Diploma Programme

Biology teacher support material

First assessment 2025

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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.

The purpose of this teacher support material

Welcome to the Diploma Programme (DP) biology teacher support material (TSM). This material is designed to assist both new and experienced teachers to build or revise their course design. It is intended to add insight, inspiration and guidance to the teacher and student journey by:

- supporting experienced and inexperienced teachers alike in structuring and delivering a course
- supporting teachers with the organization of experimental work
- complementing IB professional development.

The TSM is structured to cover generic issues such as the approaches to learning and approaches to teaching and how these relate to biology, as well as subject-specific considerations such as nature of science (NOS) and skills in the study of biology.

Acknowledgements

The International Baccalaureate (IB) would like to thank the educators who contributed time and resources to the development of the DP *Biology guide* and TSM.

Course overview

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

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

The teaching sequence

The topics can be taught in many different sequences. Examples of different possible routes through the syllabus are given in the section "Planning the teaching of the course" in this TSM. Teachers are encouraged to plan their own route according to their circumstances and interests. Wherever possible, teachers are encouraged to use local and global examples to extend students' appreciation and application of the course concepts.

Skills in the study of biology

The syllabus aims to encourage a hands-on inquiry approach wherever possible. Guided discovery and learning through seeing and doing is essential. The "Skills in the study of biology" section in the DP *Biology guide* summarizes the tools and inquiry process students are expected to experience during the course. This includes important laboratory techniques, mathematical and digital skills. Teachers are free to include these skills wherever they choose during the teaching of the course.

Nature of science (NOS)

It is expected that an awareness of the process of science pervades the course. An introduction to NOS is given in the guide and is covered in more detail in the "Nature of science" section of this TSM. Teachers are encouraged to include relevant examples and anecdotes from past and current scientific developments.

Syllabus structure and features

This section contains examples of guiding questions and linking questions from the *Biology guide* and suggests ways in which they can be incorporated into classroom discussion.

The other structures and features of the syllabus are explained in the "Syllabus format" section of the *Biology guide*.

Guiding questions

Each topic starts with two guiding questions. These are overarching questions that frame the topic and guide inquiry. They help to link the material to the theme or to the level of biological organization.

Students may be able to answer the questions in different ways at different stages of their learning, with increasing depth and breadth as their understanding of the topic develops.

The guiding questions can be used to support learning and teaching as:

- **openers** for a topic
- **tools** for the assessment of learning
- **stimuli** to generate further guiding questions.

Guiding questions as openers for a topic

The question may provide a prompt for discussions based on students' prior knowledge, either from earlier courses or from topics previously studied within the course. These discussions may help suggest ways to introduce the content.

Guiding questions as tools for the assessment of learning

The questions could be asked at various times within the study of the topics, looking for increasing breadth and depth of comprehension of the syllabus.

Guiding questions as stimuli to generate further guiding questions

Teachers and students may consider additional guiding questions, which may be included at different points in the coverage of the topic. Such questions may be used to help learning and teaching in any of the ways described above.

Linking questions

Two linking questions are provided at the end of each topic. They are designed to promote networking across the syllabus and may suggest:

- links between different topics
- references to skills in the study of biology.

In seeking to answer these questions, students are encouraged to make connections across the syllabus to illustrate the interconnectedness of concepts and the holistic nature of the subject.

Teachers are encouraged to pose their own linking questions.

Students are expected to demonstrate networked knowledge as modelled through linking questions within the external assessment.

The linking questions can be used to support learning and teaching:

- as connections between different conceptual lenses

- to apply biology in a real-world context.

Each of these approaches is explored in this section using different examples of linking questions from the *Biology guide*. Note that each response answer is just one example of how a linking question might be answered.

Linking questions as connections between different conceptual lenses

Linking questions encourage students to recognize that topics can be viewed through lenses other than a single theme or level of organization. They often invite students to inquire into concepts in biology outside the themes or levels of organization, such as regulation, specificity, directionality and energy flow. Their inclusion in the syllabus helps students to network knowledge, which is a core aspect of conceptual learning.

Note: Ideally, linking questions should connect to three different topics in the syllabus to mirror the structure of extended-response questions.

Consider the following linking questions from topic A1.1 and the examples that follow showing how they could be addressed.

Linking questions from the guide

A1.1 Water

Unity and diversity—Molecules

Standard level and higher level: 2 hours

Additional higher level: 1 hour

[...]

Linking questions

How do the various intermolecular forces of attraction affect biological systems?

What biological processes only happen at or near surfaces?

Example 1: How do the various intermolecular forces of attraction affect biological systems?

Intermolecular forces are important in biological systems (A1.1.3). These forces of attraction or repulsion between molecules affect both structure and function, for example, in DNA (A1.2.6) and in the plasma membrane (B1.1.12).

The relevant themes and levels of organization for example 1

		Level of organization			
		1. Molecules	2. Cells	3. Organisms	4. Ecosystems
Theme	A. Unity and diversity				
	B. Form and function				
	C. Interaction and interdependence				
	D. Continuity and change				

Unity and diversity—Molecules

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

Unity and diversity—Molecules

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

Form and function—Molecules

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

This linking question could be used to create an extended-response question.

Examples of extended-response questions

Intermolecular forces are important in biological systems. These forces of attraction or repulsion between molecules affect both their structure and function.

a. Outline how the properties of cohesion and adhesion are important to living things.

b. Describe the role of hydrogen bonding in the structure of DNA.

c. Explain the importance of hydrophobic interactions in the structure of the plasma membrane.

Example 2: Which biological processes only happen at or near surfaces?

A surface can serve as a habitat (A1.1.3) and be a unique location for processes such as materials exchange (B2.3.6) and intercellular communication (C2.1.6).

The relevant themes and levels of organization for example 2

		Level of organization			
		1. Molecules	2. Cells	3. Organisms	4. Ecosystems
Theme	A. Unity and diversity	■			
	B. Form and function		■		
	C. Interaction and interdependence		■		
	D. Continuity and change				

Unity and diversity—Molecules

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

Form and function—Cells

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

Interaction and interdependence—Cells

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

With respect to assessment, linking questions are relevant to extended-response questions in Part B of Paper 2. For the current example, teachers could devise their own extended-response questions for students to practise.

Examples of extended-response questions

Surfaces can serve as a habitat and be a unique location for processes such as materials exchange and intercellular communication.

Outline an example of how the surface of water acts as a habitat.

Describe the role of cell surface receptors in chemical signalling.

Explain the relationship between surface area-to-volume ratio and materials exchange.

Linking questions to apply biology in a real-world context

Also refer to the "International-mindedness" section for guidance.

Downloadable resource
Examples of linking questions to promote international-mindedness in the study of biology (PDF)

Nature of science (NOS)

The rationale for NOS

Students develop a thorough and lasting understanding of the natural sciences, which has value on several levels.

1. It develops scientific literacy—being able to engage with local and global scientific issues is central to many of the qualities in the IB learner profile.
2. It provides a framework in which students can more easily access science subjects, as in the following examples.
   - Appreciating that technological developments can create new possibilities for experiments. When radioisotopes were made available to scientists as research tools, the Hershey–Chase experiment became possible.
   - Appreciating that technological developments can open up new possibilities for computational modelling allows for the understanding of complex systems.
3. It supports student learning in theory of knowledge (TOK)—NOS understandings are the starting point for being able to think critically about the natural sciences and knowledge more broadly.

Engaging with NOS

Teachers are not expected to address NOS as a stand-alone topic, but instead to integrate it within the teaching of the subject. As always, it is best to vary the style of teaching rather than resort to a formulaic strategy for NOS. Several approaches are outlined here.

