C.4.3	Explain the light-dependent reactions.	3	Include the photoactivation of photosystem II, photolysis of water, electron transport, cyclic and non-cyclic photophosphorylation, photoactivation of photosystem I, and reduction of $NADP^+$.
C.4.4	Explain photophosphorylation in terms of chemiosmosis.	3	
C.4.5	Explain the light-independent reactions.	3	Include the roles of ribulose bisphosphate (RuBP) carboxylase, reduction of glycerate 3-phosphate (GP) to triose phosphate (TP), NADPH + H^+, ATP, regeneration of RuBP, and subsequent synthesis of more complex carbohydrates. **TOK:** The lollipop apparatus used to work out the biochemical details of the Calvin cycle shows considerable creativity. To what extent is the creation of an elegant protocol similar to the creation of a work of art?
C.4.6	Explain the relationship between the structure of the chloroplast and its function.	3	Limit this to the large surface area of thylakoids for light absorption, the small space inside thylakoids for accumulation of protons, and the fluid stroma for the enzymes of the Calvin cycle.
C.4.7	Explain the relationship between the action spectrum and the absorption spectrum of photosynthetic pigments in green plants.	3	A separate spectrum for each pigment (chlorophyll a, chlorophyll b, and so on) is not required.
C.4.8	Explain the concept of limiting factors in photosynthesis, with reference to light intensity, temperature and concentration of carbon dioxide.	3	**TOK:** This is an opportunity to discuss the need for very carefully controlled experiments. If we want to investigate the effect of one factor, all other factors that could have an influence must be controlled. In photosynthesis, the situation is relatively simple, and we can ensure that factors other than the one we are investigating are maintained at a constant and optimal level. In other areas, there are much greater problems. In the many investigations of human health, there are almost always complicating factors. For example, vegetarians have a longer life expectancy than meat eaters. We would be wrong to conclude that eating meat lowers life expectancy unless we could show that the only difference between the vegetarians and the meat eaters in our trial was the meat eating.
C.4.9	Analyse data relating to photosynthesis.	3	

Syllabus details—Options SL and HL

SL students study the core of these options and HL students study the whole option (the core and the extension material).

Option D: Evolution (15/22 hours)

Core material: D1–D3 are core material for SL and HL (15 hours).

Extension material: D4–D5 are extension material for HL only (7 hours).

D1 Origin of life on Earth

4 hours

	Assessment statement	Obj	Teacher's notes
D.1.1	Describe four processes needed for the spontaneous origin of life on Earth.	2	Include: • the non-living synthesis of simple organic molecules • the assembly of these molecules into polymers • the origin of self-replicating molecules that made inheritance possible • the packaging of these molecules into membranes with an internal chemistry different from their surroundings. **TOK:** We could question whether any investigation of the history of evolution of life on Earth can be scientific. The concept of falsifiability could be raised here.
D.1.2	Outline the experiments of Miller and Urey into the origin of organic compounds.	2	**TOK:** Scientific progress often depends upon model building, a working hypothesis and possible falsification. In this case, we may be able to show that organic compounds could arise under certain conditions, but we should consider whether we can show that they did at some time in the past, or whether they certainly did not.
D.1.3	State that comets may have delivered organic compounds to Earth.	1	Comets contain a variety of organic compounds. Heavy bombardment about 4,000 million years ago may have delivered both organic compounds and water to the early Earth.

	Assessment statement	Obj	Teacher's notes
D.1.4	Discuss possible locations where conditions would have allowed the synthesis of organic compounds.	3	Examples should include communities around deep-sea hydrothermal vents, volcanoes and extraterrestrial locations.
D.1.5	Outline two properties of RNA that would have allowed it to play a role in the origin of life.	2	Include the self-replicating and catalytic activities of RNA.
D.1.6	State that living cells may have been preceded by protobionts, with an internal chemical environment different from their surroundings.	1	Examples include coacervates and microspheres.
D.1.7	Outline the contribution of prokaryotes to the creation of an oxygen-rich atmosphere.	2	
D.1.8	Discuss the endosymbiotic theory for the origin of eukaryotes.	3	**TOK:** As with other theories that aim to explain the evolution of life on Earth, we can obtain evidence for a theory and we can assess the strength of the evidence. However, can we ever be sure that the theory explains what actually happened in the past? For something to be a scientific theory, we must also be able to test whether it is false. Can we do this if the theory relates to a past event? Is a special standard required for claims about events in the past to be scientific? If they cannot be falsified, is it enough if they allow us to make predictions?

D2 Species and speciation

5 hours

	Assessment statement	Obj	Teacher's notes
D.2.1	Define *allele frequency* and *gene pool*.	1	
D.2.2	State that evolution involves a change in allele frequency in a population's gene pool over a number of generations.	1	
D.2.3	Discuss the definition of the term species.	3	
D.2.4	Describe three examples of barriers between gene pools.	2	Examples include geographical isolation, hybrid infertility, temporal isolation and behavioural isolation.
D.2.5	Explain how polyploidy can contribute to speciation.	3	Avoid examples involving hybridization as well as polyploidy, such as the evolution of wheat.
D.2.6	Compare allopatric and sympatric speciation.	3	Speciation: the formation of a new species by splitting of an existing species. Sympatric: in the same geographical area. Allopatric: in different geographical areas.
D.2.7	Outline the process of adaptive radiation.	2	
D.2.8	Compare convergent and divergent evolution.	3	

	Assessment statement	Obj	Teacher's notes
D.2.9	Discuss ideas on the pace of evolution, including gradualism and punctuated equilibrium.	3	Gradualism is the slow change from one form to another. Punctuated equilibrium implies long periods without appreciable change and short periods of rapid evolution. Volcanic eruptions and meteor impacts affecting evolution on Earth could also be mentioned.
D.2.10	Describe one example of transient polymorphism.	2	An example of transient polymorphism is industrial melanism.
D.2.11	Describe sickle-cell anemia as an example of balanced polymorphism.	2	Sickle-cell anemia is an example of balanced polymorphism where heterozygotes (sickle-cell trait) have an advantage in malarial regions because they are fitter than either homozygote.

