Diploma Programme

Biology guide

First assessment 2016

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

IB merchandise and publications can be purchased through the IB store at http://store.ibo.org.

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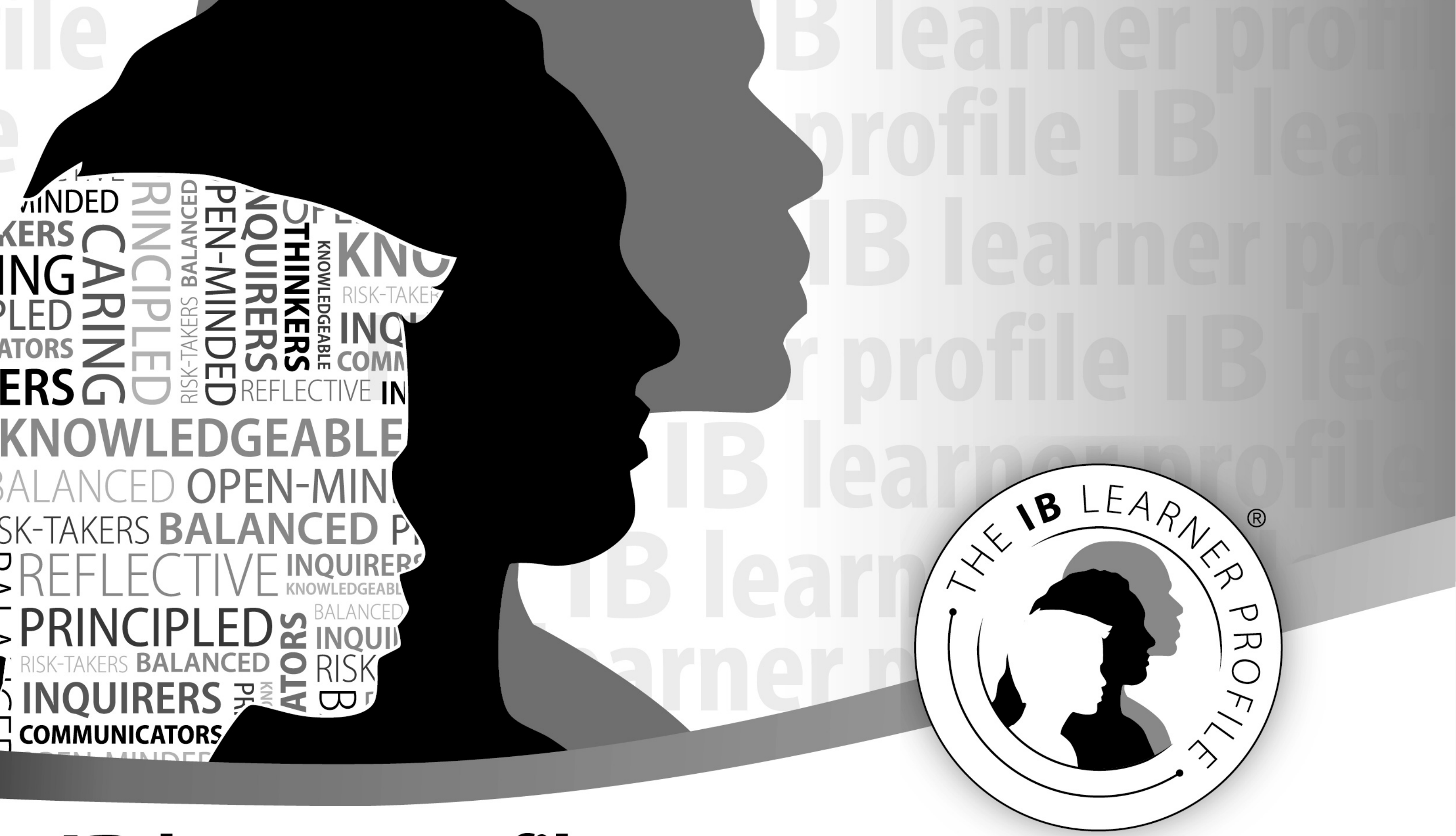
IB mission statement

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

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

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



IB learner profile

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

As IB learners we strive to be:

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

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

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

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

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

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

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

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

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

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

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

Contents

Purpose of this document

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

This guide can be found on the subject page of the online curriculum centre (OCC) at http://occ.ibo.org, a password-protected IB website designed to support IB teachers. It can also be purchased from the IB store at http://store.ibo.org.

Additional resources

Additional publications such as teacher support materials, subject reports, internal assessment guidance and grade descriptors can also be found on the OCC. Past examination papers as well as markschemes can be purchased from the IB store.

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

Acknowledgment

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

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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 model

The course is presented as six academic areas enclosing a central core (see figure 1). It encourages the concurrent study of a broad range of academic areas. Students study: two modern languages (or a modern language and a classical language); a humanities or social science subject; a science; mathematics and 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.

Figure 1

Diploma Programme model

Choosing the right combination

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

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

The core of the Diploma Programme model

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

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

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

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

Approaches to teaching and approaches to learning

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

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

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

The IB mission statement and the IB learner profile

The Diploma Programme aims to develop in students the knowledge, skills and attitudes they will need to fulfill the aims of the IB, 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.

Academic honesty

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

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

For further information on academic honesty in the IB and the Diploma Programme, please consult the IB publications *Academic honesty*, *The Diploma Programme: From principles into practice* and *General regulations: Diploma Programme*. Specific information regarding academic honesty as it pertains to external and internal assessment components of this Diploma Programme subject can be found in this guide.

Acknowledging the ideas or work of another person

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

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

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

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

Learning diversity and learning support requirements

Schools must ensure that equal access arrangements and reasonable adjustments are provided to candidates with learning support requirements that are in line with the IB documents *Candidates with assessment access requirements* and *Learning diversity within the International Baccalaureate programmes/ Special educational needs within the International Baccalaureate programmes*.

Nature of science

The Nature of science (NOS) is an overarching theme in the biology, chemistry and physics courses. This section, titled Nature of science, is in the biology, chemistry and physics guides to support teachers in their understanding of what is meant by the nature of science. The "Nature of science" section of the guide provides a comprehensive account of the nature of science in the 21st century. It will not be possible to cover in this document all the themes in detail in the three science courses, either for teaching or assessment.

It has a paragraph structure (1.1, 1.2, etc.) to link the significant points made to the syllabus (landscape pages) references on the NOS. The NOS parts in the subject-specific sections of the guide are examples of a particular understanding. The NOS statement(s) above every sub-topic outline how one or more of the NOS themes can be exemplified through the understandings, applications and skills in that sub-topic. These are not a repeat of the NOS statements found below but an elaboration of them in a specific context. See the section on "Format of the syllabus".

Technology

Although this section is about the nature of science, the interpretation of the word technology is important, and the role of technology emerging from and contributing to science needs to be clarified. In today's world, the words *science* and *technology* are often used interchangeably, however historically this is not the case. Technology emerged before science, and materials were used to produce useful and decorative artefacts long before there was an understanding of why materials had different properties that could be used for different purposes. In the modern world the reverse is the case: an understanding of the underlying science is the basis for technological developments. These new technologies in their turn drive developments in science.

Despite their mutual dependence they are based on different values: science on evidence, rationality and the quest for deeper understanding; technology on the practical, the appropriate and the useful with an increasingly important emphasis on sustainability.

1. What is science and what is the scientific endeavour?

1.1. The underlying assumption of science is that the universe has an independent, external reality accessible to human senses and amenable to human reason.

1.2. Pure science aims to come to a common understanding of this external universe; applied science and engineering develop technologies that result in new processes and products. However, the boundaries between these fields are fuzzy.

1.3. Scientists use a wide variety of methodologies which taken together, make up the process of science. There is no single "scientific method". Scientists have used, and do use, different methods at different times to build up their knowledge and ideas but they have a common understanding about what makes them all scientifically valid.

1.4. This is an exciting and challenging adventure involving much creativity and imagination as well as exacting and detailed thinking and application. Scientists also have to be ready for unplanned, surprising, accidental discoveries. The history of science shows this is a very common occurrence.

1.5. Many scientific discoveries have involved flashes of intuition and many have come from speculation or simple curiosity about particular phenomena.

1.6. Scientists have a common terminology and a common reasoning process, which involves using deductive and inductive logic through analogies and generalizations. They share mathematics, the language of science, as a powerful tool. Indeed, some scientific explanations only exist in mathematical form.

1.7. Scientists must adopt a skeptical attitude to claims. This does not mean that they disbelieve everything, but rather that they suspend judgment until they have a good reason to believe a claim to be true or false. Such reasons are based on evidence and argument.

1.8. The importance of evidence is a fundamental common understanding. Evidence can be obtained by observation or experiment. It can be gathered by human senses, primarily sight, but much modern science is carried out using instrumentation and sensors that can gather information remotely and automatically in areas that are too small, or too far away, or otherwise beyond human sense perception. Improved instrumentation and new technology have often been the drivers for new discoveries. Observations followed by analysis and deduction led to the Big Bang theory of the origin of the universe and to the theory of evolution by natural selection. In these cases, no controlled experiments were possible. Disciplines such as geology and astronomy rely strongly on collecting data in the field, but all disciplines use observation to collect evidence to some extent. Experimentation in a controlled environment, generally in laboratories, is the other way of obtaining evidence in the form of data, and there are many conventions and understandings as to how this is to be achieved.

1.9. This evidence is used to develop theories, generalize from data to form laws and propose hypotheses. These theories and hypotheses are used to make predictions that can be tested. In this way theories can be supported or opposed and can be modified or replaced by new theories.

1.10. Models, some simple, some very complex, based on theoretical understanding, are developed to explain processes that may not be observable. Computer-based mathematical models are used to make testable predictions, which can be especially useful when experimentation is not possible. Models tested against experiments or data from observations may prove inadequate, in which case they may be modified or replaced by new models.

1.11. The outcomes of experiments, the insights provided by modelling and observations of the natural world may be used as further evidence for a claim.

1.12. The growth in computing power has made modelling much more powerful. Models, usually mathematical, are now used to derive new understandings when no experiments are possible (and sometimes when they are). This dynamic modelling of complex situations involving large amounts of data, a large number of variables and complex and lengthy calculations is only possible as a result of increased computing power. Modelling of the Earth's climate, for example, is used to predict or make a range of projections of future climatic conditions. A range of different models have been developed in this field and results from different models have been compared to see which models are most accurate. Models can sometimes be tested by using data from the past and used to see if they can predict the present situation. If a model passes this test, we gain confidence in its accuracy.

1.13. Both the ideas and the processes of science can only occur in a human context. Science is carried out by a community of people from a wide variety of backgrounds and traditions, and this has clearly influenced the way science has proceeded at different times. It is important to understand, however, that to do science is to be involved in a community of inquiry with certain common principles, methodologies, understandings and processes.

2. The understanding of science

2.1. Theories, laws and hypotheses are concepts used by scientists. Though these concepts are connected, there is no progression from one to the other. These words have a special meaning in science and it is important to distinguish these from their everyday use.

2.2. Theories are themselves integrated, comprehensive models of how the universe, or parts of it, work. A theory can incorporate facts and laws and tested hypotheses. Predictions can be made from the theories and these can be tested in experiments or by careful observations. Examples are the germ theory of disease or atomic theory.

2.3. Theories generally accommodate the assumptions and premises of other theories, creating a consistent understanding across a range of phenomena and disciplines. Occasionally, however, a new theory will radically change how essential concepts are understood or framed, impacting other theories and causing what is sometimes called a “paradigm shift” in science. One of the most famous paradigm shifts in science occurred when our idea of time changed from an absolute frame of reference to an observer-dependent frame of reference within Einstein’s theory of relativity. Darwin’s theory of evolution by natural selection also changed our understanding of life on Earth.

2.4. Laws are descriptive, normative statements derived from observations of regular patterns of behaviour. They are generally mathematical in form and can be used to calculate outcomes and to make predictions. Like theories and hypotheses, laws cannot be proven. Scientific laws may have exceptions and may be modified or rejected based on new evidence. Laws do not necessarily explain a phenomenon. For example, Newton’s law of universal gravitation tells us that the force between two masses is inversely proportional to the square of the distance between them, and allows us to calculate the force between masses at any distance apart, but it does not explain why masses attract each other. Also, note that the term law has been used in different ways in science, and whether a particular idea is called a law may be partly a result of the discipline and time period at which it was developed.

2.5. Scientists sometimes form hypotheses—explanatory statements about the world that could be true or false, and which often suggest a causal relationship or a correlation between factors. Hypotheses can be tested by both experiments and observations of the natural world and can be supported or opposed.

2.6. To be scientific, an idea (for example, a theory or hypothesis) must focus on the natural world and natural explanations and must be testable. Scientists strive to develop hypotheses and theories that are compatible with accepted principles and that simplify and unify existing ideas.

2.7. The principle of Occam’s razor is used as a guide to developing a theory. The theory should be as simple as possible while maximizing explanatory power.

2.8. The ideas of correlation and cause are very important in science. A correlation is a statistical link or association between one variable and another. A correlation can be positive or negative and a correlation coefficient can be calculated that will have a value between +1, 0 and -1. A strong correlation (positive or negative) between one factor and another suggests some sort of causal relationship between the two factors but more evidence is usually required before scientists accept the idea of a causal relationship. To establish a causal relationship, ie one factor causing another, scientists need to have a plausible scientific mechanism linking the factors. This strengthens the case that one causes the other, for example smoking and lung cancer. This mechanism can be tested in experiments.

2.9. The ideal situation is to investigate the relationship between one factor and another while controlling all other factors in an experimental setting; however this is often impossible and scientists, especially in biology and medicine, use sampling, cohort studies and case control studies to strengthen their understanding of causation when experiments (such as double blind tests and clinical trials) are not possible. Epidemiology in the field of medicine involves the statistical analysis of data to discover possible correlations when little established scientific knowledge is available or the circumstances are too difficult to control entirely. Here, as in other fields, mathematical analysis of probability also plays a role.

3. The objectivity of science

3.1. Data is the lifeblood of scientists and may be qualitative or quantitative. It can be obtained purely from observations or from specifically designed experiments, remotely using electronic sensors or by direct measurement. The best data for making accurate and precise descriptions and predictions is often quantitative and amenable to mathematical analysis. Scientists analyse data and look for patterns, trends and discrepancies, attempting to discover relationships and establish causal links. This is not always possible, so identifying and classifying observations and artefacts (eg types of galaxies or fossils) is still an important aspect of scientific work.

3.2. Taking repeated measurements and large numbers of readings can improve reliability in data collection. Data can be presented in a variety of formats such as linear and logarithmic graphs that can be analysed for, say, direct or inverse proportion or for power relationships.

3.3. Scientists need to be aware of random errors and systematic errors, and use techniques such as error bars and lines of best fit on graphs to portray the data as realistically and honestly as possible. There is a need to consider whether outlying data points should be discarded or not.

3.4. Scientists need to understand the difference between errors and uncertainties, accuracy and precision, and need to understand and use the mathematical ideas of average, mean, mode, median, etc. Statistical methods such as standard deviation and chi-squared tests are often used. It is important to be able to assess how accurate a result is. A key part of the training and skill of scientists is in being able to decide which technique is appropriate in different circumstances.

3.5. It is also very important for scientists to be aware of the cognitive biases that may impact experimental design and interpretation. The confirmation bias, for example, is a well-documented cognitive bias that urges us to find reasons to reject data that is unexpected or does not conform to our expectations or desires, and to perhaps too readily accept data that agrees with these expectations or desires. The processes and methodologies of science are largely designed to account for these biases. However care must always be taken to avoid succumbing to them.

3.6. Although scientists cannot ever be certain that a result or finding is correct, we know that some scientific results are very close to certainty. Scientists often speak of "levels of confidence" when discussing outcomes. The discovery of the existence of a Higgs boson is such an example of a "level of confidence". This particle may never be directly observable, but to establish its "existence" particle physicists had to pass the self-imposed definition of what can be regarded as a discovery—the 5-sigma "level of certainty"—or about a 0.00003% chance that the effect is not real based on experimental evidence.

3.7. In recent decades, the growth in computing power, sensor technology and networks has allowed scientists to collect large amounts of data. Streams of data are downloaded continuously from many sources such as remote sensing satellites and space probes and large amounts of data are generated in gene sequencing machines. Experiments in CERN's Large Hadron Collider regularly produce 23 petabytes of data per second, which is equivalent to 13.3 years of high definition TV content per second.

3.8. Research involves analysing large amounts of this data, stored in databases, looking for patterns and unique events. This has to be done using software which is generally written by the scientists involved. The data and the software may not be published with the scientific results but would be made generally available to other researchers.

4. The human face of science

4.1. Science is highly collaborative and the scientific community is composed of people working in science, engineering and technology. It is common to work in teams from many disciplines so that different areas of expertise and specializations can contribute to a common goal that is beyond one scientific field. It is also the case that how a problem is framed in the paradigm of one discipline might limit possible solutions, so framing problems using a variety of perspectives, in which new solutions are possible, can be extremely useful.

4.2. Teamwork of this sort takes place with the common understanding that science should be open-minded and independent of religion, culture, politics, nationality, age and gender. Science involves the free global interchange of information and ideas. Of course, individual scientists are human and may have biases and prejudices, but the institutions, practices and methodologies of science help keep the scientific endeavour as a whole unbiased.

4.3. As well as collaborating on the exchange of results, scientists work on a daily basis in collaborative groups on a small and large scale within and between disciplines, laboratories, organizations and countries, facilitated even more by virtual communication. Examples of large-scale collaboration include:

- The Manhattan project, the aim of which was to build and test an atomic bomb. It eventually employed more than 130,000 people and resulted in the creation of multiple production and research sites that operated in secret, culminating in the dropping of two atomic bombs on Hiroshima and Nagasaki.
- The Human Genome Project (HGP), which was an international scientific research project set up to map the human genome. The $3-billion project beginning in 1990 produced a draft of the genome in 2000. The sequence of the DNA is stored in databases available to anyone on the internet.
- The IPCC (Intergovernmental Panel on Climate Change), organized under the auspices of The United Nations, is officially composed of about 2,500 scientists. They produce reports summarizing the work of many more scientists from all around the world.
- CERN, the European Organization for Nuclear Research, an international organization set up in 1954, is the world's largest particle physics laboratory. The laboratory, situated in Geneva, employs about 2,400 people and shares results with 10,000 scientists and engineers covering over 100 nationalities from 600 or more universities and research facilities.

All the above examples are controversial to some degree and have aroused emotions among scientists and the public.

4.4. Scientists spend a considerable amount of time reading the published results of other scientists. They publish their own results in scientific journals after a process called peer review. This is when the work of a scientist or, more usually, a team of scientists is anonymously and independently reviewed by several scientists working in the same field who decide if the research methodologies are sound and if the work represents a new contribution to knowledge in that field. They also attend conferences to make presentations and display posters of their work. Publication of peer-reviewed journals on the internet has increased the efficiency with which the scientific literature can be searched and accessed. There are a large number of national and international organizations for scientists working in specialized areas within subjects.

4.5. Scientists often work in areas, or produce findings, that have significant ethical and political implications. These areas include cloning, genetic engineering of food and organisms, stem cell and reproductive technologies, nuclear power, weapons development (nuclear, chemical and biological), transplantation of tissue and organs and in areas that involve testing on animals (see *IB animal experimentation policy*). There are also questions involving intellectual property rights and the free exchange of information that may impact significantly on a society. Science is undertaken in universities, commercial companies, government organizations, defence agencies and international organizations. Questions of patents and intellectual property rights arise when work is done in a protected environment.

4.6. The integrity and honest representation of data is paramount in science—results should not be fixed or manipulated or doctored. To help ensure academic honesty and guard against plagiarism, all sources are quoted and appropriate acknowledgment made of help or support. Peer review and the scrutiny and skepticism of the scientific community also help achieve these goals.

4.7. All science has to be funded and the source of the funding is crucial in decisions regarding the type of research to be conducted. Funding from governments and charitable foundations is sometimes for pure research with no obvious direct benefit to anyone whereas funding from private companies is often for applied research to produce a particular product or technology. Political and economic factors often determine the nature and extent of the funding. Scientists often have to spend time applying for research grants and have to make a case for what they want to research.

4.8. Science has been used to solve many problems and improve man's lot, but it has also been used in morally questionable ways and in ways that inadvertently caused problems. Advances in sanitation, clean water supplies and hygiene led to significant decreases in death rates but without compensating decreases in birth rates this led to huge population increases with all the problems of resources, energy and food supplies that entails. Ethical discussions, risk-benefit analyses, risk assessment and the precautionary principle are all parts of the scientific way of addressing the common good.

5. Scientific literacy and the public understanding of science

5.1. An understanding of the nature of science is vital when society needs to make decisions involving scientific findings and issues. How does the public judge? It may not be possible to make judgments based on the public's direct understanding of a science, but important questions can be asked about whether scientific processes were followed and scientists have a role in answering such questions.

5.2. As experts in their particular fields, scientists are well placed to explain to the public their issues and findings. Outside their specializations, they may be no more qualified than ordinary citizens to advise others on scientific issues, although their understanding of the processes of science can help them to make personal decisions and to educate the public as to whether claims are scientifically credible.

5.3. As well as comprising knowledge of how scientists work and think, scientific literacy involves being aware of faulty reasoning. There are many cognitive biases/fallacies of reasoning to which people are susceptible (including scientists) and these need to be corrected whenever possible. Examples of these are the confirmation bias, hasty generalizations, *post hoc ergo propter hoc* (false cause), the straw man fallacy, redefinition (moving the goal posts), the appeal to tradition, false authority and the accumulation of anecdotes being regarded as evidence.

5.4. When such biases and fallacies are not properly managed or corrected, or when the processes and checks and balances of science are ignored or misapplied, the result is pseudoscience. Pseudoscience is the term applied to those beliefs and practices which claim to be scientific but do not meet or follow the standards of proper scientific methodologies, ie they lack supporting evidence or a theoretical framework, are not always testable and hence falsifiable, are expressed in a non-rigorous or unclear manner and often fail to be supported by scientific testing.

5.5. Another key issue is the use of appropriate terminology. Words that scientists agree on as being scientific terms will often have a different meaning in everyday life and scientific discourse with the public needs to take this into account. For example, a theory in everyday use means a hunch or speculation, but in science an accepted theory is a scientific idea that has produced predictions that have been thoroughly tested in many different ways. An aerosol is just a spray can to the general public, but in science it is a suspension of solid or liquid particles in a gas.

5.6. Whatever the field of science—whether it is in pure research, applied research or in engineering new technology—there is boundless scope for creative and imaginative thinking. Science has achieved a great deal but there are many, many unanswered questions to challenge future scientists.

> The flow chart below is part of an interactive flow chart showing the scientific process of inquiry in practice. The interactive version can be found at "How science works: The flowchart". Understanding Science. University of California Museum of Paleontology. 1 February 2013 <http://undsci.berkeley.edu/article/scienceflowchart>.

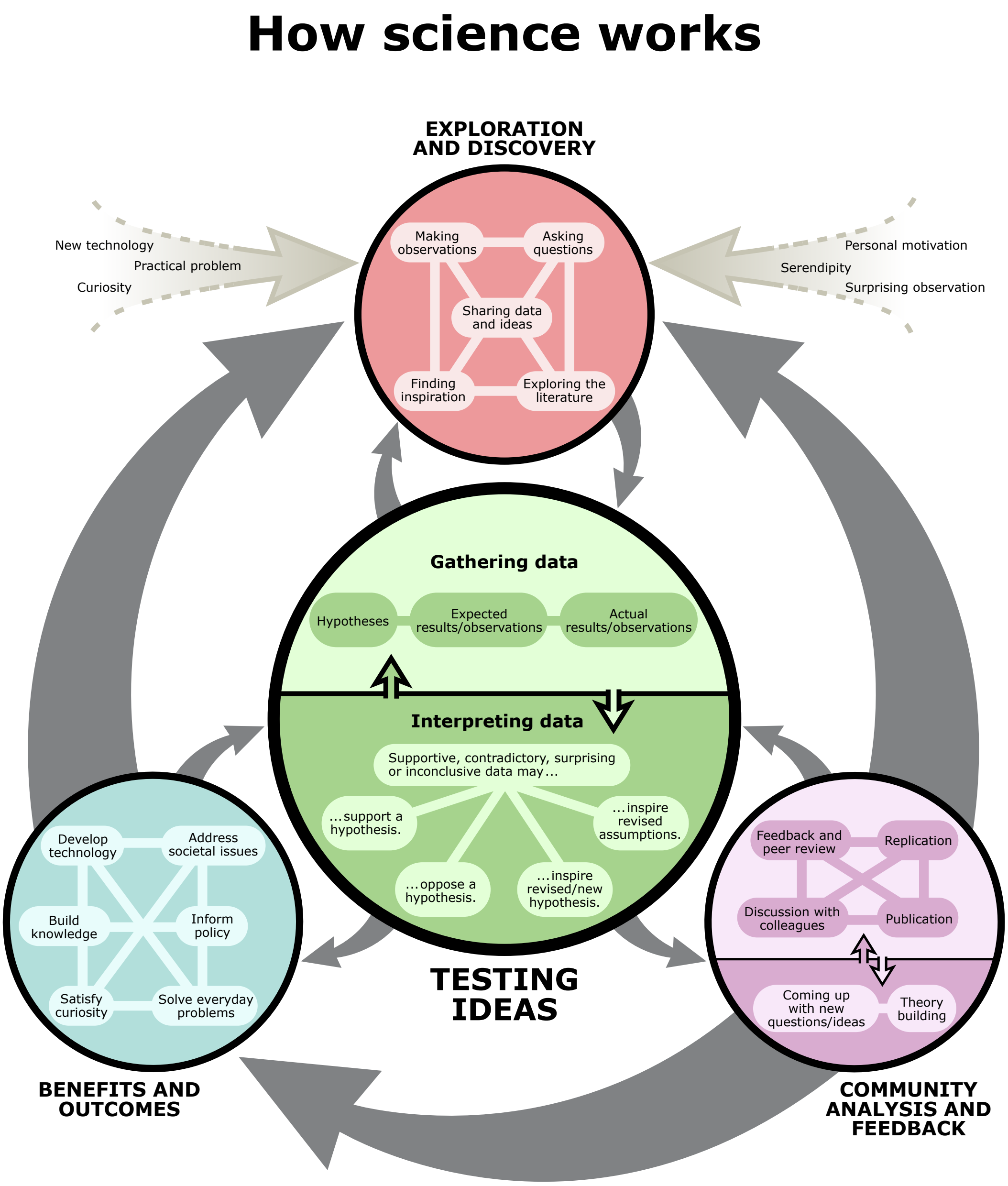

Figure 2

Pathways to scientific discovery

Nature of biology

Biology is the study of life. The first organisms appeared on the planet over 3 billion years ago and, through reproduction and natural selection, have given rise to the 8 million or so different species alive today. Estimates vary, but over the course of evolution 4 billion species could have been produced. Most of these flourished for a period of time and then became extinct as new, better adapted species took their place. There have been at least five periods when very large numbers of species became extinct and biologists are concerned that another mass extinction is under way, caused this time by human activity. Nonetheless, there are more species alive on Earth today than ever before. This diversity makes biology both an endless source of fascination and a considerable challenge.