- It is often helpful when introducing new scientific concepts to frame them in terms of the progression of science and the use of scientific methodologies. This might mean briefly revisiting a preceding model or theory, or reviewing the evidence or technology that led to new understandings.
  - It became possible to determine the function of individual organelles once ultracentrifuges had been invented and methods for using them for cell fractionation had been developed.
- The experimental programme allows for the exploration of many aspects of NOS. Additional activities can help to strengthen students' understandings.
  - Students could be presented with an experimental procedure that has clear methodological problems (e.g. it does not indicate when to stop a stopwatch during a rates-of-reaction experiment). They are asked to critique it to ensure valid data are produced. The critique can be done before, during or after the practical work.
  - Students could be provided with a data set that may or may not be as expected. Students carry out the experiment and share data to compare with the teacher's data set. This can highlight the importance of reproducibility and reliability.
  - Students could be asked to find data in the literature for further comparison.
  - The activities above could be connected so that features of the peer-review process are discussed.
- NOS might be used to set the scene and form the introduction to a topic. A teacher may choose to begin a lesson by presenting a current news article, past event or topic of debate. Alternatively, a retrospective approach could be taken, with the final minutes of a lesson or a homework task being used to look at the NOS aspects exemplified by the topic.

- A short “circus activity” (e.g. after reviewing a topic or subtopic) can be used to discuss the impact of science on society. Students rotate around five stations and are given two minutes to brainstorm possible impacts on the environmental, political, social, cultural and economic domains. A short discussion could follow to identify which area of society might be most impacted.

Real-life example	What issue is highlighted in the example?	Which aspect of NOS does the example demonstrate?
An article comparing predictions of the spread of COVID-19 based on mathematical modelling to data on virus transmission	Differences between predicted and actual transmission data suggest there are limitations to mathematical modelling in science.	Scientific models always have strengths and limitations.
Retraction by Professor Frances Arnold, a Nobel laureate in Chemistry, of a research paper she and co-researchers wrote in 2019	She explained that the results in the paper were not found to be reproducible in other studies.	Data must be reproducible before it can be considered scientifically reliable.
Nuclear power as a carbon-neutral but controversial energy source	Environmental and economic advantages to using nuclear energy must be weighed against ethical issues and environmental problems.	Ethical, environmental, political, social, cultural and economic consequences must be considered during (governmental) decision-making.

Examples of integrating NOS

To facilitate the teaching of NOS in the Diploma Programme (DP) biology course, NOS statements have been included at points in the programme where a specific syllabus item can be used to exemplify a specific aspect of NOS. Taken together, these statements should provide students with balanced coverage of the whole of NOS. It is therefore expected that all the NOS statements will be taught. Here is an example of an item from the *Biology guide* with an associated NOS statement.

A1.2.14—Evidence from the Hershey–Chase experiment for DNA as the genetic material
Students should understand how the results of the experiment support the conclusion that DNA is the genetic material. **NOS:** Students should appreciate that technological developments can open up new possibilities for experiments. When radioisotopes were made available to scientists as research tools, the Hershey–Chase experiment became possible.

The table shows a general structure that could be used to integrate NOS learning into lessons. This is a more appropriate approach than dedicating whole lessons or units to NOS.

The format that follows might be used to integrate relevant NOS aspects and other concepts that are related to experimental work, for example **hypothesis**, **reproducibility**, **reliability**, **validity**, **prediction** and **uncertainty**.

Outline	Example content (focusing on reproducibility and reliability)
Introducing NOS aspects —10 minutes	Show students an article about or tweet from Professor Frances Arnold, a Nobel laureate in Chemistry, relating to her announcement in early 2020. She retracted her 2019 paper on enzymatic synthesis of beta-lactams because the results were not reproducible. Now discuss the following questions. • What is meant by “reproducible”?

Outline	Example content (focusing on reproducibility and reliability)
	• Why is reproducibility important? • How might reproducibility affect reliability? • How might the scientific community have responded?
Group experimental work —40 minutes	Any data collection can be used here to fit a topic. Ideally, small groups each collect one set of data for a range of independent variable values.
Review of NOS concepts —10 minutes	A class discussion around NOS concepts could include the following questions. • How do individual data points from different groups compare? They would be expected to be similar but not necessarily identical. Standard deviation could be used to quantify this. • How are anomalies identified? Some educated judgement would be required to find them. If anomalies are not obvious, further repeats or checks of other secondary data may be used. • How do different groups' trendlines compare? If data are reproducible, general trends will be the same. • Would students consider the collected data to be reproducible? • How might the above points link to the reliability of the data?

NOS and the external assessment

There will be some assessment of NOS, reflecting its role as an overarching theme of the DP sciences course. The assessment questions will test general understanding of NOS, not memorization of detailed facts relating to individual NOS statements. For this reason, there is merit in teachers using contexts other than those specified in the syllabus to help to develop students' NOS understanding.

Thorough understanding of NOS will help students to perform well in data analysis questions. Skills in understanding, interpreting and analysing data presented in a variety of forms is another transferable outcome from an effectively taught course.

Students could be given a copy of the NOS table in the subject guide, either at the start of the two-year course or at the start of the revision period as the end of the course approaches. The table includes all NOS aspects and their descriptions. If a copy is provided, teachers should emphasize that this is not something to be memorized, but instead should be used for reference and for helping to develop understanding.

NOS and TOK

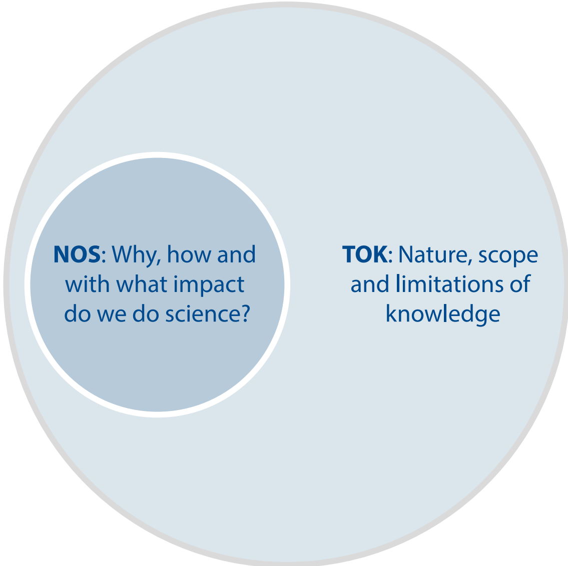
In TOK, students are encouraged to consider how knowledge claims are generated, evaluated, used and justified. This should promote an understanding of the differences between the natural sciences and disciplines such as mathematics, economics and languages.

The NOS component of the course has been designed to give students an excellent understanding of a natural science as an academic discipline. It should be a source of pride to teachers that their students can speak confidently and reflectively about natural sciences in TOK lessons. This will happen if the NOS component is integrated effectively into the teaching of the course.

Ideas relating to TOK can be addressed throughout the course. When and how frequently this is done is left up to teachers, and no specific TOK items have been included in the syllabus. There is no specific assessment of TOK in DP science examinations, although understanding of the aspects of NOS is assessed.

A Venn diagram can be used to illustrate the relationship between NOS and TOK.

The relationship between NOS and TOK



NOS focuses on understanding science through concepts such as **evidence**, **patterns and trends**, **falsification**, **theories** and **global impact of science**. These are central to scientific literacy and are considered only in the context of science.

In TOK, students are expected to think critically about their NOS understandings by exploring broad, underlying and often overlapping concepts such as **evidence**, **certainty**, **justification**, **objectivity** and **responsibility**. Considering the tensions, limitations and challenges related to these concepts in contrast with other areas of knowledge production should lead to student understandings that are nuanced and contestable. Some examples of the types of questions teachers might ask in TOK—"knowledge questions" —and possible responses to these, are provided in the following table.

Knowledge question*	Possible ideas to explore
What kinds of explanations do natural scientists offer?	• The role of scientific theories • The need for and limitations of using imagination in explanations • The extent to which we can claim certainty in a theory
How do we ensure the validity of evidence in the natural sciences?	• Problems with using inductive reasoning • The role of reproducibility • The limitations of peer review
How should we decide on appropriate ethical constraints on scientific research?	• The role of the scientific community in society • Possible tensions, e.g. for-profit companies funding healthcare research • Difficulties defining moral values

* Although these questions are focused on the natural sciences, they could equally be applied to and explored in other disciplines, such as history or the arts.

Building from NOS to TOK

NOS aspects can be extended to ask broad TOK questions (knowledge questions) that might lead to a range of possible perspectives and arguments. The *Theory of knowledge guide* highlights concepts that could be used in this exploration: **evidence**, **certainty**, **truth**, **interpretation**, **power**, **justification**, **explanation**, **objectivity**, **perspective**, **culture**, **values** and **responsibility**.