D3 Human evolution

6 hours

	Assessment statement	Obj	Teacher's notes
D.3.1	Outline the method for dating rocks and fossils using radioisotopes, with reference to ^{14}C and ^{40}K.	2	Knowledge of the degree of accuracy and the choice of isotope to use is expected. Details of the apparatus used are not required.
D.3.2	Define *half-life*.	1	
D.3.3	Deduce the approximate age of materials based on a simple decay curve for a radioisotope.	3	
D.3.4	Describe the major anatomical features that define humans as primates.	2	
D.3.5	Outline the trends illustrated by the fossils of *Ardipithecus ramidus*, *Australopithecus* including *A. afarensis* and *A. africanus*, and *Homo* including *H. habilis*, *H. erectus*, *H. neanderthalensis* and *H. sapiens*.	2	Knowledge of approximate dates and distribution of the named species is expected. Details of subspecies or particular groups (Cro-Magnon, Peking, and so on) are not required.
D.3.6	State that, at various stages in hominid evolution, several species may have coexisted.	1	An example of this is *H. neanderthalensis* and *H. sapiens*.
D.3.7	Discuss the incompleteness of the fossil record and the resulting uncertainties about human evolution.	3	Reasons for the incompleteness of the fossil record should be included. **TOK:** Paleoanthropology is an example of the diverse aspects of science, in that it is a data-poor science with largely uncontrollable subject matter. Paradigm shifts are more common in a data-poor science. The discovery of small numbers of fossils has caused huge changes in theories of human evolution, perhaps indicating that too much has been constructed on too little. Conversely, discoveries such as those made in Dmanisi, Georgia provide examples of falsification of earlier held positions, indicating why paleoanthropology can be considered a science.

	Assessment statement	Obj	Teacher's notes
D.3.8	Discuss the correlation between the change in diet and increase in brain size during hominid evolution.	3	
D.3.9	Distinguish between *genetic* and *cultural* evolution.	2	
D.3.10	Discuss the relative importance of genetic and cultural evolution in the recent evolution of humans.	3	**TOK:** This is an opportunity to enter into the nature/nurture debate. There is clear causation when a genetic factor controls a characteristic. Cultural factors are much more complex, and correlation and cause are more easily confused.

HL D4 The Hardy–Weinberg principle

2 hours

	Assessment statement	Obj	Teacher's notes
D.4.1	Explain how the Hardy–Weinberg equation is derived.	3	
D.4.2	Calculate allele, genotype and phenotype frequencies for two alleles of a gene, using the Hardy–Weinberg equation.	2	
D.4.3	State the assumptions made when the Hardy–Weinberg equation is used.	1	It must be assumed that a population is large, with random mating and a constant allele frequency over time. This implies no allele-specific mortality, no mutation, no emigration and no immigration. **Aim 7:** Electronically sharing phenotypic frequency data between classes to calculate allele frequency would be useful. Spreadsheet functions could be used to convert phenotypic frequency into allele frequency.

HL D5 Phylogeny and systematics

5 hours

	Assessment statement	Obj	Teacher's notes
D.5.1	Outline the value of classifying organisms.	2	This refers to natural classification. Include how the organization of data assists in identifying organisms, suggests evolutionary links, and allows prediction of characteristics shared by members of a group.
D.5.2	Explain the biochemical evidence provided by the universality of DNA and protein structures for the common ancestry of living organisms.	3	**TOK:** The universality of DNA and the genetic code had a profound effect on Marshall Nirenberg and other pioneering biochemists, as it showed that humans were part of the overall tree of life and were not set apart genetically. This must affect the way in which we view ourselves and the rest of the living world.
D.5.3	Explain how variations in specific molecules can indicate phylogeny.	3	**TOK:** Variations are partly due to mutations, which are unpredictable and chance events, so there must be caution in interpreting them.

	Assessment statement	Obj	Teacher's notes
D.5.4	Discuss how biochemical variations can be used as an evolutionary clock.	3	**TOK:** We must be careful not to suggest that this clock moves on at a constant and invariable rate, so interpretation of data here must be very carefully done, with the uncertainties made clear.
D.5.5	Define *clade* and *cladistics*.	1	
D.5.6	Distinguish, with examples, between *analogous* and *homologous* characteristics.	2	
D.5.7	Outline the methods used to construct cladograms and the conclusions that can be drawn from them.	2	
D.5.8	Construct a simple cladogram.	3	Morphological or biochemical data can be used.
D.5.9	Analyse cladograms in terms of phylogenetic relationships.	3	
D.5.10	Discuss the relationship between cladograms and the classification of living organisms.	3	

Option E: Neurobiology and behaviour (15/22 hours)

Core material: E1–E4 are core material for SL and HL (15 hours).

Extension material: E5–E6 are extension material for HL only (7 hours).

E1 Stimulus and response

2 hours

	Assessment statement	Obj	Teacher's notes
E.1.1	Define the terms *stimulus*, *response* and *reflex* in the context of animal behaviour.	1	A stimulus is a change in the environment (internal or external) that is detected by a receptor and elicits a response. A reflex is a rapid, unconscious response.
E.1.2	Explain the role of receptors, sensory neurons, relay neurons, motor neurons, synapses and effectors in the response of animals to stimuli.	3	**Aim 7:** Data logging using an EKG sensor to analyse neuromuscular reflexes could be used.
E.1.3	Draw and label a diagram of a reflex arc for a pain withdrawal reflex, including the spinal cord and its spinal nerves, the receptor cell, sensory neuron, relay neuron, motor neuron and effector.	1	Include white and grey matter, and ventral and dorsal roots.

	Assessment statement	Obj	Teacher's notes
E.1.4	Explain how animal responses can be affected by natural selection, using two examples.	3	Use of local examples is encouraged. The bird *Sylvia atricapilla* (blackcap) breeds during the summer in Germany and, until recently, migrated to Spain or other Mediterranean areas for winter. However, studies show that 10% of blackcaps now migrate to the UK instead. To test whether this change is genetically determined or not (and, therefore, whether it could have developed by natural selection or not), eggs were collected from parents who had migrated to the UK in the previous winter and from parents who had migrated to Spain. The young were reared and the direction in which they set off, when the time for migration came, was recorded. Birds whose parents had migrated to the UK tended to fly west, wherever they had been reared, and birds whose parents had migrated to Spain tended to fly south-west. Despite not being able to follow their parents at the time of migration, all the birds tended to fly in the direction that would take them on the same migration route as their parents. This and other evidence suggests that blackcaps are genetically programmed to respond to stimuli when they migrate so that they fly in a particular direction. The increase in the numbers of blackcaps migrating to the UK for the winter may be due to warmer winters and greater survival rates in the UK. **TOK:** There are many poor examples of supposed links between animal responses and natural selection. It is easy for us to guess how the behaviour of an animal might influence its chance of survival and reproduction, but experimental evidence from carefully controlled trials is always needed to back up our intuitions.