An interest in life is natural for humans; not only are we living organisms ourselves, but we depend on many species for our survival, are threatened by some and co-exist with many more. From the earliest cave paintings to the modern wildlife documentary, this interest is as obvious as it is ubiquitous, as biology continues to fascinate young and old all over the world.

The word "biology" was coined by German naturalist Gottfried Reinhold in 1802 but our understanding of living organisms only started to grow rapidly with the advent of techniques and technologies developed in the 18th and 19th centuries, not least the invention of the microscope and the realization that natural selection is the process that has driven the evolution of life.

Biologists attempt to understand the living world at all levels using many different approaches and techniques. At one end of the scale is the cell, its molecular construction and complex metabolic reactions. At the other end of the scale biologists investigate the interactions that make whole ecosystems function.

Many areas of research in biology are extremely challenging and many discoveries remain to be made. Biology is still a young science and great progress is expected in the 21st century. This progress is sorely needed at a time when the growing human population is placing ever greater pressure on food supplies and on the habitats of other species, and is threatening the very planet we occupy.

Teaching approach

There are a variety of approaches to the teaching of biology. By its very nature, biology lends itself to an experimental approach, and it is expected that this will be reflected throughout the course.

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. Sections of the option material may be taught within the core or the additional higher level (AHL) material if desired or the option material can be taught as a separate unit.

Science 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 timeline websites. The scientific method in its widest sense, with its emphasis on peer review, open-mindedness and freedom of thought, transcends politics, religion, gender and nationality. Where appropriate within certain topics, the syllabus details sections in the group 4 guides contain links 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 research 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 teachers and students are encouraged to access the extensive websites and databases of these international scientific organizations to enhance their appreciation of the international dimension.

Increasingly there is a recognition that many scientific problems 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. 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 IB 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.

Students' attention should be drawn to sections of the syllabus with links to international-mindedness. Examples of issues relating to international-mindedness are given within sub-topics in the syllabus content. Teachers could also use resources found on the Global Engage website (http://globalengage. ibo.org).

Distinction 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 option studied. They are presented with a syllabus that encourages the development of certain skills, attributes and attitudes, as described in the "Assessment objectives" section of the 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, in the additional higher level (AHL) material and in the common options. The distinction between SL and HL is one of breadth and depth.

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 learning, characterized by the IB learner profile attributes, 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 formal science education would be necessary. Specific topic details are not specified but students who have undertaken the IB Middle Years Programme (MYP) or studied an equivalent national science qualification or a school-based science course would be well prepared for an HL subject.

Links to the Middle Years Programme

Students who have undertaken the MYP science, design and mathematics courses will be well prepared for group 4 subjects. The alignment between MYP science and the Diploma Programme group 4 courses allows for a smooth transition for students between programmes. The concurrent planning of the new group 4 courses and MYP: Next Chapter (both launched in 2014) has helped develop a closer alignment.

Scientific inquiry is central to teaching and learning science in the MYP. It enables students to develop a way of thinking and a set of skills and processes that, while allowing them to acquire and use knowledge, equip them with the capabilities to tackle, with confidence, the internal assessment component of group 4 subjects. The vision of MYP sciences is to contribute to the development of students as 21st century learners. A holistic sciences programme allows students to develop and utilize a mixture of cognitive abilities, social skills, personal motivation, conceptual knowledge and problem-solving competencies within an inquiry-based learning environment (Rhoton 2010). Inquiry aims to support students' understanding by providing them with opportunities to independently and collaboratively investigate relevant issues through both research and experimentation. This forms a firm base of scientific understanding with deep conceptual roots for students entering group 4 courses.

In the MYP, teachers make decisions about student achievement using their professional judgment, guided by criteria that are public, precise and known in advance, ensuring that assessment is transparent. The IB describes this approach as "criterion-related"—a philosophy of assessment that is neither "norm-referenced" (where students must be compared to each other and to an expected distribution of achievement) nor "criterion-referenced" (where students must master all strands of specific criteria at lower achievement levels before they can be considered to have achieved the next level). It is important to emphasize that the single most important aim of MYP assessment (consistent with the PYP and DP) is to support curricular goals and encourage appropriate student learning. Assessments are based upon evaluating course aims and objectives and, therefore, effective teaching to the course requirements also ensures effective teaching for formal assessment requirements. Students need to understand what the assessment expectations, standards and practices are and these should all be introduced early and naturally in teaching, as well as in class and homework activities. Experience with criterion-related assessment greatly assists students entering group 4 courses with understanding internal assessment requirements.

MYP science is a concept-driven curriculum, aimed at helping the learner construct meaning through improved critical thinking and the transfer of knowledge. At the top level are *key concepts* which are broad, organizing, powerful ideas that have relevance within the science course but also transcend it, having relevance in other subject groups. These key concepts facilitate both disciplinary and interdisciplinary learning as well as making connections with other subjects. While the key concepts provide breadth, the *related concepts* in MYP science add depth to the programme. The related concept can be considered to be the big idea of the unit which brings focus and depth and leads students towards the conceptual understanding.

Across the MYP there are 16 key concepts with the three highlighted below the focus for MYP science.

The key concepts across the MYP curriculum			
Aesthetics	**Change**	Communication	Communities
Connections	Creativity	Culture	Development
Form	Global interactions	Identity	Logic
Perspective	**Relationships**	**Systems**	Time, place and space

MYP students may in addition undertake an optional onscreen concept-based assessment as further preparation for Diploma Programme science courses.

Science and theory of knowledge

The theory of knowledge (TOK) course (first assessment 2015) engages students in reflection on the nature of knowledge and on how we know what we claim to know. The course identifies eight ways of knowing: reason, emotion, language, sense perception, intuition, imagination, faith and memory. Students explore these means of producing knowledge within the context of various areas of knowledge: the natural sciences, the social sciences, the arts, ethics, history, mathematics, religious knowledge systems and indigenous knowledge systems. The course also requires students to make comparisons between the different areas of knowledge, reflecting on how knowledge is arrived at in the various disciplines, what the disciplines have in common, and the differences between them.

TOK lessons can support students in their study of science, just as the study of science can support students in their TOK course. TOK provides a space for students to engage in stimulating wider discussions about questions such as what it means for a discipline to be a science, or whether there should be ethical constraints on the pursuit of scientific knowledge. It also provides an opportunity for students to reflect on the methodologies of science, and how these compare to the methodologies of other areas of knowledge. It is now widely accepted that there is no one scientific method, in the strict Popperian sense. Instead, the sciences utilize a variety of approaches in order to produce explanations for the behaviour of the natural world. The different scientific disciplines share a common focus on utilizing inductive and deductive reasoning, on the importance of evidence, and so on. Students are encouraged to compare and contrast these methods with the methods found in, for example, the arts or in history.

In this way there are rich opportunities for students to make links between their science and TOK courses. One way in which science teachers can help students to make these links to TOK is by drawing students' attention to knowledge questions which arise from their subject content. Knowledge questions are open-ended questions about knowledge, and include questions such as:

- How do we distinguish science from pseudoscience?
- When performing experiments, what is the relationship between a scientist's expectation and their perception?
- How does scientific knowledge progress?
- What is the role of imagination and intuition in the sciences?
- What are the similarities and differences in methods in the natural sciences and the human sciences?

Examples of relevant knowledge questions are provided throughout this guide within the sub-topics in the syllabus content. Teachers can also find suggestions of interesting knowledge questions for discussion in the “Areas of knowledge” and “Knowledge frameworks” sections of the TOK guide. Students should be encouraged to raise and discuss such knowledge questions in both their science and TOK classes.

Aims

Group 4 aims

Through studying biology, chemistry or physics, 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 characterizes these subjects.

The aims enable students, through the overarching theme of the Nature of science, to:

1. appreciate scientific study and creativity within a global context through stimulating and challenging opportunities
2. acquire a body of knowledge, methods and techniques that characterize science and technology
3. 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. develop a critical awareness of the need for, and the value of, effective collaboration and communication during scientific activities
6. develop experimental and investigative scientific skills including the use of current technologies
7. develop and apply 21st century communication skills in the study of science
8. become critically aware, as global citizens, of the ethical implications of using science and technology
9. develop an appreciation of the possibilities and limitations of science and technology
10. develop an understanding of the relationships between scientific disciplines and their influence on other areas of knowledge.

Assessment objectives

The assessment objectives for biology, chemistry and physics reflect those parts of the aims that will be formally assessed either internally or externally. These assessments will centre upon the nature of science. It is the intention of these courses that students are able to fulfill the following assessment objectives:

1. Demonstrate knowledge and understanding of:
   a. facts, concepts and terminology
   b. methodologies and techniques
   c. communicating scientific information.
2. Apply:
   a. facts, concepts and terminology
   b. methodologies and techniques
   c. methods of communicating scientific information.
3. Formulate, analyse and evaluate:
   a. hypotheses, research questions and predictions
   b. methodologies and techniques
   c. primary and secondary data
   d. scientific explanations.
4. Demonstrate the appropriate research, experimental, and personal skills necessary to carry out insightful and ethical investigations.

Syllabus outline

Syllabus component	Teaching hours	
	SL	HL
Core	**95**	
1. Cell biology	15	
2. Molecular biology	21	
3. Genetics	15	
4. Ecology	12	
5. Evolution and biodiversity	12	
6. Human physiology	20	
Additional higher level (AHL)		**60**
7. Nucleic acids		9
8. Metabolism, cell respiration and photosynthesis		14
9. Plant biology		13
10. Genetics and evolution		8
11. Animal physiology		16
Option	**15**	**25**
A. Neurobiology and behaviour	15	25
B. Biotechnology and bioinformatics	15	25
C. Ecology and conservation	15	25
D. Human physiology	15	25
Practical scheme of work	**40**	**60**
Practical activities	20	40
Individual investigation (internal assessment–IA)	10	10
Group 4 project	10	10
Total teaching hours	**150**	**240**

The recommended teaching time is 240 hours to complete HL and 150 hours to complete SL courses as stated in the document *General regulations: Diploma Programme for students and their legal guardians* (2011) (page 4, Article 8.2).

Approaches to the teaching and learning of biology

Format of the syllabus

The format of the syllabus section of the group 4 guides is the same for physics, chemistry and biology. This new structure gives prominence and focus to the teaching and learning aspects.

Topics or options

Topics are numbered and options are indicated by a letter. For example, "Topic 4: Ecology", or "Option D: Human Physiology".

Sub-topics

Sub-topics are numbered as follows, "4.1: Species, communities and ecosystems". Further information and guidance about possible teaching times are contained in the teacher support materials.

Each sub-topic begins with an essential idea. The essential idea is an enduring interpretation that is considered part of the public understanding of science. This is followed by a section on the "Nature of science". This gives specific examples in context illustrating some aspects of the nature of science. These are linked directly to specific references in the "Nature of science" section of the guide to support teachers in their understanding of the general theme to be addressed.

Under the overarching Nature of science theme there are two columns. The first column lists "Understandings", which are the main general ideas to be taught. There follows an "Applications and skills" section that outlines the specific applications and skills to be developed from the understandings. A "Guidance" section gives information about the limits and constraints and the depth of treatment required for teachers and examiners. The contents of the "Nature of science" section above the two columns and contents of the first column are all legitimate items for assessment. In addition, some assessment of international-mindedness in science, from the content of the second column, will take place as in the previous course.

The second column gives suggestion to teachers about relevant references to international-mindedness. It also gives examples of TOK knowledge questions (see *Theory of knowledge* guide published 2013) that can be used to focus students' thoughts on the preparation of the TOK prescribed essay. The "Utilization" section may link the sub-topic to other parts of the subject syllabus, to other Diploma Programme subject guides or to real-world applications. Finally, the "Aims" section refers to how specific group 4 aims are being addressed in the sub-topic.

Format of the guide

Topic 1: <Title>

Essential idea: This lists the essential idea for each sub-topic.

<table>
<tr><th colspan="2">1.1 Sub-topic</th></tr>
<tr><td colspan="2">Nature of science: Relates the sub-topic to the overarching theme of Nature of science.</td></tr>
<tr><td>Understandings:
• This section will provide specifics of the content requirements for each sub-topic.
Applications and skills:
• The content of this section gives details of how students are to apply the understandings. For example, these applications could involve demonstrating mathematical calculations or practical skills.
Guidance:
• This section will provide specifics and give constraints to the requirements for the understandings and applications and skills.</td><td>International-mindedness:
• Ideas that teachers can easily integrate into the delivery of their lessons.
Theory of knowledge:
• Examples of TOK knowledge questions.
Utilization:
• Links to other topics within the Biology guide, to a variety of real-world applications and to other Diploma Programme courses.
Aims:
• Links to the group 4 subject aims.</td></tr>
</table>

Group 4 experimental skills

I hear and I forget. I see and I remember. I do and I understand.

Confucius

Integral to the experience of students in any of the group 4 courses is their experience in the classroom, laboratory or in the field. Practical activities allow students to interact directly with natural phenomena and secondary data sources. These experiences provide the students with the opportunity to design investigations, collect data, develop manipulative skills, analyse results, collaborate with peers and evaluate and communicate their findings. Experiments can be used to introduce a topic, investigate a phenomenon or allow students to consider and examine questions and curiosities.

By providing students with the opportunity for hands-on experimentation, they are carrying out some of the same processes that scientists undertake. Experimentation allows students to experience the nature of scientific thought and investigation. All scientific theories and laws begin with observations.

It is important that students are involved in an inquiry-based practical programme that allows for the development of scientific inquiry. It is not enough for students just to be able to follow directions and to simply replicate a given experimental procedure; they must be provided with the opportunities for genuine inquiry. Developing scientific inquiry skills will give students the ability to construct an explanation based on reliable evidence and logical reasoning. Once developed, these higher-order thinking skills will enable students to be lifelong learners and scientifically literate.

A school's practical scheme of work should allow students to experience the full breadth and depth of the course including the option. This practical scheme of work must also prepare students to undertake the independent investigation that is required for the internal assessment. The development of students' manipulative skills should involve them being able to follow instructions accurately and demonstrate the safe, competent and methodical use of a range of techniques and equipment.

The "Applications and skills" section of the syllabus lists specific lab skills, techniques and experiments that students must experience at some point during their study of their group 4 course. Other recommended lab skills, techniques and experiments are listed in the "Aims" section of the subject-specific syllabus pages. Aim 6 of the group 4 subjects directly relates to the development of experimental and investigative skills.

Mathematical requirements

All Diploma Programme biology students should be able to:

- perform the basic arithmetic functions: addition, subtraction, multiplication and division
- carry out calculations involving means, decimals, fractions, percentages and ratios
- represent and interpret frequency data in the form of bar charts, graphs and histograms, including direct and inverse proportion
- plot 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
- determine the mode and median of a set of data, calculate and analyse standard deviation
- select statistical tests appropriate for the analysis of particular data and interpret the results.

Use of information communication technology

The use of information communication technology (ICT) is encouraged throughout all aspects of the course in relation to both the practical programme and day-to-day classroom activities. Teachers should make use of the ICT pages of the teacher support materials.

Planning your course

The syllabus as provided in the subject guide is not intended to be a teaching order. Instead it provides detail of what must be covered by the end of the course. A school should develop a scheme of work that best works for its students. For example, the scheme of work could be developed to match available resources, to take into account student prior learning and experience, or in conjunction with other local requirements.

HL teachers may choose to teach the core and AHL topics at the same time or teach them in a spiral fashion, by teaching the core topics in year one of the course and revisiting the core topics through the delivery of the AHL topics in year two of the course. The option topic could be taught as a stand-alone topic or could be integrated into the teaching of the core and/or AHL topics.

However the course is planned, adequate time must be provided for examination revision. Time must also be given for students to reflect on their learning experience and their growth as learners.

The IB learner profile

The biology course is closely linked to the IB learner profile. By following the course, students will have engaged with the attributes of the IB learner profile. For example, the requirements of the internal assessment provide opportunities for students to develop every aspect of the profile. For each attribute of the learner profile, a number of references from the Group 4 courses are given below.

Learner profile attribute	Biology, chemistry and physics
Inquirers	Aims 2 and 6 Practical work and internal assessment
Knowledgeable	Aims 1 and 10, international-mindedness links Practical work and internal assessment
Thinkers	Aims 3 and 4, theory of knowledge links Practical work and internal assessment
Communicators	Aims 5 and 7, external assessment Practical work and internal assessment
Principled	Aims 8 and 9 Practical work and internal assessment. Ethical behaviour/practice (*Ethical practice in the Diploma Programme* poster, *IB animal experimentation policy*), academic honesty
Open-minded	Aims 8 and 9, international-mindedness links Practical work and internal assessment, the group 4 project
Caring	Aims 8 and 9 Practical work and internal assessment, the group 4 project, ethical behaviour/ practice (*Ethical practice in the Diploma Programme* poster, *IB animal experimentation policy*)
Risk-takers	Aims 1 and 6 Practical work and internal assessment, the group 4 project
Balanced	Aims 8 and 10 Practical work and internal assessment, the group 4 project and field work
Reflective	Aims 5 and 9 Practical work and internal assessment, the group 4 project

Syllabus content

	Recommended teaching hours
Core	**95 hours**
Topic 1: Cell biology	**15**
1.1 Introduction to cells	
1.2 Ultrastructure of cells	
1.3 Membrane structure	
1.4 Membrane transport	
1.5 The origin of cells	
1.6 Cell division	
Topic 2: Molecular biology	**21**
2.1 Molecules to metabolism	
2.2 Water	
2.3 Carbohydrates and lipids	
2.4 Proteins	
2.5 Enzymes	
2.6 Structure of DNA and RNA	
2.7 DNA replication, transcription and translation	
2.8 Cell respiration	
2.9 Photosynthesis	
Topic 3: Genetics	**15**
3.1 Genes	
3.2 Chromosomes	
3.3 Meiosis	
3.4 Inheritance	
3.5 Genetic modification and biotechnology	

	Recommended teaching hours
Topic 4: Ecology	**12**
4.1 Species, communities and ecosystems	
4.2 Energy flow	
4.3 Carbon cycling	
4.4 Climate change	
Topic 5: Evolution and biodiversity	**12**
5.1 Evidence for evolution	
5.2 Natural selection	
5.3 Classification of biodiversity	
5.4 Cladistics	
Topic 6: Human physiology	**20**
6.1 Digestion and absorption	
6.2 The blood system	
6.3 Defence against infectious disease	
6.4 Gas exchange	
6.5 Neurons and synapses	
6.6 Hormones, homeostasis and reproduction	
Additional higher level (AHL)	**60 hours**
Topic 7: Nucleic acids	**9**
7.1 DNA structure and replication	
7.2 Transcription and gene expression	
7.3 Translation	
Topic 8: Metabolism, cell respiration and photosynthesis	**14**
8.1 Metabolism	
8.2 Cell respiration	
8.3 Photosynthesis	
Topic 9: Plant biology	**13**
9.1 Transport in the xylem of plants	
9.2 Transport in the phloem of plants	

	Recommended teaching hours
9.3 Growth in plants	
9.4 Reproduction in plants	
Topic 10: Genetics and evolution	**8**
10.1 Meiosis	
10.2 Inheritance	
10.3 Gene pools and speciation	
Topic 11: Animal physiology	**16**
11.1 Antibody production and vaccination	
11.2 Movement	
11.3 The kidney and osmoregulation	
11.4 Sexual reproduction	

Options 15 hours (SL)/25 hours (HL)

A: Neurobiology and behaviour

Core topics

A.1 Neural development

A.2 The human brain

A.3 Perception of stimuli

Additional higher level topics

A.4 Innate and learned behaviour

A.5 Neuropharmacology

A.6 Ethology

B: Biotechnology and bioinformatics

Core topics

B.1 Microbiology: organisms in industry

B.2 Biotechnology in agriculture

B.3 Environmental protection

Additional higher level topics

B.4 Medicine

B.5 Bioinformatics

C: Ecology and conservation

Core topics

C.1 Species and communities

C.2 Communities and ecosystems

C.3 Impacts of humans on ecosystems

C.4 Conservation of biodiversity

Additional higher level topics

C.5 Population ecology

C.6 Nitrogen and phosphorus cycles

D: Human physiology

Core topics

D.1 Human nutrition

D.2 Digestion

D.3 Functions of the liver

D.4 The heart

Additional higher level topics

D.5 Hormones and metabolism

D.6 Transport of respiratory gases

Topic 1: Cell biology

15 hours

Essential idea: The evolution of multicellular organisms allowed cell specialization and cell replacement.

1.1 Introduction to cells

Nature of science:

Looking for trends and discrepancies—although most organisms conform to cell theory, there are exceptions. (3.1)

Ethical implications of research—research involving stem cells is growing in importance and raises ethical issues. (4.5)

Understandings:

- According to the cell theory, living organisms are composed of cells.
- Organisms consisting of only one cell carry out all functions of life in that cell.
- Surface area to volume ratio is important in the limitation of cell size.
- Multicellular organisms have properties that emerge from the interaction of their cellular components.
- Specialized tissues can develop by cell differentiation in multicellular organisms.
- Differentiation involves the expression of some genes and not others in a cell's genome.
- The capacity of stem cells to divide and differentiate along different pathways is necessary in embryonic development and also makes stem cells suitable for therapeutic uses.

International-mindedness:

- Stem cell research has depended on the work of teams of scientists in many countries who share results thereby speeding up the rate of progress. However, national governments are influenced by local, cultural and religious traditions that impact on the work of scientists and the use of stem cells in therapy.

Theory of knowledge:

- There is a difference between the living and the non-living environment. How are we able to know the difference?

Utilization:

- The use of stem cells in the treatment of disease is mostly at the experimental stage, with the exception of bone marrow stem cells. Scientists, however, anticipate the use of stem cell therapies as a standard method of treating a whole range of diseases in the near future, including heart disease and diabetes.

1.1 Introduction to cells

Applications and skills:

- Application: Questioning the cell theory using atypical examples, including striated muscle, giant algae and aseptate fungal hyphae.
- Application: Investigation of functions of life in *Paramecium* and one named photosynthetic unicellular organism.
- Application: Use of stem cells to treat Stargardt's disease and one other named condition.
- Application: Ethics of the therapeutic use of stem cells from specially created embryos, from the umbilical cord blood of a new-born baby and from an adult's own tissues.
- Skill: Use of a light microscope to investigate the structure of cells and tissues, with drawing of cells. Calculation of the magnification of drawings and the actual size of structures and ultrastructures shown in drawings or micrographs. (Practical 1)

Guidance:

- Students are expected to be able to name and briefly explain these functions of life: nutrition, metabolism, growth, response, excretion, homeostasis and reproduction.
- *Chlorella* or *Scenedesmus* are suitable photosynthetic unicells, but *Euglena* should be avoided as it can feed heterotrophically.
- Scale bars are useful as a way of indicating actual sizes in drawings and micrographs.

Aims:

- **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.

Essential idea: Eukaryotes have a much more complex cell structure than prokaryotes.

1.2 Ultrastructure of cells

Nature of science:

Developments in scientific research follow improvements in apparatus—the invention of electron microscopes led to greater understanding of cell structure. (1.8)

Understandings:

- Prokaryotes have a simple cell structure without compartmentalization.
- Eukaryotes have a compartmentalized cell structure.
- Electron microscopes have a much higher resolution than light microscopes.

Applications and skills:

- Application: Structure and function of organelles within exocrine gland cells of the pancreas and within palisade mesophyll cells of the leaf.
- Application: Prokaryotes divide by binary fission.
- Skill: Drawing of the ultrastructure of prokaryotic cells based on electron micrographs.
- Skill: Drawing of the ultrastructure of eukaryotic cells based on electron micrographs.
- Skill: Interpretation of electron micrographs to identify organelles and deduce the function of specialized cells.

Guidance:

- Drawings of prokaryotic cells should show the cell wall, pili and flagella, and plasma membrane enclosing cytoplasm that contains 70S ribosomes and a nucleoid with naked DNA.
- Drawings of eukaryotic cells should show a plasma membrane enclosing cytoplasm that contains 80S ribosomes and a nucleus, mitochondria and other membrane-bound organelles are present in the cytoplasm. Some eukaryotic cells have a cell wall.

International-mindedness:

- Microscopes were invented simultaneously in different parts of the world at a time when information travelled slowly. Modern-day communications have allowed for improvements in the ability to collaborate, enriching scientific endeavour.