Asking a broad question containing a TOK concept*	Example perspectives in response to the knowledge question	How might we consider the question in other areas of knowledge beyond the subject?
How accurate must predictions be to justify a claim?	Perspective 1—A scientific law such as the conservation of mass must be 100% accurate within its parameters.	Human sciences—the complexity of analysing human behaviour makes predictions inherently less accurate. Psychology—psychologists try to predict human behaviour through experience (past behaviour), experimentation and observations. Some approaches to understanding behaviour are reductionist while others take a holistic approach and take into account several factors (biological, cognitive and sociocultural). The arts—predictions are constantly tested and repurposed in the creative process. Artworks' claims are never limited to what was predicted. History—although facts, interpretations and conjectures in history may be useful to inform and have a better understanding of present and future events, they are not meant to serve as predictions. Additionally, "hindsight bias" may lead to an apparent prediction after events occur.
Does replicable data imply we are certain of our knowledge?	Perspective 1—The ability to replicate data reliably improves our confidence in the data. Perspective 2—Methodological errors may impact the validity of replicated data.	The arts—how do we consider replicas? Psychology—the field of psychology is currently experiencing a "replication crisis", resulting in concerns over the credibility of research findings. This crisis has led to the questioning of psychological research practices and findings. History—biased/partial or incorrect information in a source may be replicated in many secondary sources, which does not make the knowledge they provide more certain. A piece of information repeated in thousands of sources by mistake may lead to flawed/incomplete knowledge of historical events. In the same manner, the existence of similar accounts of a historical event (which could be considered "replicable/ confirming data") does not mean we can be absolutely certain of them.
What counts as enough evidence to corroborate a theory?	Perspective 1—The more evidence the better. Perspective 2—The type of evidence (i.e. quantitative vs anecdotal) is more important than the amount.	Mathematics—a theorem in mathematics depends on logical certainty (rigorous proof) and not "weight of evidence" (amount). Psychology—psychological theories assist in explaining and predicting human behaviour. Through research, evidence is obtained to either support or refute a theory; however, nothing is ever "proven" in psychology. Human sciences—confirmation bias (the focus or framing of a theory/hypothesis) might determine what evidence is considered and collected. Researchers may disregard evidence that contradicts a theory because they may not be looking for it.

Asking a broad question containing a TOK concept*	Example perspectives in response to the knowledge question	How might we consider the question in other areas of knowledge beyond the subject?
		Many studies in human sciences have been criticized recently because they have been conducted in relatively homogenous settings (e.g. capitalist economies, Western societies and educated populations), making the generalizations drawn from them applicable only to certain populations. This is the WEIRD ("Western, educated, industrialized, rich and democratic") critique. History—looking for sources that originated in diverse contexts (rather than just more evidence from similar sources) is necessary for getting a more complete picture. Historical arguments and narratives are constructed through available evidence, so considering the origin (and purpose) of sources, as well as their limitations, is important. Even after gathering a considerable amount of evidence, historians can make conclusions that may be valid but ultimately untrue (or only partially true). Arts (literature)—in order to present a particular interpretation (theory) of a work of art, sufficient coherent evidence needs to be presented to support it. The more evidence available to support an interpretation (in this work alone or in others by the same artist, period/movement, etc.), the more valid it can be considered.

* This is a simple way to form a TOK question, but it is by no means the only way.

Downloadable resource

Activity example: Chargaff's data (PDF)

Introduction

This section aims to explore and illustrate approaches to learning and approaches to teaching in the context of Diploma Programme (DP) biology. This course is distinct in that it is part of the IB Diploma, where concurrency of learning in different areas of study is emphasized. Connections are therefore encouraged with your students' other IB courses, and with both your local and the global context.

The IB approaches to learning and approaches to teaching offer a framework of deliberate skills and attitudes underpinning learning and teaching. These approaches aim to support the IB mission and develop skills that enhance students' learning, both during and beyond their DP experience. Connections are therefore made to the learner profile attributes and international-mindedness, and other features at the heart of an IB education, not least a broadly constructivist and student-centred approach, where contextual relevance, concurrency of learning and a connected curriculum are paramount.

The **approaches to learning** framework comprises five skills groups.

1. Thinking skills
2. Communication skills
3. Social skills
4. Self-management skills
    - Organizational skills
    - Affective skills
5. Research skills

The **approaches to teaching** refer to the six pedagogical principles that underpin IB programmes.

1. Teaching based on inquiry
2. Teaching focused on conceptual understanding
3. Teaching developed in local and global contexts
4. Teaching focused on effective teamwork and collaboration
5. Teaching designed to remove barriers to learning
6. Teaching informed by assessment

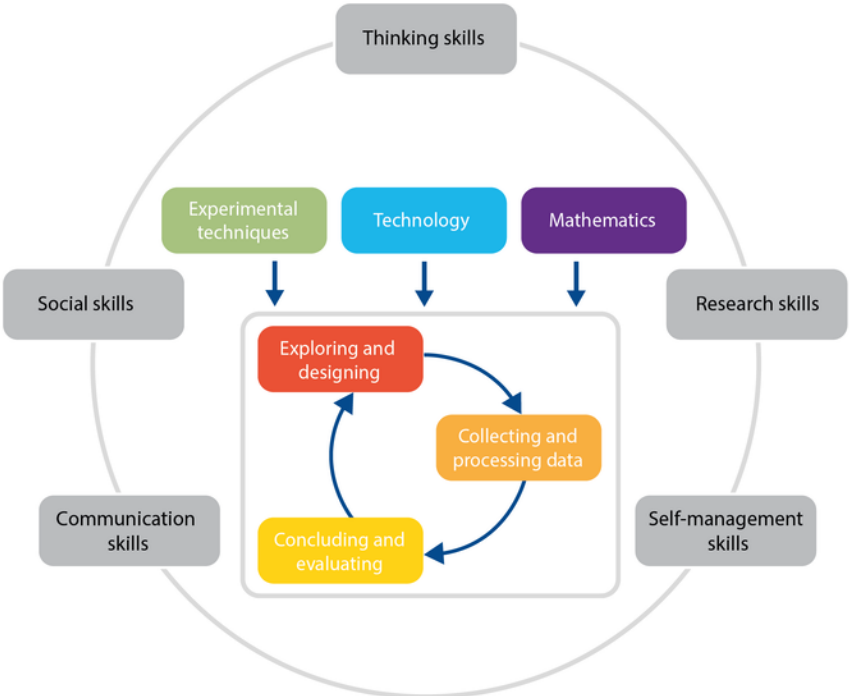
IB authorization and evaluation processes require schools to demonstrate implementation, development and review of the approaches to learning and approaches to teaching, as they relate to the *Programme standards and practices*.

This section therefore suggests how to develop different approaches to learning and approaches to teaching, for example sharing ways to help foster conceptual understanding. There are also ideas for including international-mindedness in the course, and suggestions linking topics to real-world contexts. These aim to enhance students' interest and help them see the relevance of their learning to current global challenges.

Approaches to learning

The approaches to learning framework aims to develop skills in students that support their learning throughout the DP/Careers-related Programme (CP) and beyond. They are interconnected and together support the development of the skills in the study of biology.

Tools and inquiry process for developing skills in biology



Thinking skills

Thinking skills are a broad category of approaches to learning, focusing on critical thinking, metacognition and reflection. The purpose is to develop not only discipline-specific tools in students but also curiosity, open-mindedness and creativity (International Baccalaureate, 2015). This approaches to learning skill category is connected to learner profile attributes, most significantly **thinkers**, which involves analysing and tackling problems as well as reaching reasoned, ethical decisions (International Baccalaureate, 2020a).

Nature of science (NOS) and the skills in the study of biology are two overarching frameworks in the biology curriculum. The relationship between these frameworks and approaches to learning is bidirectional: thinking skills are cultivated by and help to integrate NOS and experimental skills and techniques into the course. For example, patterns and trends are a central feature of scientific knowledge production identified as an aspect of NOS. The metacognitive awareness developed through thinking skills helps students identify and explore trends in their study of biology and at various stages of the inquiry process. Conversely, tools such as technology and mathematical skills can support the exploration of patterns and trends, which in turn helps to build thinking skills.