E2 Perception of stimuli

4 hours

	Assessment statement	Obj	Teacher's notes
E.2.1	Outline the diversity of stimuli that can be detected by human sensory receptors, including mechanoreceptors, chemoreceptors, thermoreceptors and photoreceptors.	2	Details of how each receptor functions are not required. **TOK:** Other organisms can detect stimuli that humans cannot. For example, some pollinators can detect electromagnetic radiation in the non-visible range. As a consequence, they might perceive a flower as patterned when we perceive it as plain. To what extent, therefore, is what we perceive merely a construction of reality? To what extent are we dependent upon technology to "know" the biological world?
E.2.2	Label a diagram of the structure of the human eye.	1	The diagram should include the sclera, cornea, conjunctiva, eyelid, choroid, aqueous humour, pupil, lens, iris, vitreous humour, retina, fovea, optic nerve and blind spot.

	Assessment statement	Obj	Teacher's notes
E.2.3	Annotate a diagram of the retina to show the cell types and the direction in which light moves.	2	Include names of rod and cone cells, bipolar neurons and ganglion cells.
E.2.4	Compare rod and cone cells.	3	Include: • use in dim light *versus* bright light • one type sensitive to all visible wavelengths *versus* three types sensitive to red, blue and green light • passage of impulses from a group of rod cells to a single nerve fibre in the optic nerve *versus* passage from a single cone cell to a single nerve fibre.
E.2.5	Explain the processing of visual stimuli, including edge enhancement and contralateral processing.	3	Edge enhancement occurs within the retina and can be demonstrated with the Hermann grid illusion. Contralateral processing is due to the optic chiasma, where the right brain processes information from the left visual field and vice versa. This can be illustrated by the abnormal perceptions of patients with brain lesions.
E.2.6	Label a diagram of the ear.	1	Include pinna, eardrum, bones of the middle ear, oval window, round window, semicircular canals, auditory nerve and cochlea.
E.2.7	Explain how sound is perceived by the ear, including the roles of the eardrum, bones of the middle ear, oval and round windows, and the hair cells of the cochlea.	3	The roles of the other parts of the ear are not expected.

E3 Innate and learned behaviour

4 hours

	Assessment statement	Obj	Teacher's notes
E.3.1	Distinguish between *innate* and *learned* behaviour.	2	Innate behaviour develops independently of the environmental context, whereas learned behaviour develops as a result of experience.
E.3.2	Design experiments to investigate innate behaviour in invertebrates, including either a taxis or a kinesis.	3	Examples include: • taxis—*Planaria* move towards food (chemotaxis) and *Euglena* move towards light (phototaxis) • kinesis—woodlice move about less in optimum (humid) conditions and more in an unfavourable (dry) atmosphere.
E.3.3	Analyse data from invertebrate behaviour experiments in terms of the effect on chances of survival and reproduction.	3	
E.3.4	Discuss how the process of learning can improve the chance of survival.	3	

	Assessment statement	Obj	Teacher's notes
E.3.5	Outline Pavlov's experiments into conditioning of dogs.	2	The terms unconditioned stimulus, conditioned stimulus, unconditioned response and conditioned response should be included. **TOK:** The extent to which Pavlov's theory can be applied to different examples of learning could be considered.
E.3.6	Outline the role of inheritance and learning in the development of birdsong in young birds.	2	

E4 Neurotransmitters and synapses

5 hours

	Assessment statement	Obj	Teacher's notes
E.4.1	State that some presynaptic neurons excite postsynaptic transmission and others inhibit postsynaptic transmission.	1	
E.4.2	Explain how decision-making in the CNS can result from the interaction between the activities of excitatory and inhibitory presynaptic neurons at synapses.	3	
E.4.3	Explain how psychoactive drugs affect the brain and personality by either increasing or decreasing postsynaptic transmission.	3	Include ways in which synaptic transmission can be increased or decreased. Details of the organization and functioning of the entire brain, and theories of personality or explanations for personality, are not required.
E.4.4	List three examples of excitatory and three examples of inhibitory psychoactive drugs.	1	Use the following examples. • Excitatory drugs: nicotine, cocaine and amphetamines • Inhibitory drugs: benzodiazepines, alcohol and tetrahydrocannabinol (THC).
E.4.5	Explain the effects of THC and cocaine in terms of their action at synapses in the brain.	3	Include the effects of these drugs on both mood and behaviour. **Aim 8:** The social consequences of these drugs could be considered, for the user, his or her family and the wider society.
E.4.6	Discuss the causes of addiction, including genetic predisposition, social factors and dopamine secretion.	3	

HL E5 The human brain

4 hours

	Assessment statement	Obj	Teacher's notes
E.5.1	Label, on a diagram of the brain, the medulla oblongata, cerebellum, hypothalamus, pituitary gland and cerebral hemispheres.	1	
E.5.2	Outline the functions of each of the parts of the brain listed in E.5.1.	2	Medulla oblongata: controls automatic and homeostatic activities, such as swallowing, digestion and vomiting, and breathing and heart activity. Cerebellum: coordinates unconscious functions, such as movement and balance. Hypothalamus: maintains homeostasis, coordinating the nervous and endocrine systems, secreting hormones of the posterior pituitary, and releasing factors regulating the anterior pituitary. Pituitary gland: the posterior lobe stores and releases hormones produced by the hypothalamus and the anterior lobe, and produces and secretes hormones regulating many body functions. Cerebral hemispheres: act as the integrating centre for high complex functions such as learning, memory and emotions.
E.5.3	Explain how animal experiments, lesions and FMRI (functional magnetic resonance imaging) scanning can be used in the identification of the brain part involved in specific functions.	3	Include one specific example of each. **Aim 8:** There are some important ethical issues involved in animal experimentation. **TOK:** The construction of controlled FMRI experiments has proved very difficult because of the development of conditioned reflexes in experimental subjects. Investigating the human mind will always be a challenging field.
E.5.4	Explain sympathetic and parasympathetic control of the heart rate, movements of the iris and flow of blood to the gut.	3	
E.5.5	Explain the pupil reflex.	3	
E.5.6	Discuss the concept of brain death and the use of the pupil reflex in testing for this.	3	
E.5.7	Outline how pain is perceived and how endorphins can act as painkillers.	2	Limit this to: • passage of impulses from pain receptors in the skin and other parts of the body to sensory areas of the cerebral cortex • feelings of pain due to these areas of the cerebral cortex • endorphins blocking transmission of impulses at synapses involved in pain perception.