Theory of knowledge:

- The world that we inhabit is limited by the world that we see. Is there any distinction to be drawn between knowledge claims dependent upon observations made by sense perception and knowledge claims dependent upon observations assisted by technology?

Utilization:

Syllabus and cross-curricular links:
Physics
Topic 4.4 Wave behaviour
Topic C.1 Introduction to imaging
Topic C.3 Fibreoptics

Aims:

- **Aim 8:** Developments in science, such as electron microscopy, can have economic benefits as they give commercial companies opportunities to make profits, but this can affect cooperation between scientists.

Essential idea: The structure of biological membranes makes them fluid and dynamic.

1.3 Membrane structure

Nature of science:

Using models as representations of the real world—there are alternative models of membrane structure. (1.11)

Falsification of theories with one theory being superseded by another—evidence falsified the Davson-Danielli model. (1.9)

Understandings:

- Phospholipids form bilayers in water due to the amphipathic properties of phospholipid molecules.
- Membrane proteins are diverse in terms of structure, position in the membrane and function.
- Cholesterol is a component of animal cell membranes.

Applications and skills:

- Application: Cholesterol in mammalian membranes reduces membrane fluidity and permeability to some solutes.
- Skill: Drawing of the fluid mosaic model.
- Skill: Analysis of evidence from electron microscopy that led to the proposal of the Davson-Danielli model.
- Skill: Analysis of the falsification of the Davson-Danielli model that led to the Singer-Nicolson model.

Guidance:

- Amphipathic phospholipids have hydrophilic and hydrophobic properties.
- Drawings of the fluid mosaic model of membrane structure can be two dimensional rather than three dimensional. Individual phospholipid molecules should be shown using the symbol of a circle with two parallel lines attached. A range of membrane proteins should be shown including glycoproteins.

Theory of knowledge:

- The explanation of the structure of the plasma membrane has changed over the years as new evidence and ways of analysis have come to light. Under what circumstances is it important to learn about theories that were later discredited?

Utilization:

Syllabus and cross-curricular links:
Biology
Topic 2.3 Carbohydrates and lipids
Topic 2.6 Structure of DNA and RNA

Essential idea: Membranes control the composition of cells by active and passive transport.

1.4 Membrane transport

Nature of science:

Experimental design—accurate quantitative measurement in osmosis experiments are essential. (3.1)

Understandings:

- Particles move across membranes by simple diffusion, facilitated diffusion, osmosis and active transport.
- The fluidity of membranes allows materials to be taken into cells by endocytosis or released by exocytosis. Vesicles move materials within cells.

Applications and skills:

- Application: Structure and function of sodium–potassium pumps for active transport and potassium channels for facilitated diffusion in axons.
- Application: Tissues or organs to be used in medical procedures must be bathed in a solution with the same osmolarity as the cytoplasm to prevent osmosis.
- Skill: Estimation of osmolarity in tissues by bathing samples in hypotonic and hypertonic solutions. (Practical 2)

Guidance:

- Osmosis experiments are a useful opportunity to stress the need for accurate mass and volume measurements in scientific experiments.

Utilization:

- Kidney dialysis artificially mimics the function of the human kidney by using appropriate membranes and diffusion gradients.

Syllabus and cross-curricular links:
Biology
Topic 6.5 Neurons and synapses

Aims:

- **Aim 8:** Organ donation raises some interesting ethical issues, including the altruistic nature of organ donation and concerns about sale of human organs.
- **Aim 6:** Dialysis tubing experiments can act as a model of membrane action. Experiments with potato, beetroot or single-celled algae can be used to investigate real membranes.

Essential idea: There is an unbroken chain of life from the first cells on Earth to all cells in organisms alive today.

1.5 The origin of cells

Nature of science:

Testing the general principles that underlie the natural world—the principle that cells only come from pre-existing cells needs to be verified. (1.9)

Understandings:

- Cells can only be formed by division of pre-existing cells.
- The first cells must have arisen from non-living material.
- The origin of eukaryotic cells can be explained by the endosymbiotic theory.

Applications and skills:

- Application: Evidence from Pasteur's experiments that spontaneous generation of cells and organisms does not now occur on Earth.

Guidance:

- Evidence for the endosymbiotic theory is expected. The origin of eukaryote cilia and flagella does not need to be included.
- Students should be aware that the 64 codons in the genetic code have the same meanings in nearly all organisms, but that there are some minor variations that are likely to have accrued since the common origin of life on Earth.

Theory of knowledge:

- Biology is the study of life, yet life is an emergent property. Under what circumstances is a systems approach productive in biology and under what circumstances is a reductionist approach more appropriate? How do scientists decide between competing approaches?

Utilization:

Syllabus and cross-curricular links:
Biology
Topic 5.1 Evidence for evolution

Aims:

- **Aim 6:** Pasteur's experiment can be repeated using modern apparatus.

Essential idea: Cell division is essential but must be controlled.

1.6 Cell division

Nature of science:

Serendipity and scientific discoveries—the discovery of cyclins was accidental. (1.4)

Understandings:

- Mitosis is division of the nucleus into two genetically identical daughter nuclei.
- Chromosomes condense by supercoiling during mitosis.
- Cytokinesis occurs after mitosis and is different in plant and animal cells.
- Interphase is a very active phase of the cell cycle with many processes occurring in the nucleus and cytoplasm.
- Cyclins are involved in the control of the cell cycle.
- Mutagens, oncogenes and metastasis are involved in the development of primary and secondary tumours.

Applications and skills:

- Application: The correlation between smoking and incidence of cancers.
- Skill: Identification of phases of mitosis in cells viewed with a microscope or in a micrograph.
- Skill: Determination of a mitotic index from a micrograph.

Guidance:

- The sequence of events in the four phases of mitosis should be known.
- Preparation of temporary mounts of root squashes is recommended but phases in mitosis can also be viewed using permanent slides.
- To avoid confusion in terminology, teachers are encouraged to refer to the two parts of a chromosome as sister chromatids, while they are attached to each other by a centromere in the early stages of mitosis. From anaphase onwards, when sister chromatids have separated to form individual structures, they should be referred to as chromosomes.

International-mindedness:

- Biologists in laboratories throughout the world are researching into the causes and treatment of cancer.

Theory of knowledge:

- A number of scientific discoveries are claimed to be incidental or serendipitous. To what extent might some of these scientific discoveries be the result of intuition rather than luck?

Utilization:

- The mitotic index is an important prognostic tool for predicting the response of cancer cells to chemotherapy.

Aims:

- **Aim 8:** The tobacco industry could be discussed. Suppression of the results of research by tobacco companies into the health effects of smoking tobacco was unethical. Smoking causes considerable social harm, but, with the exception of laws on production and supply in Bhutan, has never been made illegal.

Topic 2: Molecular biology

21 hours

Essential idea: Living organisms control their composition by a complex web of chemical reactions.

2.1 Molecules to metabolism

Nature of science:

Falsification of theories—the artificial synthesis of urea helped to falsify vitalism. (1.9)

Understandings:	Utilization:
• Molecular biology explains living processes in terms of the chemical substances involved. • Carbon atoms can form four covalent bonds allowing a diversity of stable compounds to exist. • Life is based on carbon compounds including carbohydrates, lipids, proteins and nucleic acids. • Metabolism is the web of all the enzyme-catalysed reactions in a cell or organism. • Anabolism is the synthesis of complex molecules from simpler molecules including the formation of macromolecules from monomers by condensation reactions. • Catabolism is the breakdown of complex molecules into simpler molecules including the hydrolysis of macromolecules into monomers.	Syllabus and cross-curricular links: Chemistry Topic 4 Chemical bonding and structure Option B Biochemistry **Aims:** • **Aim 7:** ICT can be used for molecular visualization of carbohydrates, lipids and proteins in this sub-topic and in 2.3 and 2.4. • **Aim 6:** Food tests such as the use of iodine to identify starch or Benedict's reagent to identify reducing sugars could be carried out.

2.1 Molecules to metabolism

Applications and skills:

- Application: Urea as an example of a compound that is produced by living organisms but can also be artificially synthesized.
- Skill: Drawing molecular diagrams of glucose, ribose, a saturated fatty acid and a generalized amino acid.
- Skill: Identification of biochemicals such as sugars, lipids or amino acids from molecular diagrams.

Guidance:

- Only the ring forms of D-ribose, alpha–D-glucose and beta-D-glucose are expected in drawings.
- Sugars include monosaccharides and disaccharides.
- Only one saturated fat is expected and its specific name is not necessary.
- The variable radical of amino acids can be shown as R. The structure of individual R-groups does not need to be memorized.
- Students should be able to recognize from molecular diagrams that triglycerides, phospholipids and steroids are lipids. Drawings of steroids are not expected.
- Proteins or parts of polypeptides should be recognized from molecular diagrams showing amino acids linked by peptide bonds.

Essential idea: Water is the medium of life.

2.2 Water

Nature of science:

Use theories to explain natural phenomena—the theory that hydrogen bonds form between water molecules explains the properties of water. (2.2)

Understandings:

- Water molecules are polar and hydrogen bonds form between them.
- Hydrogen bonding and dipolarity explain the cohesive, adhesive, thermal and solvent properties of water.
- Substances can be hydrophilic or hydrophobic.

Applications and skills:

- Application: Comparison of the thermal properties of water with those of methane.
- Application: Use of water as a coolant in sweat.
- Application: Modes of transport of glucose, amino acids, cholesterol, fats, oxygen and sodium chloride in blood in relation to their solubility in water.

Guidance:

- Students should know at least one example of a benefit to living organisms of each property of water.
- Transparency of water and maximum density at 4°C do not need to be included.
- Comparison of the thermal properties of water and methane assists in the understanding of the significance of hydrogen bonding in water.

International-mindedness:

- There are challenges for the increasing human population in sharing water resources equitably for drinking and irrigation, electricity generation and a range of industrial and domestic processes.

Theory of knowledge:

- Claims about the “memory of water” have been categorized as pseudoscientific. What are the criteria that can be used to distinguish scientific claims from pseudoscientific claims?

Utilization:

Syllabus and cross-curricular links:
Biology
Topic 4.3 Carbon cycling
Topic 4.4 Climate change
Physics
Topic 3.1 Thermal concepts

Aims:

- **Aim 6:** Probes can be used to determine the effect of different factors likely to influence cooling with water.

Essential idea: Compounds of carbon, hydrogen and oxygen are used to supply and store energy.

2.3 Carbohydrates and lipids

Nature of science:

Evaluating claims—health claims made about lipids in diets need to be assessed. (5.2)

Understandings:

- Monosaccharide monomers are linked together by condensation reactions to form disaccharides and polysaccharide polymers.
- Fatty acids can be saturated, monounsaturated or polyunsaturated.
- Unsaturated fatty acids can be cis or trans isomers.
- Triglycerides are formed by condensation from three fatty acids and one glycerol.

Applications and skills:

- Application: Structure and function of cellulose and starch in plants and glycogen in humans.
- Application: Scientific evidence for health risks of trans fats and saturated fatty acids.
- Application: Lipids are more suitable for long-term energy storage in humans than carbohydrates.
- Application: Evaluation of evidence and the methods used to obtain the evidence for health claims made about lipids.
- Skill: Use of molecular visualization software to compare cellulose, starch and glycogen.
- Skill: Determination of body mass index by calculation or use of a nomogram.

Guidance:

- The structure of starch should include amylose and amylopectin.
- Named examples of fatty acids are not required.
- Sucrose, lactose and maltose should be included as examples of disaccharides produced by combining monosaccharides.

International-mindedness:

- Variation in the prevalence of different health problems around the world could be discussed including obesity, dietary energy deficiency, kwashiorkor, anorexia nervosa and coronary heart disease.

Theory of knowledge:

- There are conflicting views as to the harms and benefits of fats in diets. How do we decide between competing views?

Utilization:

- Potatoes have been genetically modified to reduce the level of amylose to produce a more effective adhesive.

Syllabus and cross-curricular links:
Biology
Option B: Biotechnology and bioinformatics

Aims:

- **Aim 8:** There are social implications of obesity.

Essential idea: Proteins have a very wide range of functions in living organisms.

2.4 Proteins

Nature of science:

Looking for patterns, trends and discrepancies—most but not all organisms assemble proteins from the same amino acids. (3.1)

Understandings:

- Amino acids are linked together by condensation to form polypeptides.
- There are 20 different amino acids in polypeptides synthesized on ribosomes.
- Amino acids can be linked together in any sequence giving a huge range of possible polypeptides.
- The amino acid sequence of polypeptides is coded for by genes.
- A protein may consist of a single polypeptide or more than one polypeptide linked together.
- The amino acid sequence determines the three-dimensional conformation of a protein.
- Living organisms synthesize many different proteins with a wide range of functions.
- Every individual has a unique proteome.

Applications and skills:

- Application: Rubisco, insulin, immunoglobulins, rhodopsin, collagen and spider silk as examples of the range of protein functions.
- Application: Denaturation of proteins by heat or by deviation of pH from the optimum.
- Skill: Drawing molecular diagrams to show the formation of a peptide bond.

Utilization:

- Proteomics and the production of proteins by cells cultured in fermenters offer many opportunities for the food, pharmaceutical and other industries.

Aims:

- **Aim 7:** ICT can be used for molecular visualization of the structure of proteins.
- **Aim 8:** Obtaining samples of human blood for immunological, pharmaceutical and anthropological studies is an international endeavour with many ethical issues.

2.4 Proteins	
Guidance: • The detailed structure of the six proteins selected to illustrate the functions of proteins is not needed. • Egg white or albumin solutions can be used in denaturation experiments. • Students should know that most organisms use the same 20 amino acids in the same genetic code although there are some exceptions. Specific examples could be used for illustration.	

Essential idea: Enzymes control the metabolism of the cell.

2.5 Enzymes

Nature of science:

Experimental design—accurate, quantitative measurements in enzyme experiments require replicates to ensure reliability. (3.2)

Understandings:

- Enzymes have an active site to which specific substrates bind.
- Enzyme catalysis involves molecular motion and the collision of substrates with the active site.
- Temperature, pH and substrate concentration affect the rate of activity of enzymes.
- Enzymes can be denatured.
- Immobilized enzymes are widely used in industry.

Applications and skills:

- Application: Methods of production of lactose-free milk and its advantages.
- Skill: Design of experiments to test the effect of temperature, pH and substrate concentration on the activity of enzymes.
- Skill: Experimental investigation of a factor affecting enzyme activity. (Practical 3)

Guidance:

- Lactase can be immobilized in alginate beads and experiments can then be carried out in which the lactose in milk is hydrolysed.
- Students should be able to sketch graphs to show the expected effects of temperature, pH and substrate concentration on the activity of enzymes. They should be able to explain the patterns or trends apparent in these graphs.

Theory of knowledge:

- Development of some techniques benefits particular human populations more than others. For example, the development of lactose-free milk available in Europe and North America would have greater benefit in Africa/Asia where lactose intolerance is more prevalent. The development of techniques requires financial investment. Should knowledge be shared when techniques developed in one part of the world are more applicable in another?

Utilization:

- Enzymes are extensively used in industry for the production of items from fruit juice to washing powder.

Syllabus and cross-curricular links:
Biology
Topic 8 AHL Metabolism, cell respiration and photosynthesis

Essential idea: The structure of DNA allows efficient storage of genetic information.

2.6 Structure of DNA and RNA

Nature of science:

Using models as representation of the real world—Crick and Watson used model making to discover the structure of DNA. (1.10)

Understandings:

- The nucleic acids DNA and RNA are polymers of nucleotides.
- DNA differs from RNA in the number of strands present, the base composition and the type of pentose.
- DNA is a double helix made of two antiparallel strands of nucleotides linked by hydrogen bonding between complementary base pairs.

Applications and skills:

- Application: Crick and Watson's elucidation of the structure of DNA using model making.
- Skill: Drawing simple diagrams of the structure of single nucleotides of DNA and RNA, using circles, pentagons and rectangles to represent phosphates, pentoses and bases.

Guidance:

- In diagrams of DNA structure, the helical shape does not need to be shown, but the two strands should be shown antiparallel. Adenine should be shown paired with thymine and guanine with cytosine, but the relative lengths of the purine and pyrimidine bases do not need to be recalled, nor the numbers of hydrogen bonds between the base pairs.

Theory of knowledge:

- 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 is research in secret 'anti-scientific'? What is the relationship between shared and personal knowledge in the natural sciences?

Utilization:

Syllabus and cross-curricular links:
Biology
Topic 2.2 Water
Topic 3.5 Genetic modification and biotechnology
Topic 7 Nucleic acids

Essential Idea: Genetic information in DNA can be accurately copied and can be translated to make the proteins needed by the cell.

2.7 DNA replication, transcription and translation

Nature of science:

Obtaining evidence for scientific theories—Meselson and Stahl obtained evidence for the semi-conservative replication of DNA. (1.8)

Understandings:

- The replication of DNA is semi-conservative and depends on complementary base pairing.
- Helicase unwinds the double helix and separates the two strands by breaking hydrogen bonds.
- DNA polymerase links nucleotides together to form a new strand, using the pre-existing strand as a template.
- Transcription is the synthesis of mRNA copied from the DNA base sequences by RNA polymerase.
- Translation is the synthesis of polypeptides on ribosomes.
- The amino acid sequence of polypeptides is determined by mRNA according to the genetic code.
- Codons of three bases on mRNA correspond to one amino acid in a polypeptide.
- Translation depends on complementary base pairing between codons on mRNA and anticodons on tRNA.

Applications and skills:

- Application: Use of Taq DNA polymerase to produce multiple copies of DNA rapidly by the polymerase chain reaction (PCR).
- Application: Production of human insulin in bacteria as an example of the universality of the genetic code allowing gene transfer between species.
- Skill: Use a table of the genetic code to deduce which codon(s) corresponds to which amino acid.

Utilization:

Syllabus and cross-curricular links:
Biology
Topic 3.5 Genetic modification and biotechnology
Topic 7.2 Transcription and gene expression
Topic 7.3 Translation

Aims:

- **Aim 8:** There are ethical implications in altering the genome of an organism in order to produce proteins for medical use in humans.

2.7 DNA replication, transcription and translation	
• Skill: Analysis of Meselson and Stahl's results to obtain support for the theory of semi-conservative replication of DNA. • Skill: Use a table of mRNA codons and their corresponding amino acids to deduce the sequence of amino acids coded by a short mRNA strand of known base sequence. • Skill: Deducing the DNA base sequence for the mRNA strand. **Guidance:** • The different types of DNA polymerase do not need to be distinguished.	

Essential idea: Cell respiration supplies energy for the functions of life.

2.8 Cell respiration	
Nature of science: Assessing the ethics of scientific research—the use of invertebrates in respirometer experiments has ethical implications. (4.5)	
Understandings: • Cell respiration is the controlled release of energy from organic compounds to produce ATP. • ATP from cell respiration is immediately available as a source of energy in the cell. • Anaerobic cell respiration gives a small yield of ATP from glucose. • Aerobic cell respiration requires oxygen and gives a large yield of ATP from glucose. **Applications and skills:** • Application: Use of anaerobic cell respiration in yeasts to produce ethanol and carbon dioxide in baking. • Application: Lactate production in humans when anaerobic respiration is used to maximize the power of muscle contractions. • Skill: Analysis of results from experiments involving measurement of respiration rates in germinating seeds or invertebrates using a respirometer. **Guidance:** • Details of the metabolic pathways of cell respiration are not needed but the substrates and final waste products should be known. • There are many simple respirometers which could be used. Students are expected to know that an alkali is used to absorb CO_2, so reductions in volume are due to oxygen use. Temperature should be kept constant to avoid volume changes due to temperature fluctuations.	**Aims:** • **Aim 8**: The ethics of the use of animals in experiments could be discussed in relation to respirometer experiments. Large-scale use of food plants for biofuels and the resulting impact on food prices has ethical implications.

Essential idea: Photosynthesis uses the energy in sunlight to produce the chemical energy needed for life.

2.9 Photosynthesis

Nature of science:

Experimental design—controlling relevant variables in photosynthesis experiments is essential. (3.1)

Understandings:

- Photosynthesis is the production of carbon compounds in cells using light energy.
- Visible light has a range of wavelengths with violet the shortest wavelength and red the longest.
- Chlorophyll absorbs red and blue light most effectively and reflects green light more than other colours.
- Oxygen is produced in photosynthesis from the photolysis of water.
- Energy is needed to produce carbohydrates and other carbon compounds from carbon dioxide.
- Temperature, light intensity and carbon dioxide concentration are possible limiting factors on the rate of photosynthesis.

Applications and skills:

- Application: Changes to the Earth's atmosphere, oceans and rock deposition due to photosynthesis.
- Skill: Drawing an absorption spectrum for chlorophyll and an action spectrum for photosynthesis.
- Skill: Design of experiments to investigate the effect of limiting factors on photosynthesis.
- Skill: Separation of photosynthetic pigments by chromatograph. (Practical 4)

Utilization:

Syllabus and cross-curricular links:
Biology
Topic 2.5 Enzymes

2.9 Photosynthesis	
Guidance: • Students should know that visible light has wavelengths between 400 and 700 nanometres, but they are not expected to recall the wavelengths of specific colours of light. • Water free of dissolved carbon dioxide for photosynthesis experiments can be produced by boiling and cooling water. • Paper chromatography can be used to separate photosynthetic pigments but thin layer chromatography gives better results.	

Topic 3: Genetics

15 hours

Essential idea: Every living organism inherits a blueprint for life from its parents.

3.1 Genes

Nature of science:

Developments in scientific research follow improvements in technology—gene sequencers are used for the sequencing of genes. (1.8)

Understandings:

- A gene is a heritable factor that consists of a length of DNA and influences a specific characteristic.
- A gene occupies a specific position on a chromosome.
- The various specific forms of a gene are alleles.
- Alleles differ from each other by one or only a few bases.
- New alleles are formed by mutation.
- The genome is the whole of the genetic information of an organism.
- The entire base sequence of human genes was sequenced in the Human Genome Project.

Applications and skills:

- Application: The causes of sickle cell anemia, including a base substitution mutation, a change to the base sequence of mRNA transcribed from it and a change to the sequence of a polypeptide in hemoglobin.
- Application: Comparison of the number of genes in humans with other species.
- Skill: Use of a database to determine differences in the base sequence of a gene in two species.

International-mindedness:

- Sequencing of the human genome shows that all humans share the vast majority of their base sequences but also that there are many single nucleotide polymorphisms that contribute to human diversity.

Theory of knowledge:

- There is a link between sickle cell anemia and prevalence of malaria. How can we know whether there is a causal link in such cases or simply a correlation?

Aims:

- **Aim 7:** The use of a database to compare DNA base sequences.
- **Aim 8:** Ethics of patenting human genes.

3.1 Genes	
Guidance: • Students should be able to recall one specific base substitution that causes glutamic acid to be substituted by valine as the sixth amino acid in the hemoglobin polypeptide. • The number of genes in a species should not be referred to as genome size as this term is used for the total amount of DNA. At least one plant and one bacterium should be included in the comparison and at least one species with more genes and one with fewer genes than a human. • The Genbank® database can be used to search for DNA base sequences. The cytochrome C gene sequence is available for many different organisms and is of particular interest because of its use in reclassifying organisms into three domains. • Deletions, insertions and frame shift mutations do not need to be included.	

Essential idea: Chromosomes carry genes in a linear sequence that is shared by members of a species.

3.2 Chromosomes

Nature of science:

Developments in research follow improvements in techniques—autoradiography was used to establish the length of DNA molecules in chromosomes. (1.8)

Understandings:

- Prokaryotes have one chromosome consisting of a circular DNA molecule.
- Some prokaryotes also have plasmids but eukaryotes do not.
- Eukaryote chromosomes are linear DNA molecules associated with histone proteins.
- In a eukaryote species there are different chromosomes that carry different genes.
- Homologous chromosomes carry the same sequence of genes but not necessarily the same alleles of those genes.
- Diploid nuclei have pairs of homologous chromosomes.
- Haploid nuclei have one chromosome of each pair.
- The number of chromosomes is a characteristic feature of members of a species.
- A karyogram shows the chromosomes of an organism in homologous pairs of decreasing length.
- Sex is determined by sex chromosomes and autosomes are chromosomes that do not determine sex.

Applications and skills:

- Application: Cairns' technique for measuring the length of DNA molecules by autoradiography.
- Application: Comparison of genome size in T2 phage, *Escherichia coli*, *Drosophila melanogaster*, *Homo sapiens* and *Paris japonica*.

International-mindedness:

- Sequencing of the rice genome involved cooperation between biologists in 10 countries.

Utilization:

Syllabus and cross-curricular links:
Biology
Topic 1.6 Cell division

Aims:

- **Aim 6:** Staining root tip squashes and microscope examination of chromosomes is recommended but not obligatory.
- **Aim 7:** Use of databases to identify gene loci and protein products of genes.

3.2 Chromosomes

- Application: Comparison of diploid chromosome numbers of *Homo sapiens*, *Pan troglodytes*, *Canis familiaris*, *Oryza sativa*, *Parascaris equorum*.
- Application: Use of karyograms to deduce sex and diagnose Down syndrome in humans.
- Skill: Use of databases to identify the locus of a human gene and its polypeptide product.

Guidance:

- The terms karyotype and karyogram have different meanings. Karyotype is a property of a cell—the number and type of chromosomes present in the nucleus, not a photograph or diagram of them.
- Genome size is the total length of DNA in an organism. The examples of genome and chromosome number have been selected to allow points of interest to be raised.
- The two DNA molecules formed by DNA replication prior to cell division are considered to be sister chromatids until the splitting of the centromere at the start of anaphase. After this, they are individual chromosomes.

Essential idea: Alleles segregate during meiosis allowing new combinations to be formed by the fusion of gametes.