Examples

- Metacognition—students sharing their thought processes as they work through an explanation, test question or numerical exercise.
- Metacognition and reflection—exploring then reflecting on different ways to remember parts of the syllabus content.
- Reflection—using visible thinking routines such as “Connect, Extend, Challenge” to reflect on learning, or “I Used to Think … Now I Think …” to explore changes in thinking (Project Zero, 2015).
- Critical thinking—discussing patterns with peers across the entire programme, and doing this collaboratively and frequently.
- Critical thinking—discussing ethical implications of advances in and applications of biology. Examples include the peer-review process and the application of sustainability principles in classrooms and industry.
- Critical thinking—testing generalizations, assumptions, hypotheses and conclusions.
- Critical thinking—applying knowledge in familiar and unfamiliar situations.
- Visible thinking—engaging in practices that help make thought processes visible, such as “I Used to Think … Now I Think …” (Project Zero, 2015).

Communication skills

Communication covers a range of applications, media and skills. Good communication allows students to convey their understanding in assessments, and facilitates learning, formative assessment, interpersonal relationships and collaboration (International Baccalaureate, 2015).

Communication skills include spoken and written communication, as well as listening and body language.

Successful communication also includes constructing arguments and clear lines of reasoning. These can be used in articulating and organizing written and verbal answers, in scientific investigation and in mathematical calculations.

Communication skills clearly underpin the **communicator** learner profile attribute. Effective communication is bidirectional: not only conveying personal views and understanding, but also listening to the views of others (International Baccalaureate, 2019). Actively seeking and reflecting on other perspectives is also a feature of being **open-minded**, and therefore ties in with the IB principle of international-mindedness.

Examples

- Verbal—using visible thinking routines such as “Think, Pair, Share” (Project Zero, 2015) encourages students to engage in dialogue about the syllabus content. This gives them opportunities to practise using scientific vocabulary to articulate their understanding.
- Written—explicitly teaching methods for drafting and redrafting pieces of extended writing that are particularly suited to a scientific investigation. For example, students could practise reviewing writing at different levels.

  Students use a piece of written work, e.g. an extract from an example scientific investigation.

  - They assess its focus and its organization of ideas by extracting the main themes in each paragraph.
  - They review how clearly each paragraph conveys its main ideas.
  - They read the extract again, focusing on spelling and grammar errors.
- Written and visual—creating a scientific poster to summarize the outcome of an inquiry, instead of writing an extensive laboratory report.
- Diagrammatic—comparing and contrasting different diagrams showing a particular phenomenon.
- Symbolic—texts written in a different language so that students can discuss how much they are able to infer from it.

Social skills

Students' social skills operate at various levels: among students, between students and other members of the school community, between students and the local community, and between students and the much wider global community. Effective social skills not only support learning, but also broaden the mind and encourage responsible global citizenship. The broad relevance of social skills can be observed across several learner profile attributes (International Baccalaureate, 2020a).

- **Inquirers**: learning with others
- **Risk-takers** and **communicators**: collaboration
- **Principled**: respect for the rights of others
- **Open-minded**: seeking other points of view
- **Caring**: empathy, compassion and respect

In biology, social skills can be incorporated into learning processes by explicitly teaching communication and collaboration strategies, as well as locating the course content in local and global contexts. The collaborative sciences project is an excellent opportunity to focus on certain social skills, given its primary focus on collaboration. In addition, the project's emphasis on the United Nations Sustainable Development Goals fosters awareness of global issues and thus an awareness of the situations of others.

Examples

- Students completing the collaborative sciences project.
- Students completing a risk assessment for student-designed experiments that considers risks to self, to others and to the environment, and ways to minimize the risk.
- Providing a model of constructive and balanced feedback, and giving students explicit guidelines on giving each other feedback.
- Students and teachers working together to establish expectations through which learner profile attributes are applied, to:
  - support an empathetic, compassionate and respectful learning environment
  - encourage discussion and exploration in an atmosphere of attentive listening and critical thinking (e.g. Socratic seminars).
- Problem-solving in small groups. For example, students could explore models when investigating the effect of variables on ecosystem stability.

Self-management skills

Self-management skills are classified into two categories.

- Organizational skills
- Affective skills

Organizational skills cover the management and organization of time, tasks and resources. Effective organization can encourage balance and help to develop independence in students. These skills are therefore connected to the **balanced** and **inquirer** learner profile attributes, respectively.

Affective skills are related to traits such as state of mind, self-motivation and resilience. This set of skills is linked to the learner profile attribute of being **risk-takers**, which seeks to equip learners with the determination and forethought needed to face uncertainty, challenges and change (International Baccalaureate, 2020a).

Examples

- Organizational skills
  - Setting interim deadlines for long tasks and projects such as the scientific investigation or extended essay.

    - Exploring revision techniques such as concept mapping, note-taking and use of flash cards.
    - Explicitly teaching effective use of practice questions and markschemes.
    - Discussing strategies for organizing files, both digital and paper-based.
- Affective skills
    - Providing opportunities for low-stakes retrieval practice to build fluency, understanding and motivation.
    - Using strategies to identify and fill knowledge gaps, such as thorough test corrections or question and answer sessions.
    - Encouraging self-reflection to acknowledge progress and identify areas of opportunity. For example, the teacher gives feedback on a short piece of work including errors or missing information, and suggestions for improvement. The student then makes the relevant corrections.

Research skills

Research skills encompass competence with a range of skills that need to be deliberately taught and practised. These include finding out background information, conducting preliminary experiments, composing research questions, and collecting and analysing data. Implicit in much of this is evaluation, for example of data, hypotheses, sources, arguments, methodologies, uncertainties. This set of skills is deeply connected to the inquiry process and thus the inquirer learner profile attribute (International Baccalaureate, 2020a).

Research skills figure heavily in the skills in the study of biology, the collaborative sciences project, the scientific investigation and the extended essay.

Examples

- Developing strategies to organize references.
- Providing opportunities for presenting results of extended research projects in condensed formats, e.g. scientific posters.
- Discussing the common features of good research questions, using examples of both good and poor quality.
- Organizing class activities involving collecting data from databases.
- Comparing the reliability of different information sources, e.g. the portrayal of a scientific news item in various media sources.
- Designing and using activities involving processing, analysing and evaluating experimental results. These could be heavily scaffolded in the beginning, then gradually less so as students build up the required skills.
- Practising past paper and examination-style questions related to research questions, investigation design, data collection, analysis and evaluation.

Approaches to teaching

The approaches to teaching refer to six pedagogical principles that underpin IB programmes. They aim to empower teachers to create meaningful learning experiences.

Inquiry

Inquiry-based approaches to learning and approaches to teaching involve a high degree of student engagement and interaction to develop natural curiosity in students. The approaches can take a variety of forms that differ in their degree of teacher guidance. Banchi and Bell (2008) propose four levels of inquiry.

1. As part of **confirmation inquiry**, the question, process and outcome of the inquiry are provided by the teacher.
2. During **structured inquiry**, teacher guidance begins to be withdrawn.
3. During **guided inquiry**, teacher guidance continues to be withdrawn.
4. In **open inquiry**, students determine the question, procedure and outcome.

Other forms of inquiry-based learning and teaching include experiential learning (Kolb, 1984) and problem-based learning (Boud, Feletti, 1997).

Scientific inquiry can be experienced by everyone. Subjects such as biology offer students opportunities not only to conceptualize scientific inquiry—a central feature of NOS—but also understand it is a process that they too can undertake.

The inquiry process comprises three stages: inquiry, action and reflection. In biology, this process is evident in the skills in the study of biology, the scientific investigation and the collaborative sciences project. The inquiry process lies at the heart of the skills in the study of biology. The *Biology guide* identifies the specific inquiry skills that students must experience in their study of the course. These inquiry skills must be integrated into the course, providing students with several opportunities to master them. The collaborative sciences project also provides an opportunity to develop these inquiry skills within an interdisciplinary context and in collaboration with peers.

Effective teaching of the inquiry skills will equip students to demonstrate them in external and internal assessment. One example is when they undertake the scientific investigation, where they plan, carry out, analyse and evaluate an investigation to address a research question of their own.