HL E6 Further studies of behaviour

3 hours

	Assessment statement	Obj	Teacher's notes
E.6.1	Describe the social organization of honey bee colonies and one other non-human example.	2	Detailed structural differences and the life cycle of honey bees are not expected.
E.6.2	Outline how natural selection may act at the level of the colony in the case of social organisms.	2	
E.6.3	Discuss the evolution of altruistic behaviour using two non-human examples.	3	
E.6.4	Outline two examples of how foraging behaviour optimizes food intake, including bluegill fish foraging for *Daphnia*.	2	
E.6.5	Explain how mate selection can lead to exaggerated traits.	3	An example of this is the peacock's tail feathers.
E.6.6	State that animals show rhythmical variations in activity.	1	
E.6.7	Outline two examples illustrating the adaptive value of rhythmical behaviour patterns.	2	Examples could include the diurnal activity variation of hamsters, coordinated spawning in corals, or seasonal reproductive behaviour in deer.

Option F: Microbes and biotechnology (15/22 hours)

Core material: F1–F4 are core material for SL and HL (15 hours).

Extension material: F5–F6 are extension material for HL only (7 hours).

F1 Diversity of microbes

5 hours

	Assessment statement	Obj	Teacher's notes
F.1.1	Outline the classification of living organisms into three domains.	2	Include the use of ribosomal RNA sequences in the classification of the three domains.
F.1.2	Explain the reasons for the reclassification of living organisms into three domains.	3	
F.1.3	Distinguish between the characteristics of the three domains.	2	Include histones, introns, size of ribosomes, structure of cell walls and cell membranes. Histones are proteins associated with the three-dimensional structure of chromosomal DNA. Introns are segments of non-coding DNA within genes that are excised before translation.

	Assessment statement	Obj	Teacher's notes
F.1.4	Outline the wide diversity of habitat in the Archaea as exemplified by methanogens, thermophiles and halophiles.	2	
F.1.5	Outline the diversity of Eubacteria, including shape and cell wall structure.	2	
F.1.6	State, with one example, that some bacteria form aggregates that show characteristics not seen in individual bacteria.	1	Some pathogens produce biofilms when they reach sufficient densities. They then produce toxins and overwhelm the host. For example, *Pseudomonas aeruginosa* is the major cause of death in patients with cystic fibrosis. *Vibrio* (*Photobacterium*) *fischeri* (*V. fischeri*) is a bacterium, found in seawater, that is able to emit light (bioluminesce). Single individuals do not emit light unless they become part of a population with a high density. *V. fischeri* releases a regulatory substance into its surroundings. In a dense population, the concentration of this regulatory substance becomes high enough to trigger bioluminescence. It happens, for example, when large numbers of *V. fischeri* are living together in a mucus matrix in the light organs of a squid (*Euprymna scolopes*). This type of monitoring of population densities by a microbe is called quorum sensing.
F.1.7	Compare the structure of the cell walls of Gram-positive and Gram-negative Eubacteria.	3	Details of Gram staining of bacteria are not required.
F.1.8	Outline the diversity of structure in viruses including: naked capsid *versus* enveloped capsid; DNA *versus* RNA; and single stranded *versus* double stranded DNA or RNA.	2	Examples are not required.
F.1.9	Outline the diversity of microscopic eukaryotes, as illustrated by *Saccharomyces*, *Amoeba*, *Plasmodium*, *Paramecium*, *Euglena* and *Chlorella*.	2	Limit this to mode of nutrition and locomotion, presence or absence of cell wall, chloroplasts, cilia and flagella.

F2 Microbes and the environment

4 hours

	Assessment statement	Obj	Teacher's notes
F.2.1	List the roles of microbes in ecosystems, including producers, nitrogen fixers and decomposers.	1	
F.2.2	Draw and label a diagram of the nitrogen cycle.	1	Include the processes of nitrogen fixation (free-living, mutualistic and industrial), denitrification, nitrification, feeding, excretion, active transport of nitrate ions, and formation of ammonia by putrefaction.

	Assessment statement	Obj	Teacher's notes
F.2.3	State the roles of *Rhizobium*, *Azotobacter*, *Nitrosomonas*, *Nitrobacter* and *Pseudomonas denitrificans* in the nitrogen cycle.	1	
F.2.4	Outline the conditions that favour denitrification and nitrification.	2	
F.2.5	Explain the consequences of releasing raw sewage and nitrate fertilizer into rivers.	3	Include pathogens in bathing or drinking water, eutrophication, algal blooms, deoxygenation, increase in biochemical oxygen demand (BOD) and subsequent recovery. Names of specific organisms are not expected. **Aim 7:** Data logging using ion-specific electrodes and/or using dissolved oxygen sensors is possible.
F.2.6	Outline the role of saprotrophic bacteria in the treatment of sewage using trickling filter beds and reed bed systems.	2	
F.2.7	State that biomass can be used as raw material for the production of fuels such as methane and ethanol.	1	
F.2.8	Explain the principles involved in the generation of methane from biomass, including the conditions needed, organisms involved and the basic chemical reactions that occur.	3	A variety of types of organic matter, including manure from farm animals and cellulose, can be used as the feedstock. Several groups of bacteria are needed to complete methanogenesis. • Bacteria to convert the organic matter into organic acids and alcohol. • Other bacteria to convert these organic acids and alcohol into acetate, carbon dioxide and hydrogen. • Finally, methanogenic bacteria to create the methane, either through the reaction of carbon dioxide and hydrogen or through the breakdown of acetate.