3.3 Meiosis	
Nature of science: Making careful observations—meiosis was discovered by microscope examination of dividing germ-line cells. (1.8)	
Understandings: • One diploid nucleus divides by meiosis to produce four haploid nuclei. • The halving of the chromosome number allows a sexual life cycle with fusion of gametes. • DNA is replicated before meiosis so that all chromosomes consist of two sister chromatids. • The early stages of meiosis involve pairing of homologous chromosomes and crossing over followed by condensation. • Orientation of pairs of homologous chromosomes prior to separation is random. • Separation of pairs of homologous chromosomes in the first division of meiosis halves the chromosome number. • Crossing over and random orientation promotes genetic variation. • Fusion of gametes from different parents promotes genetic variation. **Applications and skills:** • Application: Non-disjunction can cause Down syndrome and other chromosome abnormalities. • Application: Studies showing age of parents influences chances of non-disjunction.	**Theory of knowledge:** • In 1922 the number of chromosomes counted in a human cell was 48. This remained the established number for 30 years, even though a review of photographic evidence from the time clearly showed that there were 46. For what reasons do existing beliefs carry a certain inertia? **Utilization:** • An understanding of karyotypes has allowed diagnoses to be made for the purposes of genetic counselling. Syllabus and cross-curricular links: Biology Topic 1.6 Cell division Topic 10.1 Meiosis Topic 11.4 Sexual reproduction **Aims:** • **Aim 8:** Pre-natal screening for chromosome abnormalities gives an indication of the sex of the fetus and raises ethical issues over selective abortion of female fetuses in some countries.

3.3 Meiosis	
• Application: Description of methods used to obtain cells for karyotype analysis e.g. chorionic villus sampling and amniocentesis and the associated risks. • Skill: Drawing diagrams to show the stages of meiosis resulting in the formation of four haploid cells. **Guidance:** • Preparation of microscope slides showing meiosis is challenging and permanent slides should be available in case no cells in meiosis are visible in temporary mounts. • Drawings of the stages of meiosis do not need to include chiasmata. • The process of chiasmata formation need not be explained.	

Essential idea: The inheritance of genes follows patterns.

3.4 Inheritance

Nature of science:

Making quantitative measurements with replicates to ensure reliability. Mendel's genetic crosses with pea plants generated numerical data. (3.2)

Understandings:

- Mendel discovered the principles of inheritance with experiments in which large numbers of pea plants were crossed.
- Gametes are haploid so contain only one allele of each gene.
- The two alleles of each gene separate into different haploid daughter nuclei during meiosis.
- Fusion of gametes results in diploid zygotes with two alleles of each gene that may be the same allele or different alleles.
- Dominant alleles mask the effects of recessive alleles but co-dominant alleles have joint effects.
- Many genetic diseases in humans are due to recessive alleles of autosomal genes, although some genetic diseases are due to dominant or co-dominant alleles.
- Some genetic diseases are sex-linked. The pattern of inheritance is different with sex-linked genes due to their location on sex chromosomes.
- Many genetic diseases have been identified in humans but most are very rare.
- Radiation and mutagenic chemicals increase the mutation rate and can cause genetic diseases and cancer.

Theory of knowledge:

- Mendel's theories were not accepted by the scientific community for a long time. What factors would encourage the acceptance of new ideas by the scientific community?

Utilization:

Syllabus and cross-curricular links:
Biology
Topic 1.6 Cell division

Aims:

- **Aim 8:** Social implications of diagnosis of mutations, including the effects on the family and stigmatization.

3.4 Inheritance

Applications and skills:

- Application: Inheritance of ABO blood groups.
- Application: Red-green colour blindness and hemophilia as examples of sex-linked inheritance.
- Application: Inheritance of cystic fibrosis and Huntington's disease.
- Application: Consequences of radiation after nuclear bombing of Hiroshima and accident at Chernobyl.
- Skill: Construction of Punnett grids for predicting the outcomes of monohybrid genetic crosses.
- Skill: Comparison of predicted and actual outcomes of genetic crosses using real data.
- Skill: Analysis of pedigree charts to deduce the pattern of inheritance of genetic diseases.

Guidance:

- Alleles carried on X chromosomes should be shown as superscript letters on an upper case X, such as X^h.
- The expected notation for ABO blood group alleles is:

Phenotype		*Genotype*	
	O		ii
	A		I^AI^A or I^Ai
	B		I^BI^B or I^Bi
	AB		I^AI^B

Essential idea: Biologists have developed techniques for artificial manipulation of DNA, cells and organisms.

3.5 Genetic modification and biotechnology

Nature of science:

Assessing risks associated with scientific research—scientists attempt to assess the risks associated with genetically modified crops or livestock. (4.8)

Understandings:

- Gel electrophoresis is used to separate proteins or fragments of DNA according to size.
- PCR can be used to amplify small amounts of DNA.
- DNA profiling involves comparison of DNA.
- Genetic modification is carried out by gene transfer between species.
- Clones are groups of genetically identical organisms, derived from a single original parent cell.
- Many plant species and some animal species have natural methods of cloning.
- Animals can be cloned at the embryo stage by breaking up the embryo into more than one group of cells.
- Methods have been developed for cloning adult animals using differentiated cells.

Applications and skills:

- Application: Use of DNA profiling in paternity and forensic investigations.
- Application: Gene transfer to bacteria using plasmids makes use of restriction endonucleases and DNA ligase.
- Application: Assessment of the potential risks and benefits associated with genetic modification of crops.
- Application: Production of cloned embryos produced by somatic-cell nuclear transfer.

Theory of knowledge:

- The use of DNA for securing convictions in legal cases is well established, yet even universally accepted theories are overturned in the light of new evidence in science. What criteria are necessary for assessing the reliability of evidence?

Utilization:

Syllabus and cross-curricular links:
Biology
Topic 2.7 DNA replication, transcription and translation

Aims:

- **Aim 6:** The design of a rooting experiment should ideally lead to the experiment actually being carried out by students.
- **Aim 8:** The ethics of genetic modification could be discussed.

3.5 Genetic modification and biotechnology

- Skill: Design of an experiment to assess one factor affecting the rooting of stem-cuttings.
- Skill: Analysis of examples of DNA profiles.
- Skill: Analysis of data on risks to monarch butterflies of Bt crops.

Guidance:

- Students should be able to deduce whether or not a man could be the father of a child from the pattern of bands on a DNA profile.
- Dolly can be used as an example of somatic-cell transfer.
- A plant species should be chosen for rooting experiments that forms roots readily in water or a solid medium.

Topic 4: Ecology

12 hours

Essential idea: The continued survival of living organisms including humans depends on sustainable communities.

4.1 Species, communities and ecosystems

Nature of science:

Looking for patterns, trends and discrepancies—plants and algae are mostly autotrophic but some are not. (3.1)

Understandings:

- Species are groups of organisms that can potentially interbreed to produce fertile offspring.
- Members of a species may be reproductively isolated in separate populations.
- Species have either an autotrophic or heterotrophic method of nutrition (a few species have both methods).
- Consumers are heterotrophs that feed on living organisms by ingestion.
- Detritivores are heterotrophs that obtain organic nutrients from detritus by internal digestion.
- Saprotrophs are heterotrophs that obtain organic nutrients from dead organisms by external digestion.
- A community is formed by populations of different species living together and interacting with each other.
- A community forms an ecosystem by its interactions with the abiotic environment.
- Autotrophs obtain inorganic nutrients from the abiotic environment.
- The supply of inorganic nutrients is maintained by nutrient cycling.
- Ecosystems have the potential to be sustainable over long periods of time.

International-mindedness:

- The need for sustainability in human activities could be discussed and the methods needed to promote this.

Utilization:

Syllabus and cross-curricular links:
Geography
Part 2A: Fresh water-issues and conflicts
Environmental systems and societies
Topic 2.1 Species and populations

Aims:

- **Aim 6:** It would be best for students to obtain data for the chi-squared test themselves, to give first-hand experience of field work techniques.

4.1 Species, communities and ecosystems

Applications and skills:

- Skill: Classifying species as autotrophs, consumers, detritivores or saprotrophs from a knowledge of their mode of nutrition.
- Skill: Setting up sealed mesocosms to try to establish sustainability. (Practical 5)
- Skill: Testing for association between two species using the chi-squared test with data obtained by quadrat sampling.
- Skill: Recognizing and interpreting statistical significance.

Guidance:

- Mesocosms can be set up in open tanks, but sealed glass vessels are preferable because entry and exit of matter can be prevented but light can enter and heat can leave. Aquatic systems are likely to be more successful than terrestrial ones.
- To obtain data for the chi-squared test, an ecosystem should be chosen in which one or more factors affecting the distribution of the chosen species varies. Sampling should be based on random numbers. In each quadrat the presence or absence of the chosen species should be recorded.

Essential idea: Ecosystems require a continuous supply of energy to fuel life processes and to replace energy lost as heat.

4.2 Energy flow

Nature of science:

Use theories to explain natural phenomena—the concept of energy flow explains the limited length of food chains. (2.2)

Understandings:

- Most ecosystems rely on a supply of energy from sunlight.
- Light energy is converted to chemical energy in carbon compounds by photosynthesis.
- Chemical energy in carbon compounds flows through food chains by means of feeding.
- Energy released from carbon compounds by respiration is used in living organisms and converted to heat.
- Living organisms cannot convert heat to other forms of energy.
- Heat is lost from ecosystems.
- Energy losses between trophic levels restrict the length of food chains and the biomass of higher trophic levels.

Applications and skills:

- Skill: Quantitative representations of energy flow using pyramids of energy.

Guidance:

- Pyramids of number and biomass are not required. Students should be clear that biomass in terrestrial ecosystems diminishes with energy along food chains due to loss of carbon dioxide, water and other waste products, such as urea.

International-mindedness:

- The energetics of food chains is a factor in the efficiency of food production for the alleviation of world hunger.

Utilization:

Syllabus and cross-curricular links:
Biology
Topic 2.8 Cell respiration
Topic 2.9 Photosynthesis
Physics
Topic 2.3 Work, energy and power
Topic B.2 Thermodynamics
Environmental systems and societies
Topic 2.3 Flows of energy and matter

4.2 Energy flow	
• Pyramids of energy should be drawn to scale and should be stepped, not triangular. The terms producer, first consumer and second consumer and so on should be used, rather than first trophic level, second trophic level and so on. • The distinction between energy flow in ecosystems and cycling of inorganic nutrients should be stressed. Students should understand that there is a continuous but variable supply of energy in the form of sunlight but that the supply of nutrients in an ecosystem is finite and limited.	

Essential idea: Continued availability of carbon in ecosystems depends on carbon cycling.

4.3 Carbon cycling

Nature of science:

Making accurate, quantitative measurements—it is important to obtain reliable data on the concentration of carbon dioxide and methane in the atmosphere. (3.1)

Understandings:	Utilization:
• Autotrophs convert carbon dioxide into carbohydrates and other carbon compounds. • In aquatic ecosystems carbon is present as dissolved carbon dioxide and hydrogencarbonate ions. • Carbon dioxide diffuses from the atmosphere or water into autotrophs. • Carbon dioxide is produced by respiration and diffuses out of organisms into water or the atmosphere. • Methane is produced from organic matter in anaerobic conditions by methanogenic archaeans and some diffuses into the atmosphere or accumulates in the ground. • Methane is oxidized to carbon dioxide and water in the atmosphere. • Peat forms when organic matter is not fully decomposed because of acidic and/or anaerobic conditions in waterlogged soils. • Partially decomposed organic matter from past geological eras was converted either into coal or into oil and gas that accumulate in porous rocks. • Carbon dioxide is produced by the combustion of biomass and fossilized organic matter. • Animals such as reef-building corals and mollusca have hard parts that are composed of calcium carbonate and can become fossilized in limestone.	Syllabus and cross-curricular links: Physics Topic 8.1 Energy sources Chemistry Topic C.2 Fossil fuels Topic C.5 Environmental impact—global warming **Aims:** • **Aim 8:** The ethical implications of diverting crops such as maize from a food to a fuel crop could be considered.

4.3 Carbon cycling	
Applications and skills: • Application: Estimation of carbon fluxes due to processes in the carbon cycle. • Application: Analysis of data from air monitoring stations to explain annual fluctuations. • Skill: Construct a diagram of the carbon cycle. **Guidance:** • Carbon fluxes should be measured in gigatonnes.	

Essential idea: Concentrations of gases in the atmosphere affect climates experienced at the Earth's surface.

4.4 Climate change

Nature of science:

Assessing claims—assessment of the claims that human activities are producing climate change. (5.2)

Understandings:

- Carbon dioxide and water vapour are the most significant greenhouse gases.
- Other gases including methane and nitrogen oxides have less impact.
- The impact of a gas depends on its ability to absorb long wave radiation as well as on its concentration in the atmosphere.
- The warmed Earth emits longer wavelength radiation (heat).
- Longer wave radiation is absorbed by greenhouse gases that retain the heat in the atmosphere.
- Global temperatures and climate patterns are influenced by concentrations of greenhouse gases.
- There is a correlation between rising atmospheric concentrations of carbon dioxide since the start of the industrial revolution 200 years ago and average global temperatures.
- Recent increases in atmospheric carbon dioxide are largely due to increases in the combustion of fossilized organic matter.

Applications and skills:

- Application: Threats to coral reefs from increasing concentrations of dissolved carbon dioxide.
- Application: Correlations between global temperatures and carbon dioxide concentrations on Earth.
- Application: Evaluating claims that human activities are not causing climate change.

International-mindedness:

- Release of greenhouse gases occurs locally but has a global impact, so international cooperation to reduce emissions is essential.

Theory of knowledge:

- The precautionary principle is meant to guide decision-making in conditions where a lack of certainty exists. Is certainty ever possible in the natural sciences?

Utilization:

Syllabus and cross-curricular links:
Physics
Topic 8.2 Thermal energy transfer
Geography
Part 1.3 Patterns in environmental quality and sustainability/Atmosphere and change
Environmental systems and societies
Topic 7.2 Climate change—causes and impacts

Aims:

- **Aim 7:** Databases can be used to analyse concentrations of greenhouse gases.
- **Aim 8:** There are interesting parallels between humans that are unwilling to reduce their carbon footprint and cheating in social animals. When the level of cheating rises above a certain level, social behaviour breaks down.

4.4 Climate change	
Guidance: • Carbon dioxide, methane and water vapour should be included in discussions. • The harmful consequences of ozone depletion do not need to be discussed and it should be made clear that ozone depletion is not the cause of the enhanced greenhouse effect.	

Topic 5: Evolution and biodiversity

12 hours

Essential idea: There is overwhelming evidence for the evolution of life on Earth.

5.1 Evidence for evolution

Nature of science:

Looking for patterns, trends and discrepancies—there are common features in the bone structure of vertebrate limbs despite their varied use. (3.1)

Understandings:

- Evolution occurs when heritable characteristics of a species change.
- The fossil record provides evidence for evolution.
- Selective breeding of domesticated animals shows that artificial selection can cause evolution.
- Evolution of homologous structures by adaptive radiation explains similarities in structure when there are differences in function.
- Populations of a species can gradually diverge into separate species by evolution.
- Continuous variation across the geographical range of related populations matches the concept of gradual divergence.

Applications and skills:

- Application: Development of melanistic insects in polluted areas.
- Application: Comparison of the pentadactyl limb of mammals, birds, amphibians and reptiles with different methods of locomotion.

Theory of knowledge:

- Evolutionary history is an especially challenging area of science because experiments cannot be performed to establish past events or their causes. There are nonetheless scientific methods of establishing beyond reasonable doubt what happened in some cases. How do these methods compare to those used by historians to reconstruct the past?

Utilization:

Syllabus and cross-curricular links:
Physics
Topic 7.1 Discrete energy and radioactivity
Geography
Part 1.3 Patterns in environmental quality and sustainability/Biodiversity and change
Environmental systems and societies
Topic 4 Biodiversity in ecosystems

Essential idea: The diversity of life has evolved and continues to evolve by natural selection.

5.2 Natural selection

Nature of science:

Use theories to explain natural phenomena—the theory of evolution by natural selection can explain the development of antibiotic resistance in bacteria. (2.1)

Understandings:

- Natural selection can only occur if there is variation among members of the same species.
- Mutation, meiosis and sexual reproduction cause variation between individuals in a species.
- Adaptations are characteristics that make an individual suited to its environment and way of life.
- Species tend to produce more offspring than the environment can support.
- Individuals that are better adapted tend to survive and produce more offspring while the less well adapted tend to die or produce fewer offspring.
- Individuals that reproduce pass on characteristics to their offspring.
- Natural selection increases the frequency of characteristics that make individuals better adapted and decreases the frequency of other characteristics leading to changes within the species.

Applications and skills:

- Application: Changes in beaks of finches on Daphne Major.
- Application: Evolution of antibiotic resistance in bacteria.

Guidance:

- Students should be clear that characteristics acquired during the lifetime of an individual are not heritable. The term Lamarckism is not required.

Theory of knowledge:

- Natural Selection is a theory. How much evidence is required to support a theory and what sort of counter evidence is required to refute it?

Essential idea: Species are named and classified using an internationally agreed system.

5.3 Classification of biodiversity

Nature of science:

Cooperation and collaboration between groups of scientists—scientists use the binomial system to identify a species rather than the many different local names. (4.3)

Understandings:

- The binomial system of names for species is universal among biologists and has been agreed and developed at a series of congresses.
- When species are discovered they are given scientific names using the binomial system.
- Taxonomists classify species using a hierarchy of taxa.
- All organisms are classified into three domains.
- The principal taxa for classifying eukaryotes are kingdom, phylum, class, order, family, genus and species.
- In a natural classification, the genus and accompanying higher taxa consist of all the species that have evolved from one common ancestral species.
- Taxonomists sometimes reclassify groups of species when new evidence shows that a previous taxon contains species that have evolved from different ancestral species.
- Natural classifications help in identification of species and allow the prediction of characteristics shared by species within a group.

Applications and skills:

- Application: Classification of one plant and one animal species from domain to species level.
- Application: Recognition features of bryophyta, filicinophyta, coniferophyta and angiospermophyta.

International-mindedness:

- There are international codes of nomenclature and agreements as to the principles to be followed in the classification of living organisms.

Theory of knowledge:

- 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?

5.3 Classification of biodiversity

- Application: Recognition features of porifera, cnidaria, platylhelmintha, annelida, mollusca, arthropoda and chordata.
- Application: Recognition of features of birds, mammals, amphibians, reptiles and fish.
- Skill: Construction of dichotomous keys for use in identifying specimens.

Guidance:

- Archaea, eubacteria and eukaryote should be used for the three domains.
- Members of these domains should be referred to as archaeans, bacteria and eukaryotes.
- Students should know which plant phyla have vascular tissue, but other internal details are not required.
- Recognition features expected for the selected animal phyla are those that are most useful in distinguishing the groups from each other and full descriptions of the characteristics of each phylum are not needed.
- Viruses are not classified as living organisms.

Essential idea: The ancestry of groups of species can be deduced by comparing their base or amino acid sequences.

5.4 Cladistics

Nature of science:

Falsification of theories with one theory being superseded by another—plant families have been reclassified as a result of evidence from cladistics. (1.9)

Understandings:

- A clade is a group of organisms that have evolved from a common ancestor.
- Evidence for which species are part of a clade can be obtained from the base sequences of a gene or the corresponding amino acid sequence of a protein.
- Sequence differences accumulate gradually so there is a positive correlation between the number of differences between two species and the time since they diverged from a common ancestor.
- Traits can be analogous or homologous.
- Cladograms are tree diagrams that show the most probable sequence of divergence in clades.
- Evidence from cladistics has shown that classifications of some groups based on structure did not correspond with the evolutionary origins of a group or species.

Applications and skills:

- Application: Cladograms including humans and other primates.
- Application: Reclassification of the figwort family using evidence from cladistics.
- Skill: Analysis of cladograms to deduce evolutionary relationships.

Theory of knowledge:

- A major step forward in the study of bacteria was the recognition in 1977 by Carl Woese that *Archaea* have a separate line of evolutionary descent from bacteria. Famous scientists, including Luria and Mayr, objected to his division of the prokaryotes. To what extent is conservatism in science desirable?

Topic 6: Human physiology

20 hours

Essential idea: The structure of the wall of the small intestine allows it to move, digest and absorb food.

6.1 Digestion and absorption

Nature of science:

Use models as representations of the real world—dialysis tubing can be used to model absorption in the intestine. (1.10)

Understandings:

- The contraction of circular and longitudinal muscle of the small intestine mixes the food with enzymes and moves it along the gut.
- The pancreas secretes enzymes into the lumen of the small intestine.
- Enzymes digest most macromolecules in food into monomers in the small intestine.
- Villi increase the surface area of epithelium over which absorption is carried out.
- Villi absorb monomers formed by digestion as well as mineral ions and vitamins.
- Different methods of membrane transport are required to absorb different nutrients.

Applications and skills:

- Application: Processes occurring in the small intestine that result in the digestion of starch and transport of the products of digestion to the liver.
- Application: Use of dialysis tubing to model absorption of digested food in the intestine.

Utilization:

- Some hydrolytic enzymes have economic importance, for example amylase in production of sugars from starch and in the brewing of beer.

Syllabus and cross-curricular links:
Biology
Topic 2.1 Molecules to metabolism
Topic 2.5 Enzymes

6.1 Digestion and absorption	
• Skill: Production of an annotated diagram of the digestive system. • Skill: Identification of tissue layers in transverse sections of the small intestine viewed with a microscope or in a micrograph. **Guidance:** • Students should know that amylase, lipase and an endopeptidase are secreted by the pancreas. The name trypsin and the method used to activate it are not required. • Students should know that starch, glycogen, lipids and nucleic acids are digested into monomers and that cellulose remains undigested. • Tissue layers should include longitudinal and circular muscles, mucosa and epithelium.	

Essential idea: The blood system continuously transports substances to cells and simultaneously collects waste products.

6.2 The blood system

Nature of science:

Theories are regarded as uncertain—William Harvey overturned theories developed by the ancient Greek philosopher Galen on movement of blood in the body. (1.9)

Understandings:

- Arteries convey blood at high pressure from the ventricles to the tissues of the body.
- Arteries have muscle cells and elastic fibres in their walls.
- The muscle and elastic fibres assist in maintaining blood pressure between pump cycles.
- Blood flows through tissues in capillaries. Capillaries have permeable walls that allow exchange of materials between cells in the tissue and the blood in the capillary.
- Veins collect blood at low pressure from the tissues of the body and return it to the atria of the heart.
- Valves in veins and the heart ensure circulation of blood by preventing backflow.
- There is a separate circulation for the lungs.
- The heart beat is initiated by a group of specialized muscle cells in the right atrium called the sinoatrial node.
- The sinoatrial node acts as a pacemaker.
- The sinoatrial node sends out an electrical signal that stimulates contraction as it is propagated through the walls of the atria and then the walls of the ventricles.
- The heart rate can be increased or decreased by impulses brought to the heart through two nerves from the medulla of the brain.
- Epinephrine increases the heart rate to prepare for vigorous physical activity.

Theory of knowledge:

- Our current understanding is that emotions are the product of activity in the brain rather than the heart. Is knowledge based on science more valid than knowledge based on intuition?

Utilization:

- Understanding of the structure of the cardiovascular system has allowed the development of heart surgery.

Syllabus and cross-curricular links:
Biology
Topic 2.2 Water
Topic 2.3 Carbohydrates and lipids
Topic 6.4 Gas exchange
Topic 6.6 Hormones, homeostasis and reproduction

Aims:

- **Aim 6:** A heart dissection is suggested as a means of studying heart structure.
- **Aim 8:** The social implications of coronary heart disease could be discussed.

6.2 The blood system	
Applications and skills: • Application: William Harvey's discovery of the circulation of the blood with the heart acting as the pump. • Application: Pressure changes in the left atrium, left ventricle and aorta during the cardiac cycle. • Application: Causes and consequences of occlusion of the coronary arteries. • Skill: Identification of blood vessels as arteries, capillaries or veins from the structure of their walls. • Skill: Recognition of the chambers and valves of the heart and the blood vessels connected to it in dissected hearts or in diagrams of heart structure.	

Essential idea: The human body has structures and processes that resist the continuous threat of invasion by pathogens.

6.3 Defence against infectious disease

Nature of science:

Risks associated with scientific research—Florey and Chain's tests on the safety of penicillin would not be compliant with current protocol on testing. (4.8)

Understandings:

- The skin and mucous membranes form a primary defence against pathogens that cause infectious disease.
- Cuts in the skin are sealed by blood clotting.
- Clotting factors are released from platelets.
- The cascade results in the rapid conversion of fibrinogen to fibrin by thrombin.
- Ingestion of pathogens by phagocytic white blood cells gives non-specific immunity to diseases.
- Production of antibodies by lymphocytes in response to particular pathogens gives specific immunity.
- Antibiotics block processes that occur in prokaryotic cells but not in eukaryotic cells.
- Viruses lack a metabolism and cannot therefore be treated with antibiotics. Some strains of bacteria have evolved with genes that confer resistance to antibiotics and some strains of bacteria have multiple resistance.

Applications and skills:

- Application: Causes and consequences of blood clot formation in coronary arteries.
- Application: Florey and Chain's experiments to test penicillin on bacterial infections in mice.
- Application: Effects of HIV on the immune system and methods of transmission.

International-mindedness:

- The spread and containment of diseases such as bird flu require international coordination and communication.

Utilization:

- An understanding of immunity has led to the development of vaccinations.

Syllabus and cross-curricular links:
Biology
Topic 5.2 Natural selection
Chemistry
Topic D2 Aspirin and penicillin

Aims:

- **Aim 8:** The social as well as the economic benefits of the control of bacterial diseases around the world should be stressed.
- **Aim 9:** Science has limited means in the fight against pathogens, as shown by the spread of new diseases and antibiotic-resistant bacteria.