Examples

Confirmation inquiry

Students perform a teacher-directed inquiry to confirm an outcome.

- Using molecular visualization software to study the association between the proteins and DNA within a nucleosome
- Examining models or digital collections of skulls to infer diet from the anatomical features

Structured inquiry

Students determine the outcome themselves; the aim and procedure are provided by the teacher.

- Researching the feeding habits and plastic ingestion risk of marine animals using teacher-provided websites and books

Guided inquiry

Students conduct an inquiry that addresses a question provided by the teacher, using a procedure of their choice.

- Determining enzyme-catalysed reaction rates through experimentation
- Determining rates of photosynthesis
- Answering the guiding question using their knowledge of the subtopic

Open inquiry

Students determine the question, process and analysis.

- Writing their own factual, conceptual and debatable questions in relation to a topic or subtopic
- Undertaking the collaborative sciences project
- Undertaking the scientific investigation

Experiential learning

Students engage in inquiry opportunities outside the classroom.

- Interviewing members of the school community who work in biology-related fields

Problem-based learning

Students are presented with a question or problem to solve.

Conceptual understanding

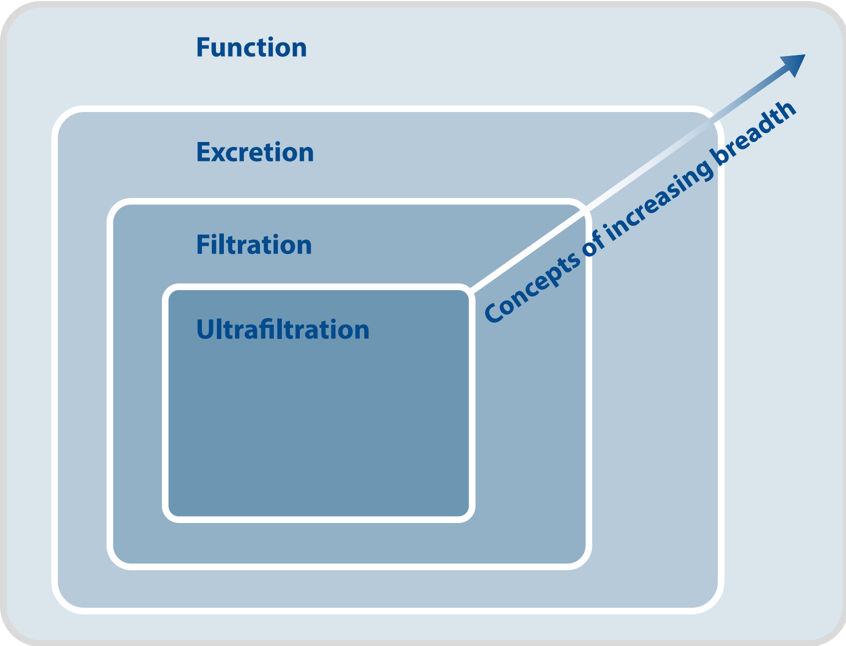
In IB programmes, conceptual understanding is defined as understanding that connects factual, procedural and metacognitive knowledge. It results from a process in which students consciously organize connections between prior and new knowledge into networks, then further develop or reconfigure those networks. This is a non-linear, ongoing process throughout which understandings evolve and misconceptions are identified and dispelled. In DP biology, these interconnections are explored through the linking questions. The linking questions in the *Biology guide* are not exhaustive, and students and teachers are invited to write their own.

Teaching for conceptual understanding is important because conceptual understanding enables students to be aware and critical of their own knowledge and understandings. They can then transfer and apply skills, knowledge and understandings to new or different contexts in creative, generative, autonomous, dynamic ways. Conceptual understanding supports the IB mission because it enables students to conceive multiple solutions to a problem, imagine different perspectives on issues, and understand more deeply how ideas change in different contexts.

Teaching approaches that promote conceptual understanding include classification, generalization, representation, internalization, concepts-in-use and near and far transfer.

A conceptual approach fosters the organization of knowledge into networks, which can evolve as students acquire new understandings. Thus, a conceptual understanding is supported by mental categories of varying breadth. These concepts or mental categories can be broad concepts that help to integrate knowledge across disciplines, or narrower, subject-specific concepts that help to organize and link disciplinary understandings. An example of a sequence of concepts of increasing breadth is shown in the figure.

Example sequence of increasing conceptual breadth

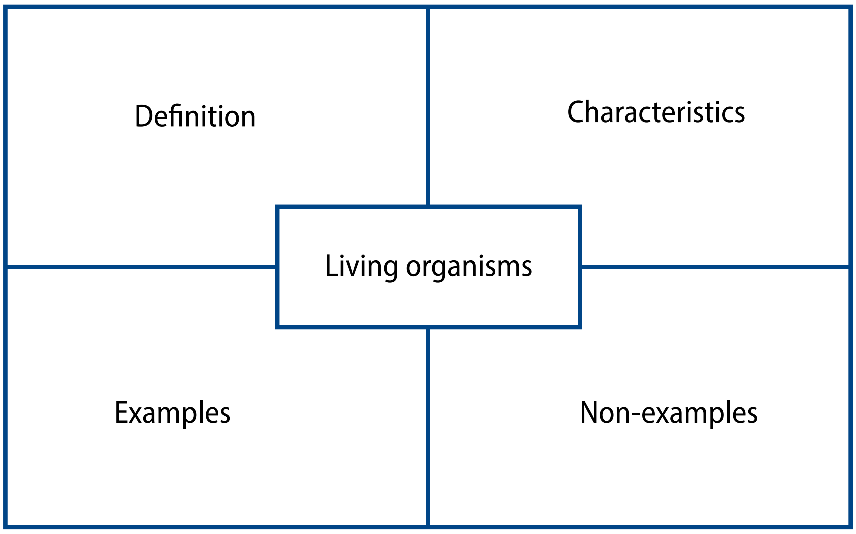


Concept-based teaching and learning does not preclude the teaching of content. In fact, a sound knowledge base is the foundation for conceptual understanding (Mills, Gay, 2018). By engaging with a conceptual approach, however, it should be remembered that ideas and knowledge—both declarative and procedural—do not exist in isolation. Concepts are connected to other concepts; they are mental abstractions constructed through experience (Taber, 2019).

Examples

- When revising several units, students write their own linking questions, share them and attempt to answer each other's questions.
- Concept mapping can be used to summarize the content of a unit. The visible thinking routine "Generate–Sort–Connect–Elaborate" can be used to structure the activity (Project Zero, 2015).
- Frayer model graphic organizers help to clarify the meaning of a concept, and to identify correct and incorrect examples of the concept, for example for living organisms.

Frayer model template in which students can summarize their understanding of living organisms



- Visible thinking routines such as those used in "The Explanation Game" or "The Ways Things Can Be Complex" (Project Zero, 2015) can be used, for example, to describe membrane structure or compare different types of molecules.

  Guiding questions or linking questions can be a helpful starting point for students to prepare for a class presentation. They may need assistance to stay on topic. One method is the Grant Wiggins backward design process (Wiggins, McTighe, 2005). The three steps of this process are as follows.

  1. Identify desired results.
  2. Determine acceptable evidence.
  3. Plan learning experiences and instruction.

Local and global contexts

Setting learning in context gives relevance to the curriculum and allows students to connect their learning to their own experiences and the world around them. Observing their surroundings through a different lens may help students understand these from a different perspective, an important component of international-mindedness and various learner profile attributes.

The scientific investigation, the collaborative sciences project and the extended essay are all excellent opportunities for students to delve into an application of biology. Applications should be emphasized by weaving many examples of local and global contexts into the course. New examples of local and global contexts may arise throughout the course. In some cases, they can be planned into teaching well ahead of time. In others, local or global news items related to biology may spark interesting conversations spontaneously.

Context can be introduced at different points in a learning sequence; it can lead into the teaching of a concept, or be used after concepts are taught (Turner, 2019). After a concept has been explained, students can be asked to apply it to a particular context or case study to reinforce the concept and transfer it to a less familiar setting.