F3 Microbes and biotechnology

3 hours

	Assessment statement	Obj	Teacher's notes
F.3.1	State that reverse transcriptase catalyses the production of DNA from RNA.	1	
F.3.2	Explain how reverse transcriptase is used in molecular biology.	3	This is an opportunity to relate some aspects of the DNA viral life cycle to that of the HIV virus (an RNA virus). This enzyme can make DNA from mature mRNA (for example, human insulin), which can then be spliced into host DNA (for example, *E. coli*), without the introns.
F.3.3	Distinguish between *somatic* and *germ line* therapy.	2	

	Assessment statement	Obj	Teacher's notes
F.3.4	Outline the use of viral vectors in gene therapy.	2	This involves the replacement of defective genes. One method involves the removal of white blood cells or bone marrow cells and, by means of a vector, the introduction and insertion of the normal gene into the chromosome. The cells are replaced in the patient so that the normal gene can be expressed. An example is the use in SCID—a condition of immune deficiency, where the replaced gene allows for the production of the enzyme ADA (adenosine deaminase).
F.3.5	Discuss the risks of gene therapy.	3	**TOK:** There have been some recent cases in countries around the world where subjects have died as a consequence of participating in a gene therapy research protocol. These cases could be examined to consider such issues as safety, conflicts of interest and other violations of ethical practice in research.

F4 Microbes and food production

3 hours

	Assessment statement	Obj	Teacher's notes
F.4.1	Explain the use of *Saccharomyces* in the production of beer, wine and bread.	3	
F.4.2	Outline the production of soy sauce using *Aspergillus oryzae*.	2	
F.4.3	Explain the use of acids and high salt or sugar concentrations in food preservation.	3	Use of local and/or international examples is recommended.
F.4.4	Outline the symptoms, method of transmission and treatment of one named example of food poisoning.	2	**TOK:** This is one of the areas where the distinction between correlation and cause could be made. A correlation may form a useful starting point in an investigation, but, ultimately, clear causal links must be established if public health is to be properly protected.

HL F5 Metabolism of microbes

2 hours

	Assessment statement	Obj	Teacher's notes
F.5.1	Define the terms *photoautotroph*, *photoheterotroph*, *chemoautotroph* and *chemoheterotroph*.	1	Photoautotroph: an organism that uses light energy to generate ATP and produce organic compounds from inorganic substances. Photoheterotroph: an organism that uses light energy to generate ATP and obtains organic compounds from other organisms. Chemoautotroph: an organism that uses energy from chemical reactions to generate ATP and produce organic compounds from inorganic substances. Chemoheterotroph: an organism that uses energy from chemical reactions to generate ATP and obtain organic compounds from other organisms.

	Assessment statement	Obj	Teacher's notes
F.5.2	State one example of a photoautotroph, photoheterotroph, chemoautotroph and chemoheterotroph.	1	
F.5.3	Compare photoautotrophs with photoheterotrophs in terms of energy sources and carbon sources.	3	
F.5.4	Compare chemoautotrophs with chemoheterotrophs in terms of energy sources and carbon sources.	3	
F.5.5	Draw and label a diagram of a filamentous cyanobacterium.	1	Use *Anabaena* and label the photosynthetic cell and the heterocyst.
F.5.6	Explain the use of bacteria in the bioremediation of soil and water.	3	Examples include selenium, solvents and pesticides in soil, and oil spills on water.

HL F6 Microbes and disease

5 hours

	Assessment statement	Obj	Teacher's notes
F.6.1	List six methods by which pathogens are transmitted and gain entry to the body.	1	
F.6.2	Distinguish between *intracellular* and *extracellular* bacterial infection using *Chlamydia* and *Streptococcus* as examples.	2	
F.6.3	Distinguish between *endotoxins* and *exotoxins*.	2	Endotoxins: lipopolysaccharides in the walls of Gram-negative bacteria that cause fever and aches. Exotoxins: specific proteins secreted by bacteria that cause symptoms such as muscle spasms (tetanus) and diarrhoea.
F.6.4	Evaluate methods of controlling microbial growth by irradiation, pasteurization, antiseptics and disinfectants.	3	
F.6.5	Outline the mechanism of the action of antibiotics, including inhibition of synthesis of cell walls, proteins and nucleic acids.	2	
F.6.6	Outline the lytic life cycle of the influenza virus.	2	

	Assessment statement	Obj	Teacher's notes
F.6.7	Define *epidemiology*.	1	Epidemiology is the study of the occurrence, distribution and control of diseases. **TOK:** This is one of the best opportunities to discuss the distinction between correlation and cause. Epidemiological studies generally look at correlations, but it can be extremely difficult to eliminate the effects of variables other than the one being studied. This is why surveys looking at the same risk factor have contradictory findings. Nonetheless, these studies continue to be carried out because of the importance of the area investigated, and because controlled experiments are often impossible. Edward Jenner's inoculation of a small boy with cowpox and then subsequently with smallpox could not be performed today. **Int:** Pathogens do not recognize national boundaries, and efforts by the medical and scientific communities to control disease must, therefore, be international. The eradication of smallpox and work towards eradicating polio are good examples of the effectiveness of international cooperation, to the benefit of all. Because of the costs and complexity of epidemiological studies, and of the research and development of control measures for diseases, developing countries are almost certain to lag behind developed ones in disease control. Programmes have been developed to aid developing countries in this area. Reasons for these aid programmes could be discussed.
F.6.8	Discuss the origin and epidemiology of one example of a pandemic.	3	A pandemic is a very widespread epidemic that affects a large geographic area, such as a continent.
F.6.9	Describe the cause, transmission and effects of malaria, as an example of disease caused by a protozoan.	2	

	Assessment statement	Obj	Teacher's notes
F.6.10	Discuss the prion hypothesis for the cause of spongiform encephalopathies.	3	**TOK:** The transmission of spongiform encephalopathies did not fit any of the conventional theories for transmission of infectious disease. There are still uncertainties about this issue, making it an interesting area for looking at the way in which scientific theories are developed and promulgated, and how the scientific community may or may not reach a consensus. This is also an area where risk could be considered—in this case, the risk (both perceived and genuine) of eating beef from certain countries. Data for the numbers of cases of new variant CJD (Creutzfeldt–Jakob disease) can be obtained from the Internet. These can be studied to see at what point it could be concluded beyond reasonable doubt that an exponential rise in cases was not occurring. It is now clear that advice given by the scientific community and national governments was misleading over several years. Once effective control measures were in place, many consumers then refused to accept advice about the safety of eating beef, showing that, when scientists lose the trust of the wider community, it may be hard to regain it. **Int:** Some may argue that BSE (bovine spongiform encephalopathy) was used as an excuse for protectionism by some national governments, but attitudes to risk vary around the world as a part of natural cultural differences. Should food safety be internationally rather than nationally regulated?