6.3 Defence against infectious disease	
Guidance: • Diagrams of skin are not required. • Subgroups of phagocyte and lymphocyte are not required but students should be aware that some lymphocytes act as memory cells and can quickly reproduce to form a clone of plasma cells if a pathogen carrying a specific antigen is re-encountered. • The effects of HIV on the immune system should be limited to a reduction in the number of active lymphocytes and a loss of the ability to produce antibodies, leading to the development of AIDS.	

Essential idea: The lungs are actively ventilated to ensure that gas exchange can occur passively.

6.4 Gas exchange

Nature of science:

Obtain evidence for theories—epidemiological studies have contributed to our understanding of the causes of lung cancer. (1.8)

Understandings and applications	Utilization and aims
Understandings: • Ventilation maintains concentration gradients of oxygen and carbon dioxide between air in alveoli and blood flowing in adjacent capillaries. • Type I pneumocytes are extremely thin alveolar cells that are adapted to carry out gas exchange. • Type II pneumocytes secrete a solution containing surfactant that creates a moist surface inside the alveoli to prevent the sides of the alveolus adhering to each other by reducing surface tension. • Air is carried to the lungs in the trachea and bronchi and then to the alveoli in bronchioles. • Muscle contractions cause the pressure changes inside the thorax that force air in and out of the lungs to ventilate them. • Different muscles are required for inspiration and expiration because muscles only do work when they contract. **Applications and skills:** • Application: Causes and consequences of lung cancer. • Application: Causes and consequences of emphysema. • Application: External and internal intercostal muscles, and diaphragm and abdominal muscles as examples of antagonistic muscle action. • Skill: Monitoring of ventilation in humans at rest and after mild and vigorous exercise. (Practical 6)	**Utilization:** Syllabus and cross-curricular links: Biology Topic 1.4 Membrane transport Topic 1.6 Cell division Topic 6.2 The blood system Physics Topic 3.2 Modelling a gas **Aims:** • **Aim 8:** The social consequences of lung cancer and emphysema could be discussed.

6.4 Gas exchange	
Guidance: • Ventilation can either be monitored by simple observation and simple apparatus or by data logging with a spirometer or chest belt and pressure meter. Ventilation rate and tidal volume should be measured, but the terms vital capacity and residual volume are not expected. • Students should be able to draw a diagram to show the structure of an alveolus and an adjacent capillary.	

Essential idea: Neurons transmit the message, synapses modulate the message.

6.5 Neurons and synapses

Nature of science:

Cooperation and collaboration between groups of scientists—biologists are contributing to research into memory and learning. (4.3)

Understandings:

- Neurons transmit electrical impulses.
- The myelination of nerve fibres allows for saltatory conduction.
- Neurons pump sodium and potassium ions across their membranes to generate a resting potential.
- An action potential consists of depolarization and repolarization of the neuron.
- Nerve impulses are action potentials propagated along the axons of neurons.
- Propagation of nerve impulses is the result of local currents that cause each successive part of the axon to reach the threshold potential.
- Synapses are junctions between neurons and between neurons and receptor or effector cells.
- When presynaptic neurons are depolarized they release a neurotransmitter into the synapse.
- A nerve impulse is only initiated if the threshold potential is reached.

Applications and skills:

- Application: Secretion and reabsorption of acetylcholine by neurons at synapses.
- Application: Blocking of synaptic transmission at cholinergic synapses in insects by binding of neonicotinoid pesticides to acetylcholine receptors.
- Skill: Analysis of oscilloscope traces showing resting potentials and action potentials.

Guidance:

- The details of structure of different types of neuron are not needed.
- Only chemical synapses are required, not electrical, and they can simply be referred to as synapses.

Utilization:

- An understanding of the workings of neurotransmitters and synapses has led to the development of numerous pharmaceuticals for the treatment of mental disorders.

Syllabus and cross-curricular links:
Biology
Topic 1.4 Membrane transport
Chemistry
Topic C6 Electrochemistry, rechargeable batteries and fuel cells
Psychology
Core: Biological level of analysis

Aims:

- **Aim 8:** The social effects of the abuse of psychoactive drugs could be considered, as could the use of the neurotoxin *Botox* for cosmetic treatments.

Essential idea: Hormones are used when signals need to be widely distributed.

6.6 Hormones, homeostasis and reproduction	
Nature of science: Developments in scientific research follow improvements in apparatus—William Harvey was hampered in his observational research into reproduction by lack of equipment. The microscope was invented 17 years after his death. (1.8)	
Understandings: • Insulin and glucagon are secreted by β and α cells of the pancreas respectively to control blood glucose concentration. • Thyroxin is secreted by the thyroid gland to regulate the metabolic rate and help control body temperature. • Leptin is secreted by cells in adipose tissue and acts on the hypothalamus of the brain to inhibit appetite. • Melatonin is secreted by the pineal gland to control circadian rhythms. • A gene on the Y chromosome causes embryonic gonads to develop as testes and secrete testosterone. • Testosterone causes pre-natal development of male genitalia and both sperm production and development of male secondary sexual characteristics during puberty. • Estrogen and progesterone cause pre-natal development of female reproductive organs and female secondary sexual characteristics during puberty. • The menstrual cycle is controlled by negative and positive feedback mechanisms involving ovarian and pituitary hormones. **Applications and skills:** • Application: Causes and treatment of Type I and Type II diabetes. • Application: Testing of leptin on patients with clinical obesity and reasons for the failure to control the disease.	**Utilization:** • Hormones are used in a variety of therapies such as replacement therapies. Syllabus and cross-curricular links: Biology Topic 3.2 Chromosomes Topic 3.3 Meiosis Topic 10.1 Meiosis Psychology Core: Biological level of analysis **Aims:** • **Aim 8:** Scientists are aware that the drugs women take in fertility treatment pose potential risks to health. Should scientific knowledge override compassionate considerations in treating infertile couples?

6.6 Hormones, homeostasis and reproduction	
• Application: Causes of jet lag and use of melatonin to alleviate it. • Application: The use in IVF of drugs to suspend the normal secretion of hormones, followed by the use of artificial doses of hormones to induce superovulation and establish a pregnancy. • Application: William Harvey's investigation of sexual reproduction in deer. • Skill: Annotate diagrams of the male and female reproductive system to show names of structures and their functions. **Guidance:** • The roles of FSH, LH, estrogen and progesterone in the menstrual cycle are expected. • William Harvey failed to solve the mystery of sexual reproduction because effective microscopes were not available when he was working, so fusion of gametes and subsequent embryo development remained undiscovered.	

Additional higher level

Topic 7: Nucleic acids

9 hours

Essential idea: The structure of DNA is ideally suited to its function.

7.1 DNA structure and replication

Nature of science:

Making careful observations—Rosalind Franklin’s X-ray diffraction provided crucial evidence that DNA is a double helix. (1.8)

Understandings:

- Nucleosomes help to supercoil the DNA.
- DNA structure suggested a mechanism for DNA replication.
- DNA polymerases can only add nucleotides to the 3′ end of a primer.
- DNA replication is continuous on the leading strand and discontinuous on the lagging strand.
- DNA replication is carried out by a complex system of enzymes.
- Some regions of DNA do not code for proteins but have other important functions.

Applications and skills:

- Application: Rosalind Franklin’s and Maurice Wilkins’ investigation of DNA structure by X-ray diffraction.
- Application: Use of nucleotides containing dideoxyribonucleic acid to stop DNA replication in preparation of samples for base sequencing.
- Application: Tandem repeats are used in DNA profiling.
- Skill: Analysis of results of the Hershey and Chase experiment providing evidence that DNA is the genetic material.
- Skill: Utilization of molecular visualization software to analyse the association between protein and DNA within a nucleosome.

Theory of knowledge:

- Highly repetitive sequences were once classified as “junk DNA” showing a degree of confidence that it had no role. To what extent do the labels and categories used in the pursuit of knowledge affect the knowledge we obtain?

Utilization:

Syllabus and cross-curricular links:
Biology
Topic 2.6 Structure of DNA and RNA

Aims:

- **Aim 6:** Students could design models to illustrate the stages of DNA replication.

7.1 DNA structure and replication	
Guidance: • Details of DNA replication differ between prokaryotes and eukaryotes. Only the prokaryotic system is expected. • The proteins and enzymes involved in DNA replication should include helicase, DNA gyrase, single strand binding proteins, DNA primase and DNA polymerases I and III. • The regions of DNA that do not code for proteins should be limited to regulators of gene expression, introns, telomeres and genes for tRNAs.	

Essential idea: Information stored as a code in DNA is copied onto mRNA.

7.2 Transcription and gene expression

Nature of science:

Looking for patterns, trends and discrepancies—there is mounting evidence that the environment can trigger heritable changes in epigenetic factors. (3.1)

Understandings:

- Transcription occurs in a 5′ to 3′ direction.
- Nucleosomes help to regulate transcription in eukaryotes.
- Eukaryotic cells modify mRNA after transcription.
- Splicing of mRNA increases the number of different proteins an organism can produce.
- Gene expression is regulated by proteins that bind to specific base sequences in DNA.
- The environment of a cell and of an organism has an impact on gene expression.

Application and skills:

- Application: The promoter as an example of non-coding DNA with a function.
- Skill: Analysis of changes in the DNA methylation patterns.

Guidance:

- RNA polymerase adds the 5′ end of the free RNA nucleotide to the 3′ end of the growing mRNA molecule.

Theory of knowledge:

- The nature versus nurture debate concerning the relative importance of an individual's innate qualities versus those acquired through experiences is still under discussion. Is it important for science to attempt to answer this question?

Utilization:

Syllabus and cross-curricular links:
Biology
Topic 2.7 DNA replication, transcription and translation

Essential idea: Information transferred from DNA to mRNA is translated into an amino acid sequence.

7.3 Translation

Nature of science:

Developments in scientific research follow improvements in computing—the use of computers has enabled scientists to make advances in bioinformatics applications such as locating genes within genomes and identifying conserved sequences. (3.7)

Understandings:

- Initiation of translation involves assembly of the components that carry out the process.
- Synthesis of the polypeptide involves a repeated cycle of events.
- Disassembly of the components follows termination of translation.
- Free ribosomes synthesize proteins for use primarily within the cell.
- Bound ribosomes synthesize proteins primarily for secretion or for use in lysosomes.
- Translation can occur immediately after transcription in prokaryotes due to the absence of a nuclear membrane.
- The sequence and number of amino acids in the polypeptide is the primary structure.
- The secondary structure is the formation of alpha helices and beta pleated sheets stabilized by hydrogen bonding.
- The tertiary structure is the further folding of the polypeptide stabilized by interactions between R groups.
- The quaternary structure exists in proteins with more than one polypeptide chain.

Application and skills:

- Application: tRNA-activating enzymes illustrate enzyme–substrate specificity and the role of phosphorylation.
- Skill: Identification of polysomes in electron micrographs of prokaryotes and eukaryotes.

Utilization:

Syllabus and cross-curricular links:
Biology
Topic 2.7 DNA replication, transcription and translation
Option B: Biotechnology and bioinformatics

7.3 Translation	
• Skill: The use of molecular visualization software to analyse the structure of eukaryotic ribosomes and a tRNA molecule. **Guidance:** • Names of the tRNA binding sites are expected as well as their roles. • Examples of start and stop codons are not required. • Polar and non-polar amino acids are relevant to the bonds formed between R groups. • Quaternary structure may involve the binding of a prosthetic group to form a conjugated protein.	

Topic 8: Metabolism, cell respiration and photosynthesis 14 hours

Essential idea: Metabolic reactions are regulated in response to the cell's needs.

8.1 Metabolism

Nature of science:

Developments in scientific research follow improvements in computing—developments in bioinformatics, such as the interrogation of databases, have facilitated research into metabolic pathways. (3.8)

Understandings:

- Metabolic pathways consist of chains and cycles of enzyme-catalysed reactions.
- Enzymes lower the activation energy of the chemical reactions that they catalyse.
- Enzyme inhibitors can be competitive or non-competitive.
- Metabolic pathways can be controlled by end-product inhibition.

Applications and skills:

- Application: End-product inhibition of the pathway that converts threonine to isoleucine.
- Application: Use of databases to identify potential new anti-malarial drugs.
- Skill: Calculating and plotting rates of reaction from raw experimental results.
- Skill: Distinguishing different types of inhibition from graphs at specified substrate concentration.

Guidance:

- Enzyme inhibition should be studied using one specific example for competitive and non-competitive inhibition.

Theory of knowledge:

- Many metabolic pathways have been described following a series of carefully controlled and repeated experiments. To what degree can looking at component parts give us knowledge of the whole?

Utilization:

- Many enzyme inhibitors have been used in medicine. For example ethanol has been used to act as a competitive inhibitor for antifreeze poisoning.
- Fomepizole, which is an inhibitor of alcohol dehydrogenase, has also been used for antifreeze poisoning.

Syllabus and cross-curricular links:
Biology
Topic 2.7 DNA replication, transcription and translation
Chemistry
Topic 6.1 Collision theory and rates of reaction

Aims:

- **Aim 6:** Experiments on enzyme inhibition can be performed.
- **Aim 7:** Computer simulations on enzyme action including metabolic inhibition are available.

Essential idea: Energy is converted to a usable form in cell respiration.

8.2 Cell respiration	
Nature of science: Paradigm shift—the chemiosmotic theory led to a paradigm shift in the field of bioenergetics. (2.3)	
Understandings: • Cell respiration involves the oxidation and reduction of electron carriers. • Phosphorylation of molecules makes them less stable. • In glycolysis, glucose is converted to pyruvate in the cytoplasm. • Glycolysis gives a small net gain of ATP without the use of oxygen. • In aerobic cell respiration pyruvate is decarboxylated and oxidized, and converted into acetyl compound and attached to coenzyme A to form acetyl coenzyme A in the link reaction. • In the Krebs cycle, the oxidation of acetyl groups is coupled to the reduction of hydrogen carriers, liberating carbon dioxide. • Energy released by oxidation reactions is carried to the cristae of the mitochondria by reduced NAD and FAD. • Transfer of electrons between carriers in the electron transport chain in the membrane of the cristae is coupled to proton pumping. • In chemiosmosis protons diffuse through ATP synthase to generate ATP. • Oxygen is needed to bind with the free protons to maintain the hydrogen gradient, resulting in the formation of water. • The structure of the mitochondrion is adapted to the function it performs.	**Theory of knowledge:** • Peter Mitchell's chemiosmotic theory encountered years of opposition before it was finally accepted. For what reasons does falsification not always result in an immediate acceptance of new theories or a paradigm shift? **Utilization:** Syllabus and cross-curricular links: Biology Topic 2.8 Cell respiration Chemistry Topic 9.1 Oxidation and reduction

8.2 Cell respiration

Applications and skills:

- Application: Electron tomography used to produce images of active mitochondria.
- Skill: Analysis of diagrams of the pathways of aerobic respiration to deduce where decarboxylation and oxidation reactions occur.
- Skill: Annotation of a diagram of a mitochondrion to indicate the adaptations to its function.

Guidance:

- The names of the intermediate compounds in gylcolysis and the Krebs cycle are not required.

Essential idea: Light energy is converted into chemical energy.

8.3 Photosynthesis

Nature of science:

Developments in scientific research follow improvements in apparatus—sources of ^{14}C and autoradiography enabled Calvin to elucidate the pathways of carbon fixation. (1.8)

Understandings:

- Light-dependent reactions take place in the thylakoid membranes and the space inside them.
- Light-independent reactions take place in the stroma.
- Reduced NADP and ATP are produced in the light-dependent reactions.
- Absorption of light by photosystems generates excited electrons.
- Photolysis of water generates electrons for use in the light-dependent reactions.
- Transfer of excited electrons occurs between carriers in thylakoid membranes.
- Excited electrons from Photosystem II are used to contribute to generate a proton gradient.
- ATP synthase in thylakoids generates ATP using the proton gradient.
- Excited electrons from Photosystem I are used to reduce NADP.
- In the light-independent reactions a carboxylase catalyses the carboxylation of ribulose bisphosphate.
- Glycerate 3-phosphate is reduced to triose phosphate using reduced NADP and ATP.
- Triose phosphate is used to regenerate RuBP and produce carbohydrates.
- Ribulose bisphosphate is reformed using ATP.
- The structure of the chloroplast is adapted to its function in photosynthesis.

Applications and skills:

- Application: Calvin's experiment to elucidate the carboxylation of RuBP.
- Skill: Annotation of a diagram to indicate the adaptations of a chloroplast to its function.

Theory of knowledge:

- The lollipop experiment 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?

Utilization:

- The Global Artificial Photosynthesis (GAP) project aims to create an artificial "leaf" within the next decade. An electronic version of the leaf that creates oxygen and hydrogen from water and sunlight has already been invented and will be developed for use in the next decade.

Syllabus and cross-curricular links:
Biology
Topic 2.9 Photosynthesis
Topic 4.2 Energy flow
Topic 4.3 Carbon cycling
Chemistry
Topic 9.1 Oxidation and reduction

Aims:

- **Aim 6:** Hill´s method demonstrating electron transfer in chloroplasts by observing DCPIP reduction, immobilization of a culture of an alga such as *Scenedesmus* in alginate beads and measurement of the rate of photosynthesis by monitoring their effect on hydrogencarbonate indicator are all possible experiments.

Topic 9: Plant biology

13 hours

Essential idea: Structure and function are correlated in the xylem of plants.

9.1 Transport in the xylem of plants

Nature of science:

Use models as representations of the real world—mechanisms involved in water transport in the xylem can be investigated using apparatus and materials that show similarities in structure to plant tissues. (1.10)

Understandings:

- Transpiration is the inevitable consequence of gas exchange in the leaf.
- Plants transport water from the roots to the leaves to replace losses from transpiration.
- The cohesive property of water and the structure of the xylem vessels allow transport under tension.
- The adhesive property of water and evaporation generate tension forces in leaf cell walls.
- Active uptake of mineral ions in the roots causes absorption of water by osmosis.

Applications and skills:

- Application: Adaptations of plants in deserts and in saline soils for water conservation.
- Application: Models of water transport in xylem using simple apparatus including blotting or filter paper, porous pots and capillary tubing.
- Skill: Drawing the structure of primary xylem vessels in sections of stems based on microscope images.
- Skill: Measurement of transpiration rates using potometers. (Practical 7)
- Skill: Design of an experiment to test hypotheses about the effect of temperature or humidity on transpiration rates.

Utilization:

Syllabus and cross-curricular links:
Biology
Topic 2.2 Water
Topics 2.9 and 8.3 Photosynthesis

Aims:

- **Aim 7:** The introduction of image processing software and digital microscopes increases further the ability to gather more data to ensure reliability.
- **Aim 6:** Measurement of stomatal apertures and the distribution of stomata using leaf casts, including replicate measurements to enhance reliability, are possible experiments.

Essential idea: Structure and function are correlated in the phloem of plants.

9.2 Transport in the phloem of plants	
Nature of science: Developments in scientific research follow improvements in apparatus—experimental methods for measuring phloem transport rates using aphid stylets and radioactively-labelled carbon dioxide were only possible when radioisotopes became available. (1.8)	
Understandings: • Plants transport organic compounds from sources to sinks. • Incompressibility of water allows transport along hydrostatic pressure gradients. • Active transport is used to load organic compounds into phloem sieve tubes at the source. • High concentrations of solutes in the phloem at the source lead to water uptake by osmosis. • Raised hydrostatic pressure causes the contents of the phloem to flow towards sinks. **Applications and skills:** • Application: Structure–function relationships of phloem sieve tubes. • Skill: Identification of xylem and phloem in microscope images of stem and root. • Skill: Analysis of data from experiments measuring phloem transport rates using aphid stylets and radioactively-labelled carbon dioxide.	**Utilization:** Syllabus and cross-curricular links: Biology Topic 1.4 Membrane transport

Essential idea: Plants adapt their growth to environmental conditions.

9.3 Growth in plants

Nature of science:

Developments in scientific research follow improvements in analysis and deduction—improvements in analytical techniques allowing the detection of trace amounts of substances has led to advances in the understanding of plant hormones and their effect on gene expression. (1.8)

Understandings:

- Undifferentiated cells in the meristems of plants allow indeterminate growth.
- Mitosis and cell division in the shoot apex provide cells needed for extension of the stem and development of leaves.
- Plant hormones control growth in the shoot apex.
- Plant shoots respond to the environment by tropisms.
- Auxin efflux pumps can set up concentration gradients of auxin in plant tissue.
- Auxin influences cell growth rates by changing the pattern of gene expression.

Applications and skills:

- Application: Micropropagation of plants using tissue from the shoot apex, nutrient agar gels and growth hormones.
- Application: Use of micropropagation for rapid bulking up of new varieties, production of virus-free strains of existing varieties and propagation of orchids and other rare species.

Guidance:

- Auxin is the only named hormone that is expected.

Theory of knowledge:

- Plants communicate chemically both internally and externally. To what extent can plants be said to have language?

Utilization:

- Micropropagation is used for rapid bulking up of new varieties of plant.

Syllabus and cross-curricular links:
Biology
Topic 3.5 Genetic modification and biotechnology

Aims:

- **Aim 6:** Investigations into tropisms could be carried out.

Essential idea: Reproduction in flowering plants is influenced by the biotic and abiotic environment.

9.4 Reproduction in plants

Nature of science:

Paradigm shift—more than 85% of the world's 250,000 species of flowering plant depend on pollinators for reproduction. This knowledge has led to protecting entire ecosystems rather than individual species. (2.3)

Understandings:

- Flowering involves a change in gene expression in the shoot apex.
- The switch to flowering is a response to the length of light and dark periods in many plants.
- Success in plant reproduction depends on pollination, fertilization and seed dispersal.
- Most flowering plants use mutualistic relationships with pollinators in sexual reproduction.

Applications and skills:

- Application: Methods used to induce short-day plants to flower out of season.
- Skill: Drawing internal structure of seeds.
- Skill: Drawing of half-views of animal-pollinated flowers.
- Skill: Design of experiments to test hypotheses about factors affecting germination.

Guidance:

- Students should understand the differences between pollination, fertilization and seed dispersal but are not required to know the details of each process.
- Flowering in so-called short-day plants such as chrysanthemums, is stimulated by long nights rather than short days.

Utilization:

- The University of Göttingen, in Germany, conducted an extensive review of scientific studies from 200 countries for 115 of the leading global crops in 2005. They found that 87 of the crop plants depend to some degree upon animal pollination, including bees. This accounts for one-third of crop production globally.

Topic 10: Genetics and evolution 8 hours

Essential idea: Meiosis leads to independent assortment of chromosomes and unique composition of alleles in daughter cells.

10.1 Meiosis

Nature of science:

Making careful observations—careful observation and record keeping turned up anomalous data that Mendel's law of independent assortment could not account for. Thomas Hunt Morgan developed the notion of linked genes to account for the anomalies. (1.8)

Understandings:

- Chromosomes replicate in interphase before meiosis.
- Crossing over is the exchange of DNA material between non-sister homologous chromatids.
- Crossing over produces new combinations of alleles on the chromosomes of the haploid cells.
- Chiasmata formation between non-sister chromatids can result in an exchange of alleles.
- Homologous chromosomes separate in meiosis I.
- Sister chromatids separate in meiosis II.
- Independent assortment of genes is due to the random orientation of pairs of homologous chromosomes in meiosis I.

Applications and skills:

- Skill: Drawing diagrams to show chiasmata formed by crossing over.

Guidance:

- Diagrams of chiasmata should show sister chromatids still closely aligned, except at the point where crossing over occurred and a chiasma was formed.

Utilization:

Syllabus and cross-curricular links:
Biology
Topic 1.6 Cell division
Topic 3.3 Meiosis
Topic 11.4 Sexual reproduction

Aims:

- **Aim 6:** Staining of lily anthers or other tissue containing germ-line cells and microscope examination to observe cells in meiosis are possible activities.

Essential idea: Genes may be linked or unlinked and are inherited accordingly.

10.2 Inheritance

Nature of science:

Looking for patterns, trends and discrepancies—Mendel used observations of the natural world to find and explain patterns and trends. Since then, scientists have looked for discrepancies and asked questions based on further observations to show exceptions to the rules. For example, Morgan discovered non-Mendelian ratios in his experiments with *Drosophila*. (3.1)

Understandings:

- Gene loci are said to be linked if on the same chromosome.
- Unlinked genes segregate independently as a result of meiosis.
- Variation can be discrete or continuous.
- The phenotypes of polygenic characteristics tend to show continuous variation.
- Chi-squared tests are used to determine whether the difference between an observed and expected frequency distribution is statistically significant.

Applications and skills:

- Application: Morgan's discovery of non-Mendelian ratios in *Drosophila*.
- Application: Completion and analysis of Punnett squares for dihybrid traits.
- Application: Polygenic traits such as human height may also be influenced by environmental factors.
- Skill: Calculation of the predicted genotypic and phenotypic ratio of offspring of dihybrid crosses involving unlinked autosomal genes.
- Skill: Identification of recombinants in crosses involving two linked genes.
- Skill: Use of a chi-squared test on data from dihybrid crosses.

Theory of knowledge:

- The law of independent assortment was soon found to have exceptions when looking at linked genes. What is the difference between a law and a theory in science?

Utilization:

- An understanding of inheritance allowed farmers to selectively breed their livestock for specific characteristics.

Syllabus and cross-curricular links:
Biology
Topic 3.4 Inheritance

Aims:

- **Aim 4:** Use analytical skills to solve genetic crosses.
- **Aim 8:** Ethical issues arise in the prevention of the inheritance of genetic disorders.

10.2 Inheritance	
Guidance: • 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: $\dfrac{T\ B}{t\ b}$ • This format will be used in examination papers, or students will be given sufficient information to allow them to deduce which alleles are linked.	

Essential idea: Gene pools change over time.