Examples

- Discussing biology-related news items, considering:
  - relevant theoretical concepts
  - the quality of scientific communication

  - examples of ethical, environmental, economic, cultural and social impacts.
- Asking students to prepare a five-minute presentation on an application of biology of their choice.
- Contributing to biology-related data collection projects at the global level (citizen science).
- Sharing examples from teachers' own university and employment experiences.
- Inviting students' relatives with biology-related careers to present to the class.
- Featuring prominent biologists in class when relevant, connecting their actions to the IB learner profile.
- Setting the introduction of new concepts in contexts where they are particularly relevant.
- Using authentic stimuli to generate class discussions or as assessment instruments. For example, the following tasks could be set as part of a class discussion about the figure "Authentic stimulus to generate class discussion or for use as an assessment instrument".
  - Using information from the diagram, calculate the percentage of primary plastics produced that are still in use.
  - Identify two pieces of information from the diagram that suggest plastics are largely non-biodegradable.
  - Extension: Carry out research online to find some of the problems associated with incinerating plastic waste.
  - Extension: Carry out research online to find some of the effects of plastic waste on marine life health and biodiversity.

Authentic stimulus to generate class discussion or for use as an assessment instrument [Source: Ritchie, Roser, 2018]

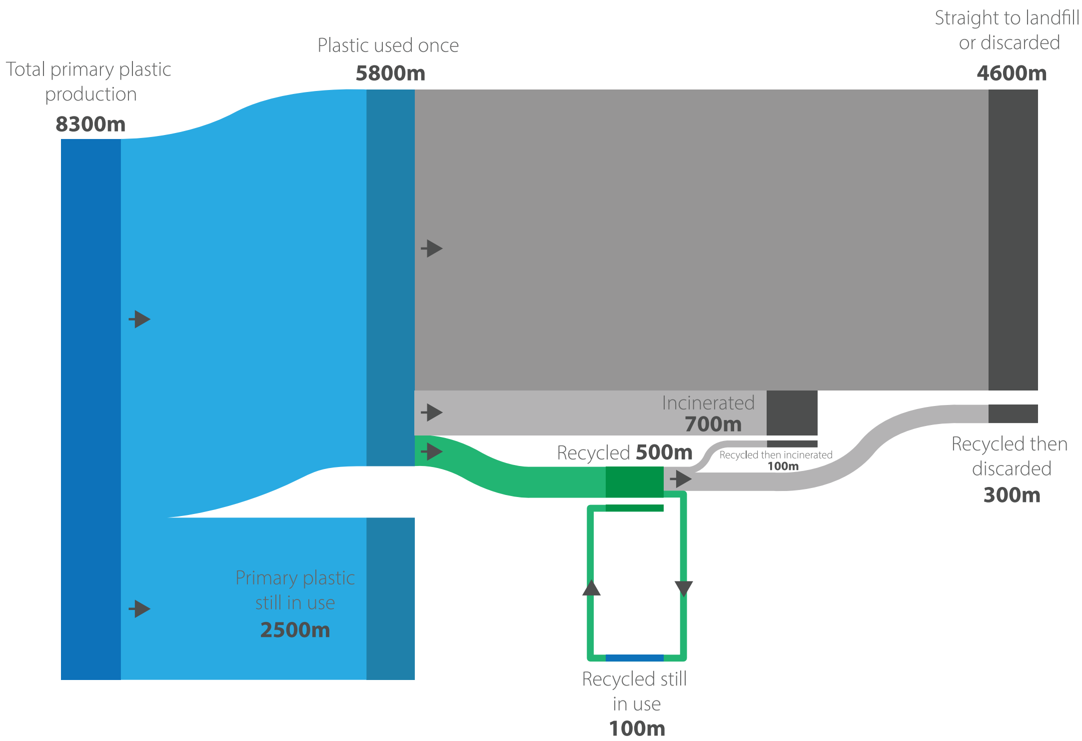
Global plastic production and its fate (1950-2015)

Our World in Data

Global production of polymer resins, synthetic fibres and additives, and its journey through to its ultimate fate (still in use, recycled, incinerated or discarded).
Figures below represent the cumulative mass of plastics over the period 1950-2015, measured in million tonnes.

Balance of plastic production and fate (m = million tonnes)

8300m produced → 4900m discarded + 800m incinerated + 2600m still in use (100m of recycled plastic)



Source: based on Geyer et al. (2017). Production, use, and fate of all plastics ever made.
This is a visualization from OurWorldinData.org, where you will find data and research on how the world is changing.

Effective teamwork and collaboration

This pedagogical principle aims to encourage collaborative relationships to create a positive and dynamic learning environment. It covers collaboration between students, and between students and their teacher. In science, it also echoes the aspects of NOS that acknowledge science as a collective endeavour.

In biology, the collaborative sciences project stands out as one of the course requirements that specifically aims to develop collaboration skills in students. Collaborative tasks can vary significantly in terms of time and configuration. Their duration can range from short pace-changers in a lesson to extended teamwork such as the collaborative sciences project. The size of collaborative groupings also varies, from pairs of students to whole-class endeavours.

Students benefit from opportunities to articulate their thinking, which can help to clarify lines of reasoning and even reveal knowledge gaps. It is also advantageous to practise using appropriate scientific vocabulary, irrespective of whether students are fluent in the language of instruction or not. Academic language is cognitively demanding, and collaborative tasks provide spaces for students to practise using correct vocabulary, building their academic fluency.

Teamwork and collaboration also encourage a learning environment in which students share their perspectives, but also consider and integrate the views of others. For example, peer feedback is valuable for both parties. The student receiving the feedback gains from acting on the suggestions for improvement given by their peer. For the student giving the feedback, it is an opportunity to practise commenting constructively.

For students to benefit fully from collaborative tasks, behavioural expectations and the nature of effective group work need to be made explicit. For example, collaboration is permitted in the early stages of the scientific investigation. Teachers must therefore be vigilant, clarifying where necessary the difference between acceptable collaboration and collusion.

Examples

Teamwork and collaboration are possible in a variety of ways.

- The collaborative sciences project
- Solving a numerical problem individually and then explaining reasoning to a partner
- Preparing a debate on a subtopic
- Collaboratively collecting experimental data and then comparing results obtained by processing and analysing that data
- Using visible thinking routines that encourage students to explain their reasoning, e.g. "Think, Pair, Share", and connecting learning to prior knowledge, e.g. "Connect, Extend, Challenge" (Project Zero, 2015)
- Short collaborative research leading to a presentation with a competitive element
- Working together to write "elevator pitches" to describe a complex idea in a short paragraph with clear sentences

Removing barriers to learning

IB approaches to teaching aim to help students set challenging and appropriate personal learning goals. Differentiation to remove barriers to learning is understood to relate to four interconnected principles. The central principle is to affirm students' identities and build self-esteem. Surrounding this are the principles of valuing prior knowledge, scaffolding learning and extending learning.

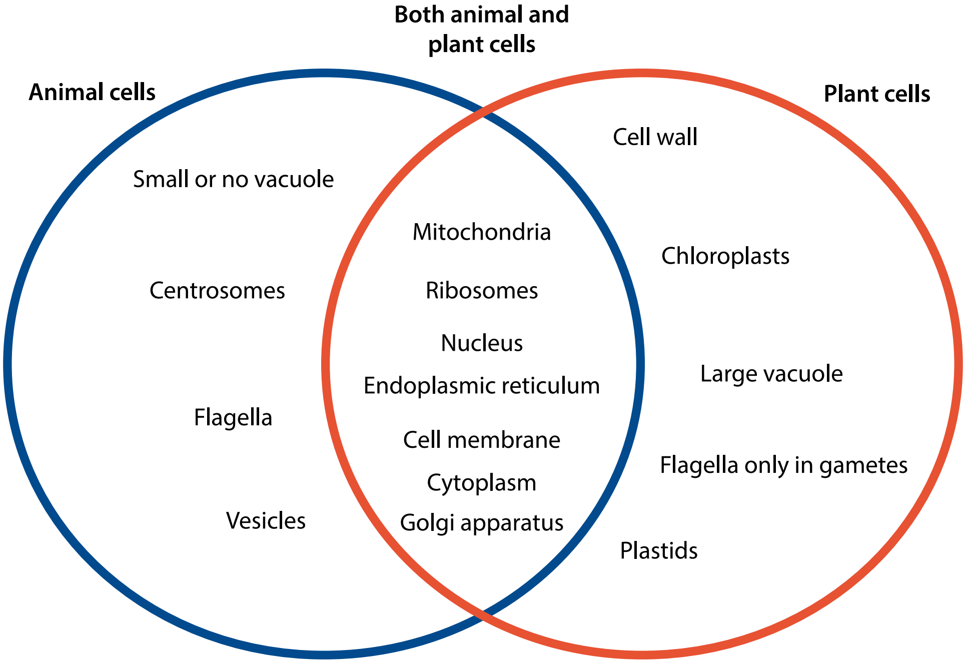
In IB programmes, language is recognized as having a vital role in learning and teaching, permeating almost all aspects of a learning environment. All IB teachers are therefore regarded as language teachers.