Option G: Ecology and conservation (15/22 hours)

Core material: G1–G3 are core material for SL and HL (15 hours).

Extension material: G4–G5 are extension material for HL only (7 hours).

G1 Community ecology

5 hours

	Assessment statement	Obj	Teacher's notes
G.1.1	Outline the factors that affect the distribution of plant species, including temperature, water, light, soil pH, salinity and mineral nutrients.	2	
G.1.2	Explain the factors that affect the distribution of animal species, including temperature, water, breeding sites, food supply and territory.	3	

	Assessment statement	Obj	Teacher's notes
G.1.3	Describe one method of random sampling, based on quadrat methods, that is used to compare the population size of two plant or two animal species.	2	
G.1.4	Outline the use of a transect to correlate the distribution of plant or animal species with an abiotic variable.	2	
G.1.5	Explain what is meant by the niche concept, including an organism's spatial habitat, its feeding activities and its interactions with other species.	3	
G.1.6	Outline the following interactions between species, giving two examples of each: competition, herbivory, predation, parasitism and mutualism.	2	
G.1.7	Explain the principle of competitive exclusion.	3	
G.1.8	Distinguish between *fundamental* and *realized* niches.	2	The fundamental niche of a species is the potential mode of existence, given the adaptations of the species. The realized niche of a species is the actual mode of existence, which results from its adaptations and competition with other species.
G.1.9	Define *biomass*.	1	
G.1.10	Describe one method for the measurement of biomass of different trophic levels in an ecosystem.	2	**Aim 8:** Ethical issues of returning the species and destructive techniques should be considered.

G2 Ecosystems and biomes

4 hours

	Assessment statement	Obj	Teacher's notes
G.2.1	Define *gross production*, *net production* and *biomass*.	1	
G.2.2	Calculate values for gross production and net production using the equation: gross production – respiration = net production.	2	GP – R = NP
G.2.3	Discuss the difficulties of classifying organisms into trophic levels.	3	
G.2.4	Explain the small biomass and low numbers of organisms in higher trophic levels.	3	

	Assessment statement	Obj	Teacher's notes
G.2.5	Construct a pyramid of energy, given appropriate information.	3	The units are kJ m^{-2} yr^{-1}.
G.2.6	Distinguish between *primary* and *secondary* succession, using an example of each.	2	
G.2.7	Outline the changes in species diversity and production during primary succession.	2	
G.2.8	Explain the effects of living organisms on the abiotic environment, with reference to the changes occurring during primary succession.	3	Include soil development, accumulation of minerals and reduced erosion.
G.2.9	Distinguish between *biome* and *biosphere*.	2	
G.2.10	Explain how rainfall and temperature affect the distribution of biomes.	3	A climograph showing the biomes in G.2.11 can be used to illustrate the interaction between these two factors.
G.2.11	Outline the characteristics of six major biomes.	2	Examples of major biomes could include: • desert • grassland • shrubland (chaparral, matorral, maquis and garigue, dry heathlands, fynbos) • temperate deciduous forest • tropical rainforest • tundra. The description should be limited to temperature, moisture and characteristics of vegetation.

G3 Impacts of humans on ecosystems

6 hours

	Assessment statement	Obj	Teacher's notes
G.3.1	Calculate the Simpson diversity index for two local communities.	2	$D = \frac{N(N-1)}{\Sigma n(n-1)}$ where D = diversity index, N = total number of organisms of all species found and n = number of individuals of a particular species. Teachers are strongly advised to make students collect actual data. This is an opportunity to use the graphic display calculator and spreadsheets.
G.3.2	Analyse the biodiversity of the two local communities using the Simpson index.	3	
G.3.3	Discuss reasons for the conservation of biodiversity using rainforests as an example.	3	Reasons should include ethical, ecological, economic and aesthetic arguments. **Aim 8:** There are environmental issues affecting the whole planet and also ethical issues involved in conservation that could be raised here.

	Assessment statement	Obj	Teacher's notes
G.3.4	List three examples of the introduction of alien species that have had significant impacts on ecosystems.	1	Choose one example of biological control, and one example each of accidental and deliberate release of invasive species.
G.3.5	Discuss the impacts of alien species on ecosystems.	3	Limit the discussion to inter-specific competition, predation, species extinction and biological control of pest species, with named examples of each.
G.3.6	Outline one example of biological control of invasive species.	2	**Aim 8:** Invasive alien species are such a widespread problem that it will almost certainly be possible to find a good local example. Such species are a real threat to the biodiversity of the planet, with many species facing extinction as a result. The uniqueness and cultural diversity of human populations are also being affected.
G.3.7	Define *biomagnification*.	1	Biomagnification is a process in which chemical substances become more concentrated at each trophic level.
G.3.8	Explain the cause and consequences of biomagnification, using a named example.	3	Examples can include biomagnification of mercury in fish, and organophosphorus pesticides, DDT or TBT (tributyl tin) in ecosystems.
G.3.9	Outline the effects of ultraviolet (UV) radiation on living tissues and biological productivity.	2	
G.3.10	Outline the effect of chlorofluorocarbons (CFCs) on the ozone layer.	2	Details of the chemical reactions are not required.
G.3.11	State that ozone in the stratosphere absorbs UV radiation.	1	There is a limit to UV absorption in the stratosphere. There is no need to mention UV-A, UV-B and UV-C.