10.3 Gene pools and speciation	
Nature of science: Looking for patterns, trends and discrepancies—patterns of chromosome number in some genera can be explained by speciation due to polyploidy. (3.1)	
Understandings: • A gene pool consists of all the genes and their different alleles, present in an interbreeding population. • Evolution requires that allele frequencies change with time in populations. • Reproductive isolation of populations can be temporal, behavioural or geographic. • Speciation due to divergence of isolated populations can be gradual. • Speciation can occur abruptly. **Applications and skills:** • Application: Identifying examples of directional, stabilizing and disruptive selection. • Application: Speciation in the genus *Allium* by polyploidy. • Skill: Comparison of allele frequencies of geographically isolated populations. **Guidance:** • Punctuated equilibrium implies long periods without appreciable change and short periods of rapid evolution.	**Theory of knowledge:** • Punctuated equilibrium was long considered an alternative theory of evolution and a challenge to the long established paradigm of Darwinian gradualism. How do paradigm shifts proceed in science and what factors are involved in their success? **Utilization:** • Many crop species have been created to be polyploid. Polyploidy increases allelic diversity and permits novel phenotypes to be generated. It also leads to hybrid vigour. Syllabus and cross-curricular links: Biology Topic 5.1 Evidence for evolution

Topic 11: Animal physiology

16 hours

Essential idea: Immunity is based on recognition of self and destruction of foreign material.

11.1 Antibody production and vaccination

Nature of science:

Consider ethical implications of research—Jenner tested his vaccine for smallpox on a child. (4.5)

Understandings:

- Every organism has unique molecules on the surface of its cells.
- Pathogens can be species-specific although others can cross species barriers.
- B lymphocytes are activated by T lymphocytes in mammals.
- Activated B cells multiply to form clones of plasma cells and memory cells.
- Plasma cells secrete antibodies.
- Antibodies aid the destruction of pathogens.
- White cells release histamine in response to allergens.
- Histamines cause allergic symptoms.
- Immunity depends upon the persistence of memory cells.
- Vaccines contain antigens that trigger immunity but do not cause the disease.
- Fusion of a tumour cell with an antibody-producing plasma cell creates a hybridoma cell.
- Monoclonal antibodies are produced by hybridoma cells.

International-mindedness:

- The World Health Organization initiated the campaign for the global eradication of smallpox in 1967. The campaign was deemed a success in 1977, only 10 years later.

Utilization:

- Human vaccines are often produced using the immune responses of other animals.

Syllabus and cross-curricular links:

Biology

Topic 6.3 Defence against infectious disease

Topic 11.4 Sexual reproduction

Geography

Part 2F: The geography of food and health

Aims:

- **Aim 7:** Use of databases to analyse epidemiological data.

11.1 Antibody production and vaccination

Applications and skills:

- Application: Smallpox was the first infectious disease of humans to have been eradicated by vaccination.
- Application: Monoclonal antibodies to HCG are used in pregnancy test kits.
- Application: Antigens on the surface of red blood cells stimulate antibody production in a person with a different blood group.
- Skill: Analysis of epidemiological data related to vaccination programmes.

Guidance:

- Limit the immune response to mammals.

Essential idea: The roles of the musculoskeletal system are movement, support and protection.

11.2 Movement

Nature of science:

Developments in scientific research follow improvements in apparatus—fluorescent calcium ions have been used to study the cyclic interactions in muscle contraction. (1.8)

Understandings:	Aims:
• Bones and exoskeletons provide anchorage for muscles and act as levers. • Synovial joints allow certain movements but not others. • Movement of the body requires muscles to work in antagonistic pairs. • Skeletal muscle fibres are multinucleate and contain specialized endoplasmic reticulum. • Muscle fibres contain many myofibrils. • Each myofibril is made up of contractile sarcomeres. • The contraction of the skeletal muscle is achieved by the sliding of actin and myosin filaments. • ATP hydrolysis and cross bridge formation are necessary for the filaments to slide. • Calcium ions and the proteins tropomyosin and troponin control muscle contractions. **Applications and skills:** • Application: Antagonistic pairs of muscles in an insect leg. • Skill: Annotation of a diagram of the human elbow. • Skill: Drawing labelled diagrams of the structure of a sarcomere. • Skill: Analysis of electron micrographs to find the state of contraction of muscle fibres.	• **Aim 7:** Use of grip strength data loggers to assess muscle fatigue. • **Aim 7:** Use of animations to visualize contraction.

11.2 Movement

Guidance:

- Elbow diagram should include cartilage, synovial fluid, joint capsule, named bones and named antagonistic muscles.
- Drawing labelled diagrams of the structure of a sarcomere should include Z lines, actin filaments, myosin filaments with heads, and the resultant light and dark bands.
- Measurement of the length of sarcomeres will require calibration of the eyepiece scale of the microscope.

Essential idea: All animals excrete nitrogenous waste products and some animals also balance water and solute concentrations.

11.3 The kidney and osmoregulation	
Nature of science: Curiosity about particular phenomena—investigations were carried out to determine how desert animals prevent water loss in their wastes. (1.5)	
Understandings: • Animals are either osmoregulators or osmoconformers. • The Malpighian tubule system in insects and the kidney carry out osmoregulation and removal of nitrogenous wastes. • The composition of blood in the renal artery is different from that in the renal vein. • The ultrastructure of the glomerulus and Bowman's capsule facilitate ultrafiltration. • The proximal convoluted tubule selectively reabsorbs useful substances by active transport. • The loop of Henle maintains hypertonic conditions in the medulla. • ADH controls reabsorption of water in the collecting duct. • The length of the loop of Henle is positively correlated with the need for water conservation in animals. • The type of nitrogenous waste in animals is correlated with evolutionary history and habitat. **Applications and skills:** • Application: Consequences of dehydration and overhydration. • Application: Treatment of kidney failure by hemodialysis or kidney transplant. • Application: Blood cells, glucose, proteins and drugs are detected in urinary tests. • Skill: Drawing and labelling a diagram of the human kidney. • Skill: Annotation of diagrams of the nephron.	**Utilization:** • The removal of kidney stones by ultra sound treatment. Syllabus and cross-curricular links: Biology Topic 1.3 Membrane structure Topic 1.4 Membrane transport

11.3 The kidney and osmoregulation	
Guidance: • ADH will be used in preference to vasopressin. • The diagram of the nephron should include glomerulus, Bowman's capsule, proximal convoluted tubule, loop of Henle, distal convoluted tubule; the relationship between the nephron and the collecting duct should be included.	

Essential idea: Sexual reproduction involves the development and fusion of haploid gametes.

11.4 Sexual reproduction

Nature of science:

Assessing risks and benefits associated with scientific research—the risks to human male fertility were not adequately assessed before steroids related to progesterone and estrogen were released into the environment as a result of the use of the female contraceptive pill. (4.8)

Understandings:

- Spermatogenesis and oogenesis both involve mitosis, cell growth, two divisions of meiosis and differentiation.
- Processes in spermatogenesis and oogenesis result in different numbers of gametes with different amounts of cytoplasm.
- Fertilization in animals can be internal or external.
- Fertilization involves mechanisms that prevent polyspermy.
- Implantation of the blastocyst in the endometrium is essential for the continuation of pregnancy.
- HCG stimulates the ovary to secrete progesterone during early pregnancy.
- The placenta facilitates the exchange of materials between the mother and fetus.
- Estrogen and progesterone are secreted by the placenta once it has formed.
- Birth is mediated by positive feedback involving estrogen and oxytocin.

Applications and skills:

- Application: The average 38-week pregnancy in humans can be positioned on a graph showing the correlation between animal size and the development of the young at birth for other mammals.
- Skill: Annotation of diagrams of seminiferous tubule and ovary to show the stages of gametogenesis.
- Skill: Annotation of diagrams of mature sperm and egg to indicate functions.

Guidance:

- Fertilization involves the acrosome reaction, fusion of the plasma membrane of the egg and sperm and the cortical reaction.

Utilization:

Syllabus and cross-curricular links:
Biology
Topic 3.3 Meiosis
Topic 6.6 Hormones, homeostasis and reproduction

Aims:

- **Aim 8:** Disputes over the responsibility for frozen human embryos.

Core topics

Essential idea: Modification of neurons starts in the earliest stages of embryogenesis and continues to the final years of life.

A.1 Neural development

Nature of science:

Use models as representations of the real world—developmental neuroscience uses a variety of animal models. (1.10)

Understandings:

- The neural tube of embryonic chordates is formed by infolding of ectoderm followed by elongation of the tube.
- Neurons are initially produced by differentiation in the neural tube.
- Immature neurons migrate to a final location.
- An axon grows from each immature neuron in response to chemical stimuli.
- Some axons extend beyond the neural tube to reach other parts of the body.
- A developing neuron forms multiple synapses.
- Synapses that are not used do not persist.
- Neural pruning involves the loss of unused neurons.
- The plasticity of the nervous system allows it to change with experience.

Applications and skills:

- Application: Incomplete closure of the embryonic neural tube can cause *spina bifida*.
- Application: Events such as strokes may promote reorganization of brain function.
- Skill: Annotation of a diagram of embryonic tissues in *Xenopus*, used as an animal model, during neurulation.

International-mindedness:

- Cultural experiences, including the acquisition of a language, results in neural pruning.

Utilization:

- Research into the growth of nerve tissue for regeneration of tissue for spinal cord injury patients is progressing.

Syllabus and cross-curricular links:
Biology
Topic 6.5 Neurons and synapses

A.1 Neural development	
Guidance: • Terminology relating to embryonic brain areas or nervous system divisions is not required.	

Essential idea: The parts of the brain specialize in different functions.

A.2 The human brain

Nature of science:

Use models as representations of the real world—the sensory homunculus and motor homunculus are models of the relative space human body parts occupy on the somatosensory cortex and the motor cortex. (1.10)

Understandings:

- The anterior part of the neural tube expands to form the brain.
- Different parts of the brain have specific roles.
- The autonomic nervous system controls involuntary processes in the body using centres located mainly in the brain stem.
- The cerebral cortex forms a larger proportion of the brain and is more highly developed in humans than other animals.
- The human cerebral cortex has become enlarged principally by an increase in total area with extensive folding to accommodate it within the cranium.
- The cerebral hemispheres are responsible for higher order functions.
- The left cerebral hemisphere receives sensory input from sensory receptors in the right side of the body and the right side of the visual field in both eyes and vice versa for the right hemisphere.
- The left cerebral hemisphere controls muscle contraction in the right side of the body and vice versa for the right hemisphere.
- Brain metabolism requires large energy inputs.

Applications and skills:

- Application: Visual cortex, Broca's area, nucleus accumbens as areas of the brain with specific functions.
- Application: Swallowing, breathing and heart rate as examples of activities coordinated by the medulla.

International-mindedness:

- The definition of living varies depending on local and national laws and culture.

Theory of knowledge:

- In medicine the concept of death is defined in terms of brain function, but sometimes conflicts can occur when the medical criteria for death differ from the family's criteria for death. To what extent should the views of the family members be given priority when making decisions in medical ethics? What criteria should be used to make ethical decisions?

Utilization:

- Angelman syndrome is a genetically inherited condition that is diagnosed from characteristically abnormal patterns on an electroencephalogram.

A.2 The human brain

- Application: Use of the pupil reflex to evaluate brain damage.
- Application: Use of animal experiments, autopsy, lesions and fMRI to identify the role of different brain parts.
- Skill: Identification of parts of the brain in a photograph, diagram or scan of the brain.
- Skill: Analysis of correlations between body size and brain size in different animals.

Guidance:

- Image of the brain should include the medulla oblongata, cerebellum, hypothalamus, pituitary gland and cerebral hemispheres.
- Although specific functions can be attributed to certain areas, brain imagery shows that some activities are spread in many areas and that the brain can even reorganize itself following a disturbance such as a stroke.

Essential idea: Living organisms are able to detect changes in the environment.

A.3 Perception of stimuli

Nature of science:

Understanding of the underlying science is the basis for technological developments—the discovery that electrical stimulation in the auditory system can create a perception of sound resulted in the development of electrical hearing aids and ultimately cochlear implants. (1.2)

Understandings:

- Receptors detect changes in the environment.
- Rods and cones are photoreceptors located in the retina.
- Rods and cones differ in their sensitivities to light intensities and wavelengths.
- Bipolar cells send the impulses from rods and cones to ganglion cells.
- Ganglion cells send messages to the brain via the optic nerve.
- The information from the right field of vision from both eyes is sent to the left part of the visual cortex and vice versa.
- Structures in the middle ear transmit and amplify sound.
- Sensory hairs of the cochlea detect sounds of specific wavelengths.
- Impulses caused by sound perception are transmitted to the brain via the auditory nerve.
- Hair cells in the semicircular canals detect movement of the head.

Applications and skills:

- Application: Red-green colour-blindness as a variant of normal trichromatic vision.
- Application: Detection of chemicals in the air by the many different olfactory receptors.
- Application: Use of cochlear implants in deaf patients.
- Skill: Labelling a diagram of the structure of the human eye.

- **Theory of knowledge:**
  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 an individual construction of reality?

Utilization:

Syllabus and cross-curricular links:
Biology
Topic 3.4 Inheritance
Physics
Topic 4.2 Travelling waves

A.3 Perception of stimuli	
• Skill: Annotation of a diagram of the retina to show the cell types and the direction in which light moves. • Skill: Labelling a diagram of the structure of the human ear. **Guidance:** • Humans' sensory receptors should include mechanoreceptors, chemoreceptors, thermoreceptors and photoreceptors. • Diagram of human eye should include the sclera, cornea, conjunctiva, eyelid, choroid, aqueous humour, pupil, lens, iris, vitreous humour, retina, fovea, optic nerve and blind spot. • Diagram of retina should include rod and cone cells, bipolar neurons and ganglion cells. • Diagram of ear should include pinna, eardrum, bones of the middle ear, oval window, round window, semicircular canals, auditory nerve and cochlea.	

Additional higher level topics

Essential idea: Behavioural patterns can be inherited or learned.

A.4 Innate and learned behaviour

Nature of science:

Looking for patterns, trends and discrepancies—laboratory experiments and field investigations helped in the understanding of different types of behaviour and learning. (3.1)

Understandings:

- Innate behaviour is inherited from parents and so develops independently of the environment.
- Autonomic and involuntary responses are referred to as reflexes.
- Reflex arcs comprise the neurons that mediate reflexes.
- Reflex conditioning involves forming new associations.
- Learned behaviour develops as a result of experience.
- Imprinting is learning occurring at a particular life stage and is independent of the consequences of behaviour.
- Operant conditioning is a form of learning that consists of trial and error experiences.
- Learning is the acquisition of skill or knowledge.
- Memory is the process of encoding, storing and accessing information.

Applications and skills:

- Application: Withdrawal reflex of the hand from a painful stimulus.
- Application: Pavlov's experiments into reflex conditioning in dogs.

Theory of knowledge:

- It is easy for us to guess how the behaviour of an animal might influence its chance of survival and reproduction. Is intuition a valid starting point for scientists?

Aims:

- **Aim 7:** Data logging using an electrocardiogram (ECG) sensor to analyse neuromuscular reflexes.
- **Aim 8:** Experiments with animals—implications of today's animal policies for experimental science in Pavlov's experiments.

A.4 Innate and learned behaviour	
• Application: The role of inheritance and learning in the development of birdsong. • Skill: Analysis of data from invertebrate behaviour experiments in terms of the effect on chances of survival and reproduction. • Skill: Drawing and labelling a diagram of a reflex arc for a pain withdrawal reflex. **Guidance:** • Drawing of reflex arc should include the receptor cell, sensory neuron, relay neuron, motor neuron and effector.	

Essential idea: Communication between neurons can be altered through the manipulation of the release and reception of chemical messengers.

A.5 Neuropharmacology

Nature of science:

Assessing risks associated with scientific research—patient advocates will often press for the speeding up of drug approval processes, encouraging more tolerance of risk. (4.5)

Understandings:

- Some neurotransmitters excite nerve impulses in postsynaptic neurons and others inhibit them.
- Nerve impulses are initiated or inhibited in post-synaptic neurons as a result of summation of all excitatory and inhibitory neurotransmitters received from presynaptic neurones.
- Many different slow-acting neurotransmitters modulate fast synaptic transmission in the brain.
- Memory and learning involve changes in neurones caused by slow-acting neurotransmitters.
- Psychoactive drugs affect the brain by either increasing or decreasing postsynaptic transmission.
- Anesthetics act by interfering with neural transmission between areas of sensory perception and the CNS.
- Stimulant drugs mimic the stimulation provided by the sympathetic nervous system.
- Addiction can be affected by genetic predisposition, social environment and dopamine secretion.

Applications and skills:

- Application: Effects on the nervous system of two stimulants and two sedatives.
- Application: The effect of anesthetics on awareness.

International-mindedness:

- Attitudes to drugs and the use of drugs differ globally. There are many cultures that use drugs to enhance rituals or religious experiences.

Utilization:

- Many psychoactive drugs have been used therapeutically to treat a range of mental illnesses and psychological disorders.

Syllabus and cross-curricular links:
Chemistry
Option D Medicinal chemistry
Topic D1 Pharmaceutical products and drug action
Topic D3 Opiates
Psychology
Core: Biological level of analysis

Aims:

- **Aim 8:** The social consequences of psychoactive drugs could be considered, for the user, his or her family and the wider society.

A.5 Neuropharmacology	
• Application: Endorphins can act as painkillers. • Skill: Evaluation of data showing the impact of MDMA (ecstasy) on serotonin and dopamine metabolism in the brain. **Guidance:** • Examples of stimulants are nicotine, cocaine or amphetamines. • Examples of sedatives are benzodiazepines, alcohol or tetrahydrocannabinol (THC).	

Essential idea: Natural selection favours specific types of behaviour.

A.6 Ethology

Nature of science:

Testing a hypothesis—experiments to test hypotheses on the migratory behaviour of blackcaps have been carried out. (1.9)

Understandings:

- Ethology is the study of animal behaviour in natural conditions.
- Natural selection can change the frequency of observed animal behaviour.
- Behaviour that increases the chances of survival and reproduction will become more prevalent in a population.
- Learned behaviour can spread through a population or be lost from it more rapidly than innate behaviour.

Applications and skills:

- Application: Migratory behaviour in blackcaps as an example of the genetic basis of behaviour and its change by natural selection.
- Application: Blood sharing in vampire bats as an example of the development of altruistic behaviour by natural selection.
- Application: Foraging behaviour in shore crabs as an example of increasing chances of survival by optimal prey choice.
- Application: Breeding strategies in coho salmon populations as an example of behaviour affecting chances of survival and reproduction.
- Application: Courtship in birds of paradise as an example of mate selection.
- Application: Synchronized oestrus in female lions in a pride as an example of innate behaviour that increases the chances of survival and reproduction of offspring.
- Application: Feeding on cream from milk bottles in blue tits as an example of the development and loss of learned behaviour.

Theory of knowledge:

- The “Just So” stories by Rudyard Kipling are literary explanations of animal behaviour. What are the features of a scientific explanation rather than a historical or literary explanation?

Utilizations:

Syllabus and cross-curricular links:
Biology
Topic 5.2 Natural selection

A.6 Ethology	
Guidance: • The seven applications in this sub-topic are intended to reinforce understanding of the general principles. The applications include a range of types of behaviour and types of animal. Other examples, including local examples that can be observed, should also be studied if possible.	

Core topics

Essential idea: Microorganisms can be used and modified to perform industrial processes.

B.1 Microbiology: organisms in industry

Nature of science:

Serendipity has led to scientific discoveries—the discovery of penicillin by Alexander Fleming could be viewed as a chance occurrence. (1.4)

Understandings:

- Microorganisms are metabolically diverse.
- Microorganisms are used in industry because they are small and have a fast growth rate.
- Pathway engineering optimizes genetic and regulatory processes within microorganisms.
- Pathway engineering is used industrially to produce metabolites of interest.
- Fermenters allow large-scale production of metabolites by microorganisms.
- Fermentation is carried out by batch or continuous culture.
- Microorganisms in fermenters become limited by their own waste products.
- Probes are used to monitor conditions within fermenters.
- Conditions are maintained at optimal levels for the growth of the microorganisms being cultured.

Applications and skills:

- Application: Deep-tank batch fermentation in the mass production of penicillin.
- Application: Production of citric acid in a continuous fermenter by *Aspergillus niger* and its use as a preservative and flavouring.

Theory of knowledge:

- Alexander Fleming discovered penicillin in England in 1928, on a discarded petri dish. To what extent was Dr Fleming's discovery a lucky observation, or do we only perceive what we are open to?

Utilization:

Syllabus and cross-curricular links:
Biology
Topic 2.1 Molecules to metabolism
Topic 4.3 Carbon cycling
Topic 6.3 Defence against infectious disease

B.1 Microbiology: organisms in industry	
• Application: Biogas is produced by bacteria and archaeans from organic matter in fermenters. • Skill: Gram staining of Gram-positive and Gram-negative bacteria. • Skill: Experiments showing zone of inhibition of bacterial growth by bactericides in sterile bacterial cultures. • Skill: Production of biogas in a small-scale fermenter.	

Essential idea: Crops can be modified to increase yields and to obtain novel products.

B.2 Biotechnology in agriculture

Nature of science:

Assessing risks and benefits associated with scientific research—scientists need to evaluate the potential of herbicide resistance genes escaping into the wild population. (4.8)

Understandings:	Utilization:
• Transgenic organisms produce proteins that were not previously part of their species' proteome. • Genetic modification can be used to overcome environmental resistance to increase crop yields. • Genetically modified crop plants can be used to produce novel products. • Bioinformatics plays a role in identifying target genes. • The target gene is linked to other sequences that control its expression. • An open reading frame is a significant length of DNA from a start codon to a stop codon. • Marker genes are used to indicate successful uptake. • Recombinant DNA must be inserted into the plant cell and taken up by its chromosome or chloroplast DNA. • Recombinant DNA can be introduced into whole plants, leaf discs or protoplasts. • Recombinant DNA can be introduced by direct physical and chemical methods or indirectly by vectors. **Applications and skills:** • Application: Use of tumour-inducing (Ti) plasmid of *Agrobacterium tumefaciens* to introduce glyphosate resistance into soybean crops. • Application: Genetic modification of tobacco mosaic virus to allow bulk production of Hepatitis B vaccine in tobacco plants.	Syllabus and cross-curricular links: Biology Topic 1.5 The origin of cells Topic 3.5 Genetic modification and biotechnology Environmental systems and societies Topic 5.2 Terrestrial food production systems **Aims:** • **Aim 7:** Use of bioinformatics to determine sequences to be modified. • **Aim 8:** There are ethical and political implications in the introduction of the genetically modified potato Amflora in Europe.

B.2 Biotechnology in agriculture	
• Application: Production of Amflora potato (*Solanum tuberosum*) for paper and adhesive industries. • Skill: Evaluation of data on the environmental impact of glyphosate-tolerant soybeans. • Skill: Identification of an open reading frame (ORF). **Guidance:** • A significant length of DNA for an open reading frame contains sufficient nucleotides to code for a polypeptide chain. • Limit the chemical methods of introducing genes into plants to calcium chloride and liposomes. • Limit the physical methods of introducing genes into plants to electroporation, microinjection and biolistics (gunshot). • Limit vectors to *Agrobacterium tumefaciens* and tobacco mosaic virus.	

Essential idea: Biotechnology can be used in the prevention and mitigation of contamination from industrial, agricultural and municipal wastes.

B.3 Environmental protection

Nature of science:

Developments in scientific research follow improvements in apparatus—using tools such as the laser scanning microscope has led researchers to deeper understanding of the structure of biofilms. (1.8)

Understandings:

- Responses to pollution incidents can involve bioremediation combined with physical and chemical procedures.
- Microorganisms are used in bioremediation.
- Some pollutants are metabolized by microorganisms.
- Cooperative aggregates of microorganisms can form biofilms.
- Biofilms possess emergent properties.
- Microorganisms growing in a biofilm are highly resistant to antimicrobial agents.
- Microorganisms in biofilms cooperate through quorum sensing.
- Bacteriophages are used in the disinfection of water systems.

Applications and skills:

- Application: Degradation of benzene by halophilic bacteria such as *Marinobacter*.
- Application: Degradation of oil by *Pseudomonas*.
- Application: Conversion by *Pseudomonas* of methyl mercury into elemental mercury.
- Application: Use of biofilms in trickle filter beds for sewage treatment.
- Skill: Evaluation of data or media reports on environmental problems caused by biofilms.

Guidance:

- Examples of environmental problems caused by biofilms could include clogging and corrosion of pipes, transfer of microorganisms in ballast water or contamination of surfaces in food production.

International-mindedness:

- During oil spills scientists from different parts of the world work together to protect the environment.

Theory of knowledge:

- Emergent properties are the outcome of the interaction of the elements of a system. In what context is a reductionist approach to science productive and in what context is a reductionist approach problematic?

Utilization:

Syllabus and cross-curricular links:
Biology
Topic 1 Cell biology
Chemistry
Option C2 Fossil fuels
Environmental systems and societies
Topic 4.4 Water pollution
Topic 6.3 Photochemical smog
Topic 6.4 Acid deposition

Additional higher level topics

Essential idea: Biotechnology can be used in the diagnosis and treatment of disease.