Examples

There are numerous ways to remove barriers to learning.

- Affirming identity and building self-esteem
  - Asking students to construct glossaries containing definitions in their preferred language, as well as the language of instruction (if this is different)
  - Reducing cognitive load in practical instructions by minimizing textual elements and maximizing diagrammatic elements
- Valuing prior knowledge
  - Identifying prior knowledge through diagnostic quizzes or mind mapping
  - Activating prior knowledge through linking questions
- Scaffolding learning
  - Using graphic organizers to represent processes or relationships
    - Flow charts for processes
    - Venn diagrams for similarities and differences

Venn diagram comparing and contrasting the organelles in plant and animal cells

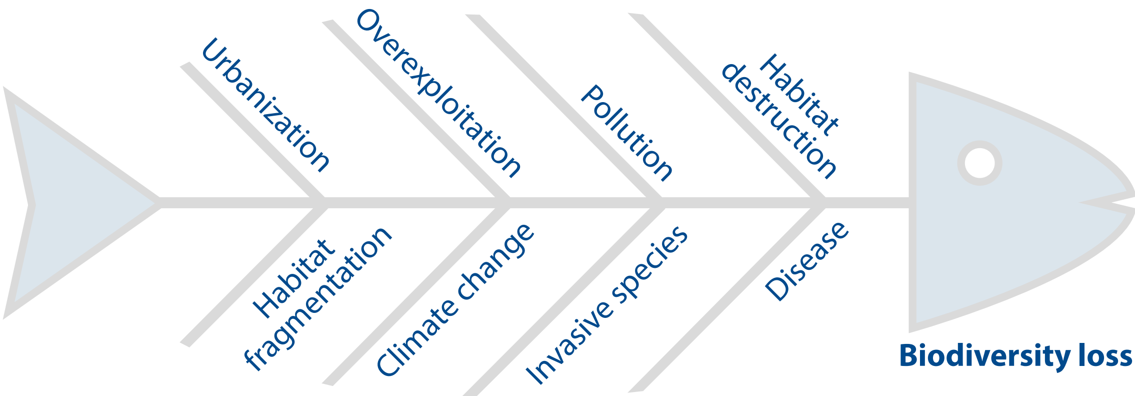


- Fishbone diagrams examining the causes leading to an effect

  Downloadable resource

  Blank fishbone template (PDF)

Fishbone diagram of the different factors that cause loss of biodiversity



- Practising sequences of steps to master technical skills
  - Mathematical skills can be a barrier to learning in some topics of biology. Showing scaffolds to students during an activity can help them to follow a sequence of steps with confidence. There are several topics that expect mathematical skills, e.g. calculating size and magnification in topic A2.2 or calculating percentage difference in topic C3.2

    For example, when calculating the size of a cell, the measurement for one cell (labelled X) could be given through a worked example. Then students could be asked to calculate the actual length of another cell (labelled Y) using this information. With this template the mathematics is no longer a barrier to understanding a question about something biological, e.g. cell elongation

To calculate the actual size of a cell:

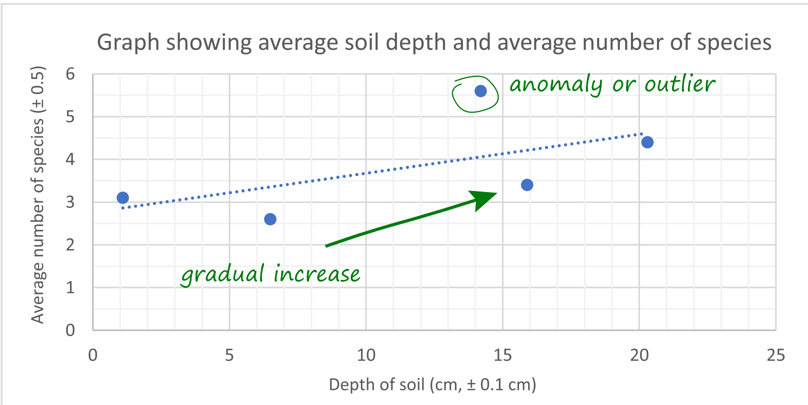
1. measure the scale bar in mm
2. measure the length of the cell in mm
3. divide the cell length by the scale bar length
4. multiply by the number written on the scale bar

- Using sentence starters to help scaffold answers. For example, these sentences could help students to analyse a graph
  - This graph shows …
  - A pattern I notice in the graph is …
  - When the … increases, then the … (increases/decreases/stays the same)
  - A difference between … and … is …
  - A similarity between … and … is …
  - A reason for the pattern could be …
- Annotating data to provide guidance about the terminology that can be used when describing data

Data labelled with descriptive mathematical terminology

Ecological experiments to test if there is a correlation between the depth of soil and the average number of species in the school grounds.					
Raw data (initials of experimenters)	SP	BM	KR	CJ	ME
Depth of soil (cm, ± 0.1 cm)	20.3	1.1	6.5	14.2	15.9
Average number of species (± 0.5)	4.4	3.1	2.6	5.6	3.4
Correlation coefficient, r = 0.59					

weak correlation



- Extending learning
  - Applying concepts learned in a new, unfamiliar context or use of case studies
  - Exploring interdisciplinary links

Assessment

Assessment provides valuable information that supports learning and teaching and therefore should take place continually throughout the course. Assessment feeds back into the teaching process, providing information that facilitates the synchronization of learning and teaching. It is a key two-way process that can be used to improve learning, teaching and assessment. Teachers and students' own peers provide students with feedback on how to consolidate their understanding and move forward. Meanwhile, students provide teachers with feedback on their misconceptions, knowledge gaps, levels of understanding and levels of engagement, all of which inform the teacher's subsequent decisions.

Throughout the DP and CP, students work towards demonstrating the course assessment objectives through formative assessments. Some assessment tasks will be dedicated to measuring student learning and will inform predicted grades as well as internal reporting of student progress. Assessment of learning should be aligned with the course assessment objectives and grade descriptors. In biology, this involves providing opportunities for the students to develop the skills and techniques required to undertake the scientific investigation and exposing them to questions of the style and type they will encounter in external examinations.

- Multiple-choice questions
- Short-answer questions
- Extended-response questions
- Data-based questions

These types of questions assess connections between concepts-, NOS- and skills-related knowledge, and will be set in a context such as experimental work and day-to-day applications of biology.

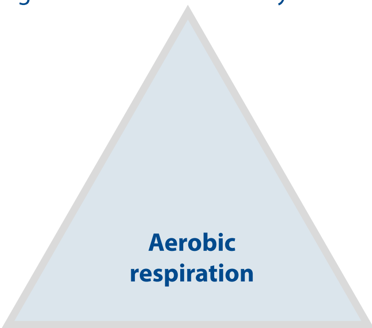
Examples

Assessment in biology can take many forms.

- Students practising data-based questions
- Using multiple-choice questions to uncover student misconceptions
- Students assigning a level of confidence to their responses to multiple-choice questions (5 for "absolutely certain", 3 for "I think this is correct", 1 for "guess"), and applying positive and negative marking. Students can also be encouraged to justify their reasoning for each response
- Students exploring and researching an application of biology, then presenting this in a variety of formats. Examples include a formal research paper, a scientific poster, an article for the school newspaper, a video or podcast, a presentation or assembly and an infographic
- Students doing peer and self-assessment using the internal assessment criteria
- Students doing self-assessment using rubrics and markschemes
- Setting short report tasks on practical experiences
- Delving into students' understanding of a concept by asking them to consider it on multiple levels, e.g. macroscopic observations, microscopic behaviour and symbolic representations

Graphic organizer to delve into students' understanding

Macroscopic level
Describe what you see when a plant is placed inside a bag or glass container in a sunny location.