HL G4 Conservation of biodiversity

3 hours

	Assessment statement	Obj	Teacher's notes
G.4.1	Explain the use of biotic indices and indicator species in monitoring environmental change.	3	
G.4.2	Outline the factors that contributed to the extinction of one named animal species.	2	Examples could include the Carolina parakeet, dodo, passenger pigeon and thylacine (Tasmanian wolf).
G.4.3	Outline the biogeographical features of nature reserves that promote the conservation of diversity.	2	Limit this to edge effects, size and habitat corridors. Large nature reserves usually promote conservation of biodiversity more effectively than small ones. The ecology of the edges of ecosystems is different from the central areas due to edge effects. An example of an edge effect is the egg-laying habits of the cowbird of the western United States. It feeds in open areas, but it lays its eggs in the nests of other birds near the edges of forests. Fragmentation of forests has led to a considerable increase in cowbird populations because of the increase in forest edge. Wildlife corridors allow organisms to move between different parts of a fragmented habitat, for example, tunnels under busy roads.

	Assessment statement	Obj	Teacher's notes
G.4.4	Discuss the role of active management techniques in conservation.	3	Use a local example wherever possible to illustrate this.
G.4.5	Discuss the advantages of *in situ* conservation of endangered species (terrestrial and aquatic nature reserves).	3	
G.4.6	Outline the use of *ex situ* conservation measures, including captive breeding of animals, botanic gardens and seed banks.	2	

HL G5 Population ecology

4 hours

	Assessment statement	Obj	Teacher's notes
G.5.1	Distinguish between *r-strategies* and *K-strategies*.	2	An r-strategy involves investing more resources into producing many offspring, having a short life span, early maturity, reproducing only once and having a small body size. A K-strategy involves investing more resources into development and long-term survival. This involves a longer life span and late maturity, and is more likely to involve parental care, the production of few offspring, and reproducing more than once. There are organisms that display extreme r- or K-strategies, but most organisms have life histories that are intermediate on the continuum. Some organisms such as *Drosophila* switch strategies depending on environmental conditions.
G.5.2	Discuss the environmental conditions that favour either r-strategies or K-strategies.	3	In a predictable environment, in order to maximize fitness, it pays to invest resources in long-term development and long life (K-strategy). In an unstable environment, it is better to produce as many offspring as quickly as possible (r-strategy). Of concern is that ecological disruption favours r-strategists such as pathogens and pest species.
G.5.3	Describe one technique used to estimate the population size of an animal species based on a capture–mark–release–recapture method.	2	Various mark-and-recapture methods exist. Knowledge of the Lincoln index (which involves one mark–release–recapture cycle) is required, as follows. Population size $= \frac{n_1 \times n_2}{n_3}$ where n_1 = number of individuals initially caught, marked and released, n_2 = total number of individuals caught in the second sample, and n_3 = number of marked individuals in the second sample. Although simulations can be carried out (for example, sampling beans in sawdust), it is much more valuable if this is accompanied by a real exercise on a population of animals. The limitations and difficulties of the method can be fully appreciated, and some notion of the importance of sample size can be explained. It is important that students appreciate the need for choosing an appropriate method for marking organisms.

	Assessment statement	Obj	Teacher's notes
G.5.4	Describe the methods used to estimate the size of commercial fish stocks.	2	
G.5.5	Outline the concept of maximum sustainable yield in the conservation of fish stocks.	2	**Aim 8:** There are clear ethical, social, environmental and economic issues here, some of which conflict with each other. **TOK:** Data about fish stocks is very difficult to obtain and interpret, allowing huge differences in views on what is sustainable. In addition to fishing, whale hunting is an area where there is widespread disagreement about what is sustainable and also what is ethical.
G.5.6	Discuss international measures that would promote the conservation of fish.	3	**Aim 8:** As in G.5.5, there are many issues involved here, and there is a chance to discuss the need for international agreement and cooperation in a world that is largely governed at a national level, with large areas of ocean under no government control at all. **TOK:** This is a chance to discuss decision-making, based partly on scientific evidence, that has to take place at an international level.

Syllabus details—Options HL

Option H: Further human physiology (22 hours)

This option is available at HL only.

HL H1 Hormonal control

3 hours

	Assessment statement	Obj	Teacher's notes
H.1.1	State that hormones are chemical messengers secreted by endocrine glands into the blood and transported to specific target cells.	1	
H.1.2	State that hormones can be steroids, proteins and tyrosine derivatives, with one example of each.	1	
H.1.3	Distinguish between the mode of action of *steroid* hormones and *protein* hormones.	2	Steroid hormones enter cells and interact with genes directly. Protein hormones bind to receptors in the membrane, which causes the release of a secondary messenger inside the cell.
H.1.4	Outline the relationship between the hypothalamus and the pituitary gland.	2	Include the portal vein connecting the hypothalamus and the anterior pituitary gland, and the neurosecretory cells connecting the hypothalamus and the posterior pituitary gland.
H.1.5	Explain the control of ADH (vasopressin) secretion by negative feedback.	3	Include neurosecretory cells in the hypothalamus, transport of ADH to the posterior pituitary gland for storage, and release under stimulus by osmoreceptors in the hypothalamus.

HL H2 Digestion

4 hours

	Assessment statement	Obj	Teacher's notes
H.2.1	State that digestive juices are secreted into the alimentary canal by glands, including salivary glands, gastric glands in the stomach wall, the pancreas and the wall of the small intestine.	1	
H.2.2	Explain the structural features of exocrine gland cells.	3	Include the secretory cells grouped into acini and ducts, and the ultrastructure of secretory cells as seen in the electron micrographs.
H.2.3	Compare the composition of saliva, gastric juice and pancreatic juice.	3	