B.4 Medicine

Nature of science:

Developments in scientific research follow improvements in technology—innovation in technology has allowed scientists to diagnose and treat diseases. (1.8)

Understandings and skills	Theory of knowledge and utilization
Understandings: • Infection by a pathogen can be detected by the presence of its genetic material or by its antigens. • Predisposition to a genetic disease can be detected through the presence of markers. • DNA microarrays can be used to test for genetic predisposition or to diagnose the disease. • Metabolites that indicate disease can be detected in blood and urine. • Tracking experiments are used to gain information about the localization and interaction of a desired protein. • Biopharming uses genetically modified animals and plants to produce proteins for therapeutic use. • Viral vectors can be used in gene therapy. **Applications and skills:** • Application: Use of PCR to detect different strains of influenza virus. • Application: Tracking tumour cells using transferin linked to luminescent probes.	**Theory of knowledge:** • There have been cases around the world where subjects have died as a consequence of participating in a gene therapy research protocol. How is the decision to proceed with risky procedures made? • What constitutes an acceptable level of risk for allowing humans to be involved in scientific research? **Utilization:** Syllabus and cross-curricular links: Biology Topic 3.5 Genetic modification and biotechnology Topic 6.3 Defence against infectious disease Topic 11.1 Antibody production and vaccination

B.4 Medicine	
• Application: Biopharming of antithrombin. • Application: Use of viral vectors in the treatment of Severe Combined Immunodeficiency (SCID). • Skill: Analysis of a simple microarray. • Skill: Interpretation of the results of an ELISA diagnostic test.	

Essential idea: Bioinformatics is the use of computers to analyse sequence data in biological research.

B.5 Bioinformatics

Nature of science:

Cooperation and collaboration between groups of scientists—databases on the internet allow scientists free access to information. (4.3)

Understandings:

- Databases allow scientists easy access to information.
- The body of data stored in databases is increasing exponentially.
- BLAST searches can identify similar sequences in different organisms.
- Gene function can be studied using model organisms with similar sequences.
- Sequence alignment software allows comparison of sequences from different organisms.
- BLASTn allows nucleotide sequence alignment while BLASTp allows protein alignment.
- Databases can be searched to compare newly identified sequences with sequences of known function in other organisms.
- Multiple sequence alignment is used in the study of phylogenetics.
- EST is an expressed sequence tag that can be used to identify potential genes.

Applications and skills:

- Application: Use of knockout technology in mice to determine gene function.
- Application: Discovery of genes by EST data mining.
- Skill: Explore chromosome 21 in databases (for example in Ensembl).
- Skill: Use of software to align two proteins.
- Skill: Use of software to construct simple cladograms and phylograms of related organisms using DNA sequences.

Theory of knowledge:

- Knowledge claims justified by reference to databases raise unique knowledge questions. How reliable are knowledge claims justified by reference to data sources developed for different purposes by different researchers using different methods?

Aims:

- **Aim 6:** Sequence alignment of related proteins such as hemoglobin and myoglobin could be investigated.

Core topics

Essential idea: Community structure is an emergent property of an ecosystem.

C.1 Species and communities

Nature of science:

Use models as representations of the real world—zones of stress and limits of tolerance graphs are models of the real world that have predictive power and explain community structure. (1.10)

Understandings:

- The distribution of species is affected by limiting factors.
- Community structure can be strongly affected by keystone species.
- Each species plays a unique role within a community because of the unique combination of its spatial habitat and interactions with other species.
- Interactions between species in a community can be classified according to their effect.
- Two species cannot survive indefinitely in the same habitat if their niches are identical.

Applications and skills:

- Application: Distribution of one animal and one plant species to illustrate limits of tolerance and zones of stress.
- Application: Local examples to illustrate the range of ways in which species can interact within a community.
- Application: The symbiotic relationship between *Zooxanthellae* and reef-building coral reef species.
- Skill: Analysis of a data set that illustrates the distinction between fundamental and realized niche.
- Skill: Use of a transect to correlate the distribution of plant or animal species with an abiotic variable.

Theory of knowledge:

- Random samples are taken in studies involving large geographical areas or if limited time is available. Is random sampling a useful tool for scientists despite the potential for sampling bias?

Utilization:

Syllabus and cross-curricular links:
Geography
Part 2C Extreme environments

Aims:

- **Aim 6:** Factors influencing herbivory could be investigated.

Essential idea: Changes in community structure affect and are affected by organisms.

C.2 Communities and ecosystems

Nature of science:

Use models as representations of the real world—pyramids of energy model the energy flow through ecosystems. (1.10)

Understandings:

- Most species occupy different trophic levels in multiple food chains.
- A food web shows all the possible food chains in a community.
- The percentage of ingested energy converted to biomass is dependent on the respiration rate.
- The type of stable ecosystem that will emerge in an area is predictable based on climate.
- In closed ecosystems energy but not matter is exchanged with the surroundings.
- Disturbance influences the structure and rate of change within ecosystems.

Applications and skills:

- Application: Conversion ratio in sustainable food production practices.
- Application: Consideration of one example of how humans interfere with nutrient cycling.
- Skill: Comparison of pyramids of energy from different ecosystems.
- Skill: Analysis of a climograph showing the relationship between temperature, rainfall and the type of ecosystem.
- Skill: Construction of Gersmehl diagrams to show the inter-relationships between nutrient stores and flows between taiga, desert and tropical rainforest.

Theory of knowledge:

- Do the entities in scientists' models, for example trophic levels or Gersmehl diagrams, actually exist, or are they primarily useful inventions for predicting and explaining the natural world?

Utilization:

- Poikilotherms (animals that have a variable body temperature) are more effective producers of protein than homeotherms (animals that maintain a regulated body temperature) as they have a higher rate of conversion of food to biomass.

Syllabus and cross-curricular links:
Biology
Topic 4.2 Energy flow

C.2 Communities and ecosystems	
• Skill: Analysis of data showing primary succession. • Skill: Investigation into the effect of an environmental disturbance on an ecosystem. **Guidance:** • Examples of aspects to investigate in the ecosystem could be species diversity, nutrient cycling, water movement, erosion, leaf area index, among others.	

Essential idea: Human activities impact on ecosystem function.

C.3 Impacts of humans on ecosystems	
Nature of science: Assessing risks and benefits associated with scientific research—the use of biological control has associated risk and requires verification by tightly controlled experiments before it is approved. (4.8)	
Understandings: • Introduced alien species can escape into local ecosystems and become invasive. • Competitive exclusion and the absence of predators can lead to reduction in the numbers of endemic species when alien species become invasive. • Pollutants become concentrated in the tissues of organisms at higher trophic levels by biomagnification. • Macroplastic and microplastic debris has accumulated in marine environments. **Applications and skills:** • Application: Study of the introduction of cane toads in Australia and one other local example of the introduction of an alien species. • Application: Discussion of the trade-off between control of the malarial parasite and DDT pollution. • Application: Case study of the impact of marine plastic debris on Laysan albatrosses and one other named species. • Skill*:* Analysis of data illustrating the causes and consequences of biomagnification. • Skill: Evaluation of eradication programmes and biological control as measures to reduce the impact of alien species.	**International-mindedness:** • Over 100 countries across the globe have agreed to ban the production of CFCs to reduce the depletion of the ozone layer. **Aims:** • **Aim 8:** Many developed countries export toxic waste to less developed countries. Is financial compensation a fair exchange for hazardous waste?

Essential idea: Entire communities need to be conserved in order to preserve biodiversity.

C.4 Conservation of biodiversity

Nature of science:

Scientists collaborate with other agencies—the preservation of species involves international cooperation through intergovernmental and non-governmental organizations. (4.3)

Understandings:

- An indicator species is an organism used to assess a specific environmental condition.
- Relative numbers of indicator species can be used to calculate the value of a biotic index.
- *In situ* conservation may require active management of nature reserves or national parks.
- *Ex situ* conservation is the preservation of species outside their natural habitats.
- Biogeographic factors affect species diversity.
- Richness and evenness are components of biodiversity.

Applications and skills:

- Application: Case study of the captive breeding and reintroduction of an endangered animal species.
- Application: Analysis of the impact of biogeographic factors on diversity limited to island size and edge effects.
- Skill: Analysis of the biodiversity of two local communities using Simpson's reciprocal index of diversity.

Guidance:

- The formula for Simpson's reciprocal index of diversity is:

$$D = \frac{N(N-1)}{\Sigma n(n-1)}$$

D = diversity index, N = total number of organisms of all species found and n = number of individuals of a particular species.

Aims:

- **Aim 8:** Scientists supported by governments are devoting relatively large amounts of effort to save particular animal species. Can criteria be established to justify a hierarchy of value of one species over another?

Additional higher level topics

Essential idea: Dynamic biological processes impact population density and population growth.

C.5 Population ecology

Nature of science:

Avoiding bias—a random number generator helps to ensure population sampling is free from bias. (5.4)

Understandings:

- Sampling techniques are used to estimate population size.
- The exponential growth pattern occurs in an ideal, unlimited environment.
- Population growth slows as a population reaches the carrying capacity of the environment.
- The phases shown in the sigmoid curve can be explained by relative rates of natality, mortality, immigration and emigration.
- Limiting factors can be top down or bottom up.

Applications and skills:

- Application: Evaluating the methods used to estimate the size of commercial stock of marine resources.
- Application: Use of the capture-mark-release-recapture method to estimate the population size of an animal species.
- Application: Discussion of the effect of natality, mortality, immigration and emigration on population size.

International-mindedness:

- The issues around the growing global human population are of international concern regardless of different growth rates in different countries.

Utilization:

Syllabus and cross-curricular links:
Geography
Part 1.1 Populations in transition
Environmental systems and societies
Topic 8.4 Human population carrying capacity

C.5 Population ecology	
• Application: Analysis of the effect of population size, age and reproductive status on sustainable fishing practices. • Application: Bottom-up control of algal blooms by shortage of nutrients and top-down control by herbivory. • Skill: Modelling the growth curve using a simple organism such as yeast or species of *Lemna*.	

Essential idea: Soil cycles are subject to disruption.

C.6 Nitrogen and phosphorus cycles	
Nature of science: Assessing risks and benefits of scientific research—agricultural practices can disrupt the phosphorus cycle. (4.8)	
Understandings: • Nitrogen-fixing bacteria convert atmospheric nitrogen to ammonia. • *Rhizobium* associates with roots in a mutualistic relationship. • In the absence of oxygen denitrifying bacteria reduce nitrate in the soil. • Phosphorus can be added to the phosphorus cycle by application of fertilizer or removed by the harvesting of agricultural crops. • The rate of turnover in the phosphorus cycle is much lower than the nitrogen cycle. • Availability of phosphate may become limiting to agriculture in the future. • Leaching of mineral nutrients from agricultural land into rivers causes eutrophication and leads to increased biochemical oxygen demand. **Applications and skills:** • Application: The impact of waterlogging on the nitrogen cycle. • Application: Insectivorous plants as an adaptation for low nitrogen availability in waterlogged soils. • Skill: Drawing and labelling a diagram of the nitrogen cycle. • Skill: Assess the nutrient content of a soil sample.	**Utilization:** • Crop rotations allow the renewal of soil nutrients by allowing an area to remain "fallow".

Core topics

Essential idea: A balanced diet is essential to human health.

D.1 Human nutrition	
Nature of science: Falsification of theories with one theory being superseded by another—scurvy was thought to be specific to humans, because attempts to induce the symptoms in laboratory rats and mice were entirely unsuccessful. (1.9)	
Understandings: • Essential nutrients cannot be synthesized by the body, therefore they have to be included in the diet. • Dietary minerals are essential chemical elements. • Vitamins are chemically diverse carbon compounds that cannot be synthesized by the body. • Some fatty acids and some amino acids are essential. • Lack of essential amino acids affects the production of proteins. • Malnutrition may be caused by a deficiency, imbalance or excess of nutrients in the diet. • Appetite is controlled by a centre in the hypothalamus. • Overweight individuals are more likely to suffer hypertension and type II diabetes. • Starvation can lead to breakdown of body tissue. **Applications and skills:** • Application: Production of ascorbic acid by some mammals, but not others that need a dietary supply. • Application: Cause and treatment of phenylketonuria (PKU).	**International-mindedness:** • The Vitamin and Mineral Nutrition Information System (VMNIS), formerly known as the Micronutrient Deficiency Information System (MDIS), was established in 1991 following a request by the World Health Assembly to strengthen surveillance of micronutrient deficiencies at the global level. **Theory of knowledge:** • There are positive effects of exposure to sun such as the production of Vitamin D as well as health risks associated with exposure to UV rays. How can conflicting knowledge claims be balanced? **Utilization:** Syllabus and cross-curricular links: Biology Topic 6.1 Digestion and absorption Geography Part 2F The geography of food and health Chemistry Topic B5 Vitamins

D.1 Human nutrition

- Application: Lack of Vitamin D or calcium can affect bone mineralization and cause rickets or osteomalacia.
- Application: Breakdown of heart muscle due to anorexia.
- Application: Cholesterol in blood as an indicator of the risk of coronary heart disease.
- Skill: Determination of the energy content of food by combustion.
- Skill: Use of databases of nutritional content of foods and software to calculate intakes of essential nutrients from a daily diet.

Essential idea: Digestion is controlled by nervous and hormonal mechanisms.

D.2 Digestion

Nature of science:

Serendipity and scientific discoveries—the role of gastric acid in digestion was established by William Beaumont while observing the process of digestion in an open wound caused by gunshot. (1.4)

Understandings:	Utilization:
• Nervous and hormonal mechanisms control the secretion of digestive juices. • Exocrine glands secrete to the surface of the body or the lumen of the gut. • The volume and content of gastric secretions are controlled by nervous and hormonal mechanisms. • Acid conditions in the stomach favour some hydrolysis reactions and help to control pathogens in ingested food. • The structure of cells of the epithelium of the villi is adapted to the absorption of food. • The rate of transit of materials through the large intestine is positively correlated with their fibre content. • Materials not absorbed are egested. **Applications and skills:** • Application: The reduction of stomach acid secretion by proton pump inhibitor drugs. • Application: Dehydration due to cholera toxin. • Application: *Helicobacter pylori* infection as a cause of stomach ulcers. • Skill: Identification of exocrine gland cells that secrete digestive juices and villus epithelium cells that absorb digested foods from electron micrographs. **Guidance:** • Adaptations of villus epithelial cells include microvilli and mitochondria.	Syllabus and cross-curricular links: Biology Topic 1.2 Ultrastructure of cells Topic 6.5 Neurons and synapses Chemistry Topic D4 pH regulation of stomach

Essential idea: The chemical composition of the blood is regulated by the liver.

D.3 Functions of the liver

Nature of science:

Educating the public on scientific claims—scientific studies have shown that high-density lipoprotein could be considered "good" cholesterol. (5.2)

Understandings:

- The liver removes toxins from the blood and detoxifies them.
- Components of red blood cells are recycled by the liver.
- The breakdown of erythrocytes starts with phagocytosis of red blood cells by Kupffer cells.
- Iron is carried to the bone marrow to produce hemoglobin in new red blood cells.
- Surplus cholesterol is converted to bile salts.
- Endoplasmic reticulum and Golgi apparatus in hepatocytes produce plasma proteins.
- The liver intercepts blood from the gut to regulate nutrient levels.
- Some nutrients in excess can be stored in the liver.

Applications and skills:

- Application: Causes and consequences of jaundice.
- Application: Dual blood supply to the liver and differences between sinusoids and capillaries.

Theory of knowledge:

- Excessive alcohol consumption may cause liver cirrhosis. Are attitudes to drugs and alcohol an example of something that is relative to culture? Is all knowledge dependent on culture?

Aims:

- **Aim 6:** Temporary mounts of hepatocytes can be prepared from fresh liver.
- **Aim 8:** Given the pressure on health resources, especially the availability of organs for transplant, should an alcoholic be allowed a liver transplant?

Essential idea: Internal and external factors influence heart function.

D.4 The heart

Nature of science:

Developments in scientific research followed improvements in apparatus or instrumentation—the invention of the stethoscope led to improved knowledge of the workings of the heart. (1.8)

Understandings:

- Structure of cardiac muscle cells allows propagation of stimuli through the heart wall.
- Signals from the sinoatrial node that cause contraction cannot pass directly from atria to ventricles.
- There is a delay between the arrival and passing on of a stimulus at the atrioventricular node.
- This delay allows time for atrial systole before the atrioventricular valves close.
- Conducting fibres ensure coordinated contraction of the entire ventricle wall.
- Normal heart sounds are caused by the atrioventricular valves and semilunar valves closing causing changes in blood flow.

Applications and skills:

- Application: Use of artificial pacemakers to regulate the heart rate.
- Application: Use of defibrillation to treat life-threatening cardiac conditions.
- Application: Causes and consequences of hypertension and thrombosis.
- Skill: Measurement and interpretation of the heart rate under different conditions.
- Skill: Interpretation of systolic and diastolic blood pressure measurements.
- Skill: Mapping of the cardiac cycle to a normal ECG trace.
- Skill: Analysis of epidemiological data relating to the incidence of coronary heart disease.

Guidance:

- Include branching and intercalated discs in structure of cardiac muscle.

Theory of knowledge:

- Symbols are used as a form of non-verbal communication. Why is the heart used as a symbol for love? What is the importance of symbols in different areas of knowledge?

Additional higher level topics

Essential idea: Hormones are not secreted at a uniform rate and exert their effect at low concentrations.

D.5 Hormones and metabolism

Nature of science:

Cooperation and collaboration between groups of scientists—the International Council for the Control of Iodine Deficiency Disorders includes a number of scientists who work to eliminate the harm done by iodine deficiency. (4.3)

Understandings:

- Endocrine glands secrete hormones directly into the bloodstream.
- Steroid hormones bind to receptor proteins in the cytoplasm of the target cell to form a receptor–hormone complex.
- The receptor–hormone complex promotes the transcription of specific genes.
- Peptide hormones bind to receptors in the plasma membrane of the target cell.
- Binding of hormones to membrane receptors activates a cascade mediated by a second messenger inside the cell.
- The hypothalamus controls hormone secretion by the anterior and posterior lobes of the pituitary gland.
- Hormones secreted by the pituitary control growth, developmental changes, reproduction and homeostasis.

Applications and skills:

- Application: Some athletes take growth hormones to build muscles.
- Application: Control of milk secretion by oxytocin and prolactin.

Aims:

- **Aim 8:** There are numerous drugs that can enhance performance. Is the use of these drugs acceptable in terms of conducting a fair test as long as all athletes have equal access to them?

Essential idea: Red blood cells are vital in the transport of respiratory gases.

D.6 Transport of respiratory gases

Nature of science:

Scientists have a role in informing the public—scientific research has led to a change in public perception of smoking. (5.1)

Understandings:

- Oxygen dissociation curves show the affinity of hemoglobin for oxygen.
- Carbon dioxide is carried in solution and bound to hemoglobin in the blood.
- Carbon dioxide is transformed in red blood cells into hydrogencarbonate ions.
- The Bohr shift explains the increased release of oxygen by hemoglobin in respiring tissues.
- Chemoreceptors are sensitive to changes in blood pH.
- The rate of ventilation is controlled by the respiratory control centre in the medulla oblongata.
- During exercise the rate of ventilation changes in response to the amount of CO_2 in the blood.
- Fetal hemoglobin is different from adult hemoglobin allowing the transfer of oxygen in the placenta onto the fetal hemoglobin.

Applications and skills:

- Application: Consequences of high altitude for gas exchange.
- Application: pH of blood is regulated to stay within the narrow range of 7.35 to 7.45.
- Application: Causes and treatments of emphysema.
- Skill: Analysis of dissociation curves for hemoglobin and myoglobin.
- Skill: Identification of pneumocytes, capillary endothelium cells and blood cells in light micrographs and electron micrographs of lung tissue.

Utilization:

- Training camps for athletes are frequently located at high altitude to increase the hemoglobin content of the blood. This puts the athlete at an advantage when they return to lower ground for competition.

Syllabus and cross-curricular links:
Biology
Topic 6.4 Gas exchange
Physics
Topic 3.2 Modelling a gas

Aims:

- **Aim 8:** Some sports, such as high-altitude mountain climbing or scuba diving, may push the limits of the human body beyond endurance and cause damage. Should they be controlled or banned?

Assessment in the Diploma Programme

General

Assessment is an integral part of teaching and learning. The most important aims of assessment in the Diploma Programme are that it should support curricular goals and encourage appropriate student learning. Both external and internal assessments are used in the Diploma Programme. IB examiners mark work produced for external assessment, while work produced for internal assessment is marked by teachers and externally moderated by the IB.

There are two types of assessment identified by the IB.

- Formative assessment informs both teaching and learning. It is concerned with providing accurate and helpful feedback to students and teachers on the kind of learning taking place and the nature of students' strengths and weaknesses in order to help develop students' understanding and capabilities. Formative assessment can also help to improve teaching quality, as it can provide information to monitor progress towards meeting the course aims and objectives.
- Summative assessment gives an overview of previous learning and is concerned with measuring student achievement.

The Diploma Programme primarily focuses on summative assessment designed to record student achievement at, or towards the end of, the course of study. However, many of the assessment instruments can also be used formatively during the course of teaching and learning, and teachers are encouraged to do this. A comprehensive assessment plan is viewed as being integral with teaching, learning and course organization. For further information, see the IB *Programme standards and practices* document.

The approach to assessment used by the IB is criterion-related, not norm-referenced. This approach to assessment judges students' work by their performance in relation to identified levels of attainment, and not in relation to the work of other students. For further information on assessment within the Diploma Programme please refer to the publication *Diploma Programme assessment: Principles and practice*.

To support teachers in the planning, delivery and assessment of the Diploma Programme courses, a variety of resources can be found on the OCC or purchased from the IB store (http://store.ibo.org). Additional publications such as specimen papers and markschemes, teacher support materials, subject reports and grade descriptors can also be found on the OCC. Past examination papers as well as markschemes can be purchased from the IB store.

Methods of assessment

The IB uses several methods to assess work produced by students.

Assessment criteria

Assessment criteria are used when the assessment task is open-ended. Each criterion concentrates on a particular skill that students are expected to demonstrate. An assessment objective describes what students should be able to do, and assessment criteria describe how well they should be able to do it. Using assessment criteria allows discrimination between different answers and encourages a variety of responses.

Each criterion comprises a set of hierarchically ordered level descriptors. Each level descriptor is worth one or more marks. Each criterion is applied independently using a best-fit model. The maximum marks for each criterion may differ according to the criterion's importance. The marks awarded for each criterion are added together to give the total mark for the piece of work.

Markbands

Markbands are a comprehensive statement of expected performance against which responses are judged. They represent a single holistic criterion divided into level descriptors. Each level descriptor corresponds to a range of marks to differentiate student performance. A best-fit approach is used to ascertain which particular mark to use from the possible range for each level descriptor.

Analytic markschemes

Analytic markschemes are prepared for those examination questions that expect a particular kind of response and/or a given final answer from students. They give detailed instructions to examiners on how to break down the total mark for each question for different parts of the response.

Marking notes

For some assessment components marked using assessment criteria, marking notes are provided. Marking notes give guidance on how to apply assessment criteria to the particular requirements of a question.

Inclusive assessment arrangements

Inclusive assessment arrangements are available for candidates with assessment access requirements. These arrangements enable candidates with diverse needs to access the examinations and demonstrate their knowledge and understanding of the constructs being assessed.

The IB document *Candidates with assessment access requirements* provides details on all the inclusive assessment arrangements available to candidates with learning support requirements. The IB document *Learning diversity within the International Baccalaureate programmes/Special educational needs within the International Baccalaureate programmes* outlines the position of the IB with regard to candidates with diverse learning needs in the IB programmes. For candidates affected by adverse circumstances, the IB documents *General regulations: Diploma Programme* and the *Handbook of procedures for the Diploma Programme* provide details on access consideration.

Responsibilities of the school

The school is required to ensure that equal access arrangements and reasonable adjustments are provided to candidates with learning support requirements that are in line with the IB documents *Candidates with assessment access requirements* and *Learning diversity within the International Baccalaureate programmes/ Special educational needs within the International Baccalaureate programmes*.

Assessment outline—SL

First assessment 2016

Component	Overall weighting (%)	Approximate weighting of objectives (%)		Duration (hours)
		1+2	3	
Paper 1	20	10	10	¾
Paper 2	40	20	20	1¼
Paper 3	20	10	10	1
Internal assessment	20	Covers objectives 1, 2, 3 and 4		10

Assessment outline—HL

First assessment 2016

Component	Overall weighting (%)	Approximate weighting of objectives (%)		Duration (hours)
		1+2	3	
Paper 1	20	10	10	1
Paper 2	36	18	18	2¼
Paper 3	24	12	12	1¼
Internal assessment	20	Covers objectives 1, 2, 3 and 4		10

External assessment

Detailed markschemes specific to each examination paper are used to assess students.

External assessment details—SL

Paper 1

Duration: ¾ hour
Weighting: 20%
Marks: 30

- 30 multiple-choice questions on core material, about 15 of which are common with HL.
- The questions on paper 1 test assessment objectives 1, 2 and 3.
- The use of calculators is not permitted.
- No marks are deducted for incorrect answers.

Paper 2

Duration: 1¼ hours
Weighting: 40%
Marks: 50

- Data-based question.
- Short-answer and extended-response questions on core material.
- One out of two extended response questions to be attempted by candidates.
- The questions on paper 2 test assessment objectives 1, 2 and 3.
- The use of calculators is permitted. (See calculator section on the OCC.)

Paper 3

Duration: 1 hour
Weighting: 20%
Marks: 35

- This paper will have questions on core and SL option material.
- Section A: candidates answer all questions, two to three short-answer questions based on experimental skills and techniques, analysis and evaluation, using unseen data linked to the core material.
- Section B: short-answer and extended-response questions from one option.
- The questions on paper 3 test assessment objectives 1, 2 and 3.
- The use of calculators is permitted. (See calculator section on the OCC.)

External assessment details—HL

Paper 1

Duration: 1 hour
Weighting: 20%
Marks: 40

- 40 multiple-choice questions on core and AHL material, about 15 of which are common with SL.
- The questions on paper 1 test assessment objectives 1, 2 and 3.
- The use of calculators is not permitted.
- No marks are deducted for incorrect answers.

Paper 2

Duration: 2¼ hours
Weighting: 36%
Marks: 72

- Data-based question.
- Short-answer and extended-response questions on core and AHL material.
- Two out of three extended response questions to be attempted by candidates.
- The questions on paper 2 test assessment objectives 1, 2 and 3.
- The use of calculators is permitted. (See calculator section on the OCC.)

Paper 3

Duration: 1¼ hours
Weighting: 24%
Marks: 45

- Section A: candidates answer all questions, two to three short-answer questions based on experimental skills and techniques, analysis and evaluation, using unseen data linked to the core and AHL material.
- Section B: short-answer and extended-response questions from one option.
- The questions on paper 3 test assessment objectives 1, 2 and 3.
- The use of calculators is permitted. (See calculator section on the OCC.)

Internal assessment

Purpose of internal assessment

Internal assessment is an integral part of the course and is compulsory for both SL and HL students. It enables students to demonstrate the application of their skills and knowledge, and to pursue their personal interests, without the time limitations and other constraints that are associated with written examinations. The internal assessment should, as far as possible, be woven into normal classroom teaching and not be a separate activity conducted after a course has been taught.

The internal assessment requirements at SL and at HL are the same. This internal assessment section of the guide should be read in conjunction with the internal assessment section of the teacher support materials.

Guidance and authenticity

The work submitted for internal assessment must be the student's own work. However, it is not the intention that students should decide upon a title or topic and be left to work on the internal assessment component without any further support from the teacher. The teacher should play an important role during both the planning stage and the period when the student is working on the internally assessed work. It is the responsibility of the teacher to ensure that students are familiar with:

- the requirements of the type of work to be internally assessed
- the IB animal experimentation policy and the biology course safety guidelines
- the assessment criteria—students must understand that the work submitted for assessment must address these criteria effectively.

Teachers and students must discuss the internally assessed work. Students should be encouraged to initiate discussions with the teacher to obtain advice and information, and students must not be penalized for seeking guidance. As part of the learning process, teachers should read and give advice to students on one draft of the work. The teacher should provide oral or written advice on how the work could be improved, but not edit the draft. The next version handed to the teacher must be the final version for submission.

It is the responsibility of teachers to ensure that all students understand the basic meaning and significance of concepts that relate to academic honesty, especially authenticity and intellectual property. Teachers must ensure that all student work for assessment is prepared according to the requirements and must explain clearly to students that the internally assessed work must be entirely their own. Where collaboration between students is permitted, it must be clear to all students what the difference is between collaboration and collusion.

All work submitted to the IB for moderation or assessment must be authenticated by a teacher, and must not include any known instances of suspected or confirmed academic misconduct. Each student must confirm that the work is his or her authentic work and constitutes the final version of that work. Once a student has officially submitted the final version of the work it cannot be retracted. The requirement to confirm the authenticity of work applies to the work of all students, not just the sample work that will be submitted to the IB for the purpose of moderation. For further details refer to the IB publication *Academic honesty* (2011), *The Diploma Programme: From principles into practice* (2009) and the relevant articles in *General regulations: Diploma Programme* (2011).

Authenticity may be checked by discussion with the student on the content of the work, and scrutiny of one or more of the following:

- the student's initial proposal
- the first draft of the written work
- the references cited
- the style of writing compared with work known to be that of the student
- the analysis of the work by a web-based plagiarism detection service such as http://www.turnitin.com.

The same piece of work cannot be submitted to meet the requirements of both the internal assessment and the extended essay.

Group work

Each investigation is an individual piece of work based on different data collected or measurements generated. Ideally, students should work on their own when collecting data. In some cases, data collected or measurements made can be from a group experiment provided each student collected his or her own data or made his or her own measurements. In biology, in some cases, group data or measurements may be combined to provide enough for individual analysis. Even in this case, each student should have collected and recorded their own data and they should clearly indicate which data are theirs.

It should be made clear to students that all work connected with the investigation should be their own. It is therefore helpful if teachers try to encourage in students a sense of responsibility for their own learning so that they accept a degree of ownership and take pride in their own work.

Time allocation

Internal assessment is an integral part of the biology course, contributing 20% to the final assessment in the SL and the HL courses. This weighting should be reflected in the time that is allocated to teaching the knowledge, skills and understanding required to undertake the work, as well as the total time allocated to carry out the work.

It is recommended that a total of approximately 10 hours of teaching time for both SL and HL should be allocated to the work. This should include:

- time for the teacher to explain to students the requirements of the internal assessment
- class time for students to work on the internal assessment component and ask questions
- time for consultation between the teacher and each student
- time to review and monitor progress, and to check authenticity.

Safety requirements and recommendations

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

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.

The Laboratory Safety Institute's Laboratory Safety Guidelines...

40 suggestions for a safer lab

Steps Requiring Minimal Expense

1. Have a written health, safety and environmental affairs (HS&E) policy statement.
2. Organize a departmental HS&E committee of employees, management, faculty, staff and students that will meet regularly to discuss HS&E issues.
3. Develop an HS&E orientation for all new employees and students.
4. Encourage employees and students to care about their health and safety and that of others.
5. Involve every employee and student in some aspect of the safety program and give each specific responsibilities.
6. Provide incentives to employees and students for safety performance.
7. Require all employees to read the appropriate safety manual. Require students to read the institution's laboratory safety rules. Have both groups sign a statement that they have done so, understand the contents, and agree to follow the procedures and practices. Keep these statements on file in the department office
8. Conduct periodic, unannounced laboratory inspections to identify and correct hazardous conditions and unsafe practices. Involve students and employees in simulated OSHA inspections.
9. Make learning how to be safe an integral and important part of science education, your work, and your life.
10. Schedule regular departmental safety meetings for all students and employees to discuss the results of inspections and aspects of laboratory safety.
11. When conducting experiments with hazards or potential hazards, ask yourself these questions:
    - What are the hazards?
    - What are the worst possible things that could go wrong?
    - How will I deal with them?
    - What are the prudent practices, protective facilities and equipment necessary to minimize the risk of exposure to the hazards?
12. Require that all accidents (incidents) be reported, evaluated by the departmental safety committee, and discussed at departmental safety meetings.
13. Require every pre-lab/pre-experiment discussion to include consideration of the health and safety aspects.
14. Don't allow experiments to run unattended unless they are failsafe.
15. Forbid working alone in any laboratory and working without prior knowledge of a staff member.
16. Extend the safety program beyond the laboratory to the automobile and the home.
17. Allow only minimum amounts of flammable liquids in each laboratory.
18. Forbid smoking, eating and drinking in the laboratory.
19. Do not allow food to be stored in chemical refrigerators.

20. Develop plans and conduct drills for dealing with emergencies such as fire, explosion, poisoning, chemical spill or vapour release, electric shock, bleeding and personal contamination.
21. Require good housekeeping practices in all work areas.
22. Display the phone numbers of the fire department, police department, and local ambulance either on or immediately next to every phone.
23. Store acids and bases separately. Store fuels and oxidizers separately.
24. Maintain a chemical inventory to avoid purchasing unnecessary quantities of chemicals.
25. Use warning signs to designate particular hazards.
26. Develop specific work practices for individual experiments, such as those that should be conducted only in a ventilated hood or involve particularly hazardous materials. When possible most hazardous experiments should be done in a hood.

Steps Requiring Moderate Expense

27. Allocate a portion of the departmental budget to safety.
28. Require the use of appropriate eye protection at all times in laboratories and areas where chemicals are transported.
29. Provide adequate supplies of personal protective equipment—safety glasses, goggles, face shields, gloves, lab coats and bench top shields.
30. Provide fire extinguishers, safety showers, eye wash fountains, first aid kits, fire blankets and fume hoods in each laboratory and test or check monthly.
31. Provide guards on all vacuum pumps and secure all compressed gas cylinders.
32. Provide an appropriate supply of first aid equipment and instruction on its proper use.
33. Provide fireproof cabinets for storage of flammable chemicals.
34. Maintain a centrally located departmental safety library:
    - "Safety in School Science Labs", Clair Wood, 1994, Kaufman & Associates, 101 Oak Street, Wellesley, MA 02482
    - "The Laboratory Safety Pocket Guide", 1996, Genium Publisher, One Genium Plaza, Schnectady, NY
    - "Safety in Academic Chemistry Laboratories", ACS, 1155 Sixteenth Street NW, Washington, DC 20036
    - "Manual of Safety and Health Hazards in The School Science Laboratory", "Safety in the School Science Laboratory", "School Science Laboratories: A guide to Some Hazardous Substances" Council of State Science Supervisors (now available only from LSI.)
    - "Handbook of Laboratory Safety", 4th Edition, CRC Press, 2000 Corporate Boulevard NW, Boca Raton, FL 33431
    - "Fire Protection Guide on Hazardous Materials", National Fire Protection Association, Batterymarch Park, Quincy, MA 02269
    - "Prudent Practices in the Laboratory: Handling and Disposal of Hazardous Chemicals", 2nd Edition, 1995
    - "Biosafety in the Laboratory", National Academy Press, 2101 Constitution Avenue, NW, Washington, DC 20418
    - "Learning By Accident", Volumes 1-3, 1997-2000, The Laboratory Safety Institute, Natick, MA 01760

    (All are available from LSI.)

35. Remove all electrical connections from inside chemical refrigerators and require magnetic closures.
36. Require grounded plugs on all electrical equipment and install ground fault interrupters (GFIs) where appropriate.
37. Label all chemicals to show the name of the material, the nature and degree of hazard, the appropriate precautions, and the name of the person responsible for the container.
38. Develop a program for dating stored chemicals and for recertifying or discarding them after predetermined maximum periods of storage.
39. Develop a system for the legal, safe and ecologically acceptable disposal of chemical wastes.
40. Provide secure, adequately spaced, well ventilated storage of chemicals.

LSi
The Laboratory Safety Institute

Using assessment criteria for internal assessment

For internal assessment, a number of assessment criteria have been identified. Each assessment criterion has level descriptors describing specific achievement levels, together with an appropriate range of marks. The level descriptors concentrate on positive achievement, although for the lower levels failure to achieve may be included in the description.

Teachers must judge the internally assessed work at SL and at HL against the criteria using the level descriptors.

- Assessment criteria are the same for both SL and HL.
- The aim is to find, for each criterion, the descriptor that conveys most accurately the level attained by the student, using the best-fit model. A best-fit approach means that compensation should be made when a piece of work matches different aspects of a criterion at different levels. The mark awarded should be one that most fairly reflects the balance of achievement against the criterion. It is not necessary for every single aspect of a level descriptor to be met for that mark to be awarded.
- When assessing a student's work, teachers should read the level descriptors for each criterion until they reach a descriptor that most appropriately describes the level of the work being assessed. If a piece of work seems to fall between two descriptors, both descriptors should be read again and the one that more appropriately describes the student's work should be chosen.
- Where there are two or more marks available within a level, teachers should award the upper marks if the student's work demonstrates the qualities described to a great extent; the work may be close to achieving marks in the level above. Teachers should award the lower marks if the student's work demonstrates the qualities described to a lesser extent; the work may be close to achieving marks in the level below.
- Only whole numbers should be recorded; partial marks (fractions and decimals) are not acceptable.
- Teachers should not think in terms of a pass or fail boundary, but should concentrate on identifying the appropriate descriptor for each assessment criterion.

- The highest level descriptors do not imply faultless performance but should be achievable by a student. Teachers should not hesitate to use the extremes if they are appropriate descriptions of the work being assessed.
- A student who attains a high achievement level in relation to one criterion will not necessarily attain high achievement levels in relation to the other criteria. Similarly, a student who attains a low achievement level for one criterion will not necessarily attain low achievement levels for the other criteria. Teachers should not assume that the overall assessment of the students will produce any particular distribution of marks.
- It is recommended that the assessment criteria be made available to students.

Practical work and internal assessment

General introduction

The internal assessment requirements are the same for biology, chemistry and physics. The internal assessment, worth 20% of the final assessment, consists of one scientific investigation. The individual investigation should cover a topic that is commensurate with the level of the course of study.

Student work is internally assessed by the teacher and externally moderated by the IB. The performance in internal assessment at both SL and HL is marked against common assessment criteria, with a total mark out of 24.

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

The internal assessment task will be one scientific investigation taking about 10 hours and the write-up should be about 6 to 12 pages long. Investigations exceeding this length will be penalized in the communication criterion as lacking in conciseness.

The practical investigation, with generic criteria, will allow a wide range of practical activities satisfying the varying needs of biology, chemistry and physics. The investigation addresses many of the learner profile attributes well. See section on "Approaches to teaching and learning" for further links.

The task produced should be complex and commensurate with the level of the course. It should require a purposeful research question and the scientific rationale for it. The marked exemplar material in the teacher support material will demonstrate that the assessment will be rigorous and of the same standard as the assessment in the previous courses.

Some of the possible tasks include:

- a hands-on laboratory investigation
- using a spreadsheet for analysis and modelling
- extracting data from a database and analysing it graphically
- producing a hybrid of spreadsheet/database work with a traditional hands-on investigation
- using a simulation provided it is interactive and open-ended.

Some tasks may consist of relevant and appropriate qualitative work combined with quantitative work.

The tasks include the traditional hands-on practical investigations as in the previous course. The depth of treatment required for hands-on practical investigations is unchanged from the previous internal assessment and will be shown in detail in the teacher support materials. In addition, detailed assessment of specific aspects of hands-on practical work will be assessed in the written papers as detailed in the relevant topic(s) in the "Syllabus content" section of the guide.

The task will have the same assessment criteria for SL and HL. The five assessment criteria are personal engagement, exploration, analysis, evaluation and communication.

Internal assessment details

Internal assessment component

Duration: 10 hours
Weighting: 20%

- Individual investigation.
- This investigation covers assessment objectives 1, 2, 3 and 4.

Internal assessment criteria

The new assessment model uses five criteria to assess the final report of the individual investigation with the following raw marks and weightings assigned:

Personal engagement	Exploration	Analysis	Evaluation	Communication	Total
2 (8%)	6 (25%)	6 (25%)	6 (25%)	4 (17%)	24 (100%)

Levels of performance are described using multiple indicators per level. In many cases the indicators occur together in a specific level, but not always. Also, not all indicators are always present. This means that a candidate can demonstrate performances that fit into different levels. To accommodate this, the IB assessment models use markbands and advise examiners and teachers to use a **best-fit approach** in deciding the appropriate mark for a particular criterion.

Teachers should read the guidance on using markbands shown above in the section called "Using assessment criteria for internal assessment" before starting to mark. It is also essential to be fully acquainted with the marking of the exemplars in the teacher support material. The precise meaning of the command terms used in the criteria can be found in the glossary of the subject guides.

Personal engagement

This criterion assesses the extent to which the student engages with the exploration and makes it their own. Personal engagement may be recognized in different attributes and skills. These could include addressing personal interests or showing evidence of independent thinking, creativity or initiative in the designing, implementation or presentation of the investigation.

Mark	Descriptor
0	The student's report does not reach a standard described by the descriptors below.
1	**The evidence of personal engagement with the exploration is limited with little independent thinking, initiative or creativity.** The justification given for choosing the research question and/or the topic under investigation does not demonstrate **personal significance, interest or curiosity.** There is little evidence of **personal input and initiative** in the designing, implementation or presentation of the investigation.
2	**The evidence of personal engagement with the exploration is clear with significant independent thinking, initiative or creativity.** The justification given for choosing the research question and/or the topic under investigation demonstrates **personal significance, interest or curiosity.** There is evidence of **personal input and initiative** in the designing, implementation or presentation of the investigation.

Exploration

This criterion assesses the extent to which the student establishes the scientific context for the work, states a clear and focused research question and uses concepts and techniques appropriate to the Diploma Programme level. Where appropriate, this criterion also assesses awareness of safety, environmental, and ethical considerations.

Mark	Descriptor
0	The student's report does not reach a standard described by the descriptors below.
1–2	The topic of the investigation is identified and a research question of some relevance is **stated but it is not focused**. The background information provided for the investigation is **superficial** or of limited relevance and does not aid the understanding of the context of the investigation. The methodology of the investigation is only appropriate to address the research question to a very limited extent since it takes into consideration few of the significant factors that may influence the relevance, reliability and sufficiency of the collected data. The report shows evidence of limited awareness of the significant **safety,** ethical or environmental issues that are **relevant to the methodology of the investigation***.
3–4	The topic of the investigation is identified and a relevant but not fully focused research question is described. The background information provided for the investigation is mainly appropriate and relevant and aids the understanding of the context of the investigation. The methodology of the investigation is mainly appropriate to address the research question but has limitations since it takes into consideration only some of the significant factors that may influence the relevance, reliability and sufficiency of the collected data. The report shows evidence of some awareness of the significant **safety,** ethical or environmental issues that are **relevant to the methodology of the investigation***.

Mark	Descriptor
5–6	The topic of the investigation is identified and a relevant and fully focused research question is clearly described. The background information provided for the investigation is entirely appropriate and relevant and enhances the understanding of the context of the investigation. The methodology of the investigation is highly appropriate to address the research question because it takes into consideration all, or nearly all, of the significant factors that may influence the relevance, reliability and sufficiency of the collected data. The report shows evidence of full awareness of the significant **safety,** ethical or environmental issues that are **relevant to the methodology of the investigation***.

* This indicator should only be applied when appropriate to the investigation. See exemplars in TSM.

Analysis

This criterion assesses the extent to which the student's report provides evidence that the student has selected, recorded, processed and **interpreted** the data in ways that are relevant to the research question and can support a conclusion.

Mark	Descriptor
0	The student's report does not reach a standard described by the descriptors below.
1–2	The report includes **insufficient relevant** raw data to support a valid conclusion to the research question. Some **basic** data processing is carried out but is either too **inaccurate or too insufficient to lead to a valid** conclusion. The report shows evidence of little consideration of the impact of measurement uncertainty on the analysis. The processed data is incorrectly or insufficiently interpreted so that the conclusion is invalid or very incomplete.
3–4	The report includes relevant but incomplete quantitative and qualitative raw data that could support a simple or partially valid conclusion to the research question. Appropriate and sufficient data processing is carried out that could lead to a broadly valid conclusion but there are significant inaccuracies and inconsistencies in the processing. The report shows evidence of some consideration of the impact of measurement uncertainty on the analysis. The processed data is interpreted so that a broadly valid but incomplete or limited conclusion to the research question can be deduced.

Mark	Descriptor
5–6	The report includes sufficient relevant quantitative and qualitative raw data that could support a detailed and valid conclusion to the research question. Appropriate and sufficient data processing is carried out with **the accuracy** required to enable a conclusion to the research question to be drawn that is fully **consistent** with the experimental data. The report shows evidence of full and appropriate consideration of the impact of measurement uncertainty on the analysis. The processed data is correctly interpreted so that a completely valid and detailed conclusion to the research question can be deduced.

Evaluation

This criterion assesses the extent to which the student's report provides evidence of evaluation of the investigation and the results with regard to the research question and the accepted scientific context.

Mark	Descriptor
0	The student's report does not reach a standard described by the descriptors below.
1–2	A conclusion is **outlined** which is not relevant to the research question or is not supported by the data presented. The conclusion makes superficial comparison to the accepted scientific context. Strengths and weaknesses of the investigation, such as limitations of the data and sources of error, are **outlined** but are restricted to an **account** of **the practical** or **procedural issues** faced. The student has **outlined** very few realistic and relevant suggestions for the improvement and extension of the investigation.
3–4	A conclusion is **described** which is relevant to the research question and supported by the data presented. A conclusion is described which makes some relevant comparison to the accepted scientific context. Strengths and weaknesses of the investigation, such as limitations of the data and sources of error, are **described** and provide evidence of some awareness of the **methodological issues*** involved in establishing the conclusion. The student has **described** some realistic and relevant suggestions for the improvement and extension of the investigation.

Mark	Descriptor
5–6	A detailed conclusion is **described and justified** which is entirely relevant to the research question and fully supported by the data presented. A conclusion is correctly **described and justified** through relevant comparison to the accepted scientific context. Strengths and weaknesses of the investigation, such as limitations of the data and sources of error, are **discussed** and provide evidence of a clear understanding of the **methodological issues*** involved in establishing the conclusion. The student has **discussed** realistic and relevant suggestions for the improvement and extension of the investigation.

*See exemplars in TSM for clarification.

Communication

This criterion assesses whether the investigation is presented and reported in a way that supports effective communication of the focus, process and outcomes.

Mark	Descriptor
0	The student's report does not reach a standard described by the descriptors below.
1–2	**The presentation of the investigation is unclear, making it difficult to understand the focus, process and outcomes.** The report is not well structured and is unclear: the necessary information on focus, process and outcomes is missing or is presented in an incoherent or disorganized way. The understanding of the focus, process and outcomes of the investigation is obscured by the presence of inappropriate or irrelevant information. There are many errors in the use of subject-specific terminology and conventions*.
3–4	**The presentation of the investigation is clear. Any errors do not hamper understanding of the focus, process and outcomes**. The report is well structured and clear: the necessary information on focus, process and outcomes is present and presented in a coherent way. The report is relevant and concise thereby facilitating a ready understanding of the focus, process and outcomes of the investigation. The use of subject-specific terminology and conventions is appropriate and correct. Any errors do not hamper understanding.

*For example, incorrect/missing labelling of graphs, tables, images; use of units, decimal places. For issues of referencing and citations refer to the "Academic honesty" section.

Rationale for practical work

Although the requirements for IA are centred on the investigation, the different types of practical activities 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 much scientific work
- developing an appreciation of scientists' use of secondary data from databases
- developing an appreciation of scientists' use of modelling
- developing an appreciation of the benefits and limitations of scientific methodology.

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 practical work 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 investigation.

Planning your practical scheme of work

Teachers are free to formulate their own practical schemes of work by choosing practical activities 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 experiments 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 practical activities by joining in the discussion forums and adding resources in the subject home pages.

Flexibility

The practical programme is flexible enough to allow a wide variety of practical activities to be carried out. These could include:

- short labs or projects extending over several weeks
- computer simulations
- using databases for secondary data
- developing and using models

- data-gathering exercises such as questionnaires, user trials and surveys
- data-analysis exercises
- fieldwork.

Practical work documentation

Details of the practical scheme of work are recorded on *Form 4/PSOW* provided in the *Handbook of Procedures*. A copy of the class *4/PSOW* form must be included with any sample set sent for moderation. For an SL only class or an HL only class, only one *4/PSOW* is required, but for a mixed SL/HL class, separate *4/PSOW* forms are required for SL and HL.

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 and 10 hours for the internal assessment investigation. (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.)

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, rather than the **products of, such an activity.**

In most cases 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.

Students studying environmental systems and societies are not required to undertake 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 "develop an understanding of the relationships between scientific disciplines and their influence on other areas of knowledge". 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 developing the practical scheme of work, 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 are 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 21st century communication 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 technology (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, websites, digital video and so on).

Aim 8: "become critically aware, as global citizens, of the ethical implications of using science and technology."

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.

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 logistical reasons some schools may opt for single subject groups, with one or more topics in the action phase. This model is less desirable as it does not show the mixed subject collaboration in which many scientists are involved.

Model D: collaboration with another school

The collaborative model is open to any school. To this end, the IB provides an electronic collaboration board on the OCC where schools can post their project ideas and invite collaboration from other schools. 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 Programme students or schools with Diploma Programme course 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 IB 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 schoolwork 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 and the teacher then decides 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.

A reflective statement written by each student on their involvement in the group 4 project must be included on the coversheet for each internal assessment investigation. See *Handbook of Procedures* for more details.

Glossary of command terms

Command terms with definitions

Students should be familiar with the following key terms and phrases used in examination questions. Although these terms will be used frequently in examination questions, other terms may be used to direct students to present an argument in a specific way.

These command terms indicate the depth of treatment required.

Assessment objective 1

Define	Give the precise meaning of a word, phrase, concept or physical quantity.
Draw	Represent by means of a labelled, accurate diagram or graph, using a pencil. A ruler (straight edge) should be used for straight lines. Diagrams should be drawn to scale. Graphs should have points correctly plotted (if appropriate) and joined in a straight line or smooth curve.
Label	Add labels to a diagram.
List	Give a sequence of brief answers with no explanation.
Measure	Obtain a value for a quantity.
State	Give a specific name, value or other brief answer without explanation or calculation.

Assessment objective 2

Annotate	Add brief notes to a diagram or graph.
Calculate	Obtain a numerical answer showing the relevant stages in the working (unless instructed not to do so).
Describe	Give a detailed account.
Distinguish	Make clear the differences between two or more concepts or items.
Estimate	Obtain an approximate value.
Identify	Provide an answer from a number of possibilities.
Outline	Give a brief account or summary.

Assessment objective 3

Analyse	Break down in order to bring out the essential elements or structure.
Comment	Give a judgment based on a given statement or result of a calculation.
Compare	Give an account of the similarities between two (or more) items or situations, referring to both (all) of them throughout.
Compare and contrast	Give an account of similarities and differences between two (or more) items or situations, referring to both (all) of them throughout.
Construct	Display information in a diagrammatic or logical form.
Deduce	Reach a conclusion from the information given.
Design	Produce a plan, simulation or model.
Determine	Obtain the only possible answer.
Discuss	Offer a considered and balanced review that includes a range of arguments, factors or hypotheses. Opinions or conclusions should be presented clearly and supported by appropriate evidence.
Evaluate	Make an appraisal by weighing up the strengths and limitations.
Explain	Give a detailed account including reasons or causes.
Predict	Give an expected result.
Sketch	Represent by means of a diagram or graph (labelled as appropriate). The sketch should give a general idea of the required shape or relationship, and should include relevant features.
Suggest	Propose a solution, hypothesis or other possible answer.

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This bibliography lists the principal works used to inform the curriculum review. It is not an exhaustive list and does not include all the literature available: judicious selection was made in order to better advise and guide teachers. This bibliography is not a list of recommended textbooks.

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