	Assessment statement	Obj	Teacher's notes
H.2.4	Outline the control of digestive juice secretion by nerves and hormones, using the example of secretion of gastric juice.	2	Limit this to the initial release of gastric juice under nerve stimulation after sight or smell of food, and sustained release under the influence of gastrin secreted when food is in the stomach.
H.2.5	Outline the role of membrane-bound enzymes on the surface of epithelial cells in the small intestine in digestion.	2	Some digestive enzymes (for example, maltase) are immobilized in the exposed plasma membranes of epithelial cells in intestinal villi.
H.2.6	Outline the reasons for cellulose not being digested in the alimentary canal.	2	
H.2.7	Explain why pepsin and trypsin are initially synthesized as inactive precursors and how they are subsequently activated.	3	
H.2.8	Discuss the roles of gastric acid and *Helicobacter pylori* in the development of stomach ulcers and stomach cancers.	3	**TOK:** This is an example of a paradigm shift, where existing ideas about the tolerance of bacteria to stomach acid were incorrect but persisted for a time despite the evidence. The story of how the Australians Robin Warren and Barry Marshall made the discovery and struggled to convince the scientific and medical community is well worth telling.
H.2.9	Explain the problem of lipid digestion in a hydrophilic medium and the role of bile in overcoming this.	3	Lipid molecules tend to coalesce and are only accessible to lipase at the lipid–water interface. Bile molecules have a hydrophilic end and a hydrophobic end, and thus prevent lipid droplets coalescing. The maximum surface is exposed to lipases. The need for lipase to be water-soluble and to have an active site to which a hydrophobic substrate binds should be mentioned.

HL H3 Absorption of digested foods

2 hours

	Assessment statement	Obj	Teacher's notes
H.3.1	Draw and label a diagram showing a transverse section of the ileum as seen under a light microscope.	1	Include mucosa and layers of longitudinal and circular muscle.
H.3.2	Explain the structural features of an epithelial cell of a villus as seen in electron micrographs, including microvilli, mitochondria, pinocytotic vesicles and tight junctions.	3	
H.3.3	Explain the mechanisms used by the ileum to absorb and transport food, including facilitated diffusion, active transport and endocytosis.	3	
H.3.4	List the materials that are not absorbed and are egested.	1	Limit this to cellulose, lignin, bile pigments, bacteria and intestinal cells.

HL H4 Functions of the liver

3 hours

	Assessment statement	Obj	Teacher's notes
H.4.1	Outline the circulation of blood through liver tissue, including the hepatic artery, hepatic portal vein, sinusoids and hepatic vein.	2	The difference in structure between sinusoids and capillaries should also be mentioned. Reference to lobules or acini is not required.
H.4.2	Explain the role of the liver in regulating levels of nutrients in the blood.	3	
H.4.3	Outline the role of the liver in the storage of nutrients, including carbohydrate, iron, vitamin A and vitamin D.	2	
H.4.4	State that the liver synthesizes plasma proteins and cholesterol.	1	
H.4.5	State that the liver has a role in detoxification.	1	
H.4.6	Describe the process of erythrocyte and hemoglobin breakdown in the liver, including phagocytosis, digestion of globin and bile pigment formation.	2	
H.4.7	Explain the liver damage caused by excessive alcohol consumption.	3	

HL H5 The transport system

5 hours

	Assessment statement	Obj	Teacher's notes
H.5.1	Explain the events of the cardiac cycle, including atrial and ventricular systole and diastole, and heart sounds.	3	**Aim 7:** Data logging using an EKG sensor is possible.
H.5.2	Analyse data showing pressure and volume changes in the left atrium, left ventricle and the aorta, during the cardiac cycle.	3	Recall of quantitative data is not expected.
H.5.3	Outline the mechanisms that control the heartbeat, including the roles of the SA (sinoatrial) node, AV (atrioventricular) node and conducting fibres in the ventricular walls.	2	Bundles of His and Purkinje fibres are not required.
H.5.4	Outline atherosclerosis and the causes of coronary thrombosis.	2	

	Assessment statement	Obj	Teacher's notes
H.5.5	Discuss factors that affect the incidence of coronary heart disease.	3	Risk factors include having parents who have experienced heart attacks (genetic), age, being male, smoking, obesity, eating too much saturated fat and cholesterol, and lack of exercise. **TOK:** This is an area where a huge amount of data from epidemiological studies has been obtained, but the interpretation of this data is fraught with difficulty. Rates of heart disease in different countries have often been correlated with individual factors, and a causal link has then been claimed. In other studies, data has been used selectively to try to establish statistically significant trends. The concept of risk factors could be questioned on the grounds of the complex interaction between factors. If individuals alter their lifestyles to reduce a risk factor, this may not necessarily affect their overall risk of heart disease. A distinction could also be drawn between indicators of risk, such as the levels of certain substances in the blood and factors that actually cause coronary heart disease.

HL H6 Gas exchange

5 hours

	Assessment statement	Obj	Teacher's notes
H.6.1	Define *partial pressure*.	1	
H.6.2	Explain the oxygen dissociation curves of adult hemoglobin, fetal hemoglobin and myoglobin.	3	
H.6.3	Describe how carbon dioxide is carried by the blood, including the action of carbonic anhydrase, the chloride shift and buffering by plasma proteins.	2	
H.6.4	Explain the role of the Bohr shift in the supply of oxygen to respiring tissues.	3	
H.6.5	Explain how and why ventilation rate varies with exercise.	3	Limit this to the effects of changes in carbon dioxide concentration leading to a lowering of blood pH. This is detected by chemosensors in the aorta and carotid arteries that send impulses to the breathing centre of the brain. Nerve impulses are then sent to the diaphragm and the intercostal muscles to increase contraction or relaxation rates.
H.6.6	Outline the possible causes of asthma and its effects on the gas exchange system.	2	
H.6.7	Explain the problem of gas exchange at high altitudes and the way the body acclimatizes.	3	

Mathematical requirements

All Diploma Programme biology students should be able to:

- perform the basic arithmetic functions: addition, subtraction, multiplication and division
- recognize basic geometric shapes
- carry out simple calculations within a biological context involving decimals, fractions, percentages, ratios, approximations, reciprocals and scaling
- use standard notation (for example, 3.6×10^6)
- use direct and inverse proportion
- represent and interpret frequency data in the form of bar charts, column graphs and histograms, and interpret pie charts and nomograms
- determine the mode and median of a set of data
- plot and interpret graphs (with suitable scales and axes) involving two variables that show linear or non-linear relationships
- plot and interpret scattergraphs to identify a correlation between two variables, and appreciate that the existence of a correlation does not establish a causal relationship
- demonstrate sufficient knowledge of probability to understand how Mendelian ratios arise and to calculate such ratios using a Punnett grid
- make approximations of numerical expressions
- recognize and use the relationships between length, surface area and volume.