Microscopic level
Draw a diagram showing how stomata in a leaf open and close.

Representational level
Write down the word equation for aerobic cell respiration.

International-mindedness

The IB aims to develop "inquiring, knowledgeable and caring young people who help to create a better and more peaceful world through education that builds intercultural understanding and respect". International-mindedness recognizes similarities and affirms differences between communities, peoples and nations. Knowledge and understanding of similarity allow for the construction of common foundations, while recognition and affirmation of difference encourage a celebration and valuing of diversity.

With this in mind, teachers of DP biology should provide opportunities for students to foster international-mindedness within the context of the course, underpinned by a focus on global engagement. Global engagement represents a commitment to address humanity's greatest challenges in the classroom and beyond. Such challenges may relate to the environment; development; conflict, rights and cooperation. One of the aims of the course is to model solutions to local and global problems in a scientific context. DP biology students and teachers are therefore expected to explore local and global issues relating to the content of the syllabus. There is a close connection between international-mindedness and the IB learner profile attributes, which underpin, and are central to, understanding what it means to be internationally minded.

Along with their exposure to international-mindedness elsewhere in the DP, students should be prepared to be successful global citizens of the future.

Engaging with international-mindedness

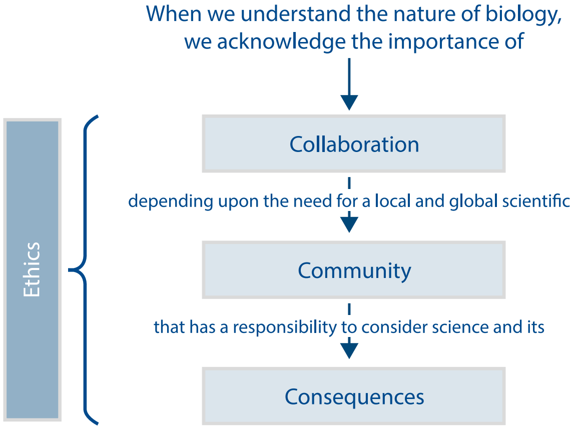
Teachers are not expected to address international-mindedness as a stand-alone topic, but instead to integrate it within the teaching of the subject.

This teacher support material (TSM) supports the teaching and learning of biology and includes a number of ideas and suggestions. The aim is to aid all IB teachers in addressing the need to include international-mindedness in their delivery of the course. These ideas and suggestions are by no means mandatory nor exhaustive and teachers are encouraged to generate alternative approaches and share ideas as they plan and deliver the content.

The "Biology and international-mindedness" section of the *Biology guide* highlights the international nature of science and might be a good starting point to consider the role of a scientist in a global community.

For practical purposes, it might be useful here to break down the term *international-mindedness* into specific concepts that are particularly relevant in the context of science: *collaboration*, *community*, *consequences* and *ethics*. Please note that a consideration of ethics can provide valuable overlap with the IB theory of knowledge (TOK) course.

International-mindedness through the lens of collaboration, community, consequences and ethics



A focus on these concepts throughout the course can help design learning engagements that develop international-mindedness. The table below provides scaffolding questions that might be used to unpack these concepts.

Scaffolding questions to help develop international-mindedness

This table contains a list of possible scaffolding questions that can be used to develop international-mindedness. They can also be applied to specific real-life contexts.

Concept	Scaffolding questions for developing international-mindedness
Collaboration	• Why is collaboration necessary? • What scale of collaboration is required in science? • What does scientific collaboration look like?
Community	• Who is involved in the scientific community? • What structures and organizations might be found in the scientific community?
Consequences	• How might new scientific knowledge impact future scientific research? • Which areas of society might be impacted by scientific knowledge? • How significant are the consequences of science on other areas of society? • Does every society respond similarly to scientific research?
Ethics (note overlap with the TOK course)	• What responsibilities do individual scientists possess in carrying out their own research? • What responsibilities do journals, research facilities and scientific organizations possess? • Who is responsible for the communication of science within the public domain? • Should scientific research be subject to ethical constraints?

Exploring international-mindedness

Real-life context	International-mindedness connections
The International Space Station (ISS) is a multinational project currently involving five space agencies. Research carried out on the ISS has led to many advancements in many areas of science that may not have been possible on Earth.	Collaboration can occur on an international level. Scientific progress is rarely dependent on the work of a single scientist. This is an example of contributions from different nationalities, although the question of why certain nations are represented more than others is a valid question.
Role of World Health Organization during the COVID-19 pandemic.	A good example of a scientific organization responsible for supporting and advising national health policies across the globe.
The Surgisphere COVID-19 scandal involved the publishing of two papers in well-respected scientific journals that were later found to be based on highly suspicious and possibly false data.	An example of a major failing in the peer-review process with global implications in how governments dealt with the COVID-19 pandemic.
The influence of big data companies in scientific progress during the COVID-19 pandemic.	Commercial companies can impact the scope of scientific progress. Ethical questions can be raised regarding the access and use of personal medical data.
Research on vaping and its interplay with politics. US and UK policy have significant differences.	This is an example of how scientific information can be interpreted and used differently when it enters the political domain.

Examples

There are several ways to approach international-mindedness. The downloadable files are only potential approaches to promoting international-mindedness. If used, these examples should be adapted to individual settings, circumstances and groups of students.

Downloadable resources

- Examples of linking questions to promote international-mindedness in the study of biology (PDF)
- Template: An activity to promote international-mindedness in biology (PDF)
- International-mindedness activity example: Response to new viral strains (PDF)

The first resource contains examples of additional linking questions that are conceptual or debatable in nature and related to global ideas beyond the immediate content of the course. They also aim to encourage problem-solving and the development of learner profile attributes. As with the linking questions within the syllabus, students and teachers will hopefully be stimulated to develop further questions of their own that relate to aspects of international-mindedness.

Each international-mindedness question has been assigned one or more areas of global challenge, providing contexts for inquiry and discussion. Some aspects of international-mindedness inherent in these questions may also promote elements of NOS; TOK; and creativity, activity, service (CAS).

In some cases, a linking question may lead to an idea for a world studies extended essay. This would involve a student developing a more specific research question to explore an "issue of global importance", allocated to an appropriate world studies area of study.

The following tables have some general structures that could be used to integrate international-mindedness development in lessons or sections of lessons.

Research and discussion

Suggested timing (25 minutes)	Example content (for a focus on collaboration and consequences)
5 minutes	Presentation of a real-life context, e.g. collaborations to create COVID-19 vaccines.
10 minutes	In groups, students are asked to research the real-life context using the following prompts. • Who collaborated? • Was the collaboration on a local or global level? • Why was the collaboration necessary? • What are the consequences of this new knowledge? (It may also raise interesting questions about the independence of scientific collaboration beyond political tensions between countries.)
10 minutes	Groups share their findings.

Mini-presentations

Suggested timing (40 minutes)	Example content (for a focus on community and consequences)
5 minutes	Present students with a number of national and international scientific organizations. • Intergovernmental Panel on Climate Change (IPCC) • World Health Organization (WHO) • Food and Agriculture Organization (FAO) • Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) • International Union of Biological Sciences (IUBS) • International Union of Biochemistry and Molecular Biology (IUBMB) • International Society of Zoological Sciences (ISZS) • Society for Conservation Biology (SCB) • National biology-related organization in your school context
15 minutes	Individually or in small groups, students are asked to research one of the organizations using the following prompts. • What does it do? • Where does it work? • Who funds it? • What are the consequences of its work? • How might it be relevant to you?
20 minutes	Individuals or groups make presentations (2–3 minutes) on their findings.

Debate

<table>
<tr><th>Suggested timing
(45 minutes)</th><th>Example content (for a focus on ethics)</th></tr>
<tr><td>5 minutes</td><td>Brief outline of an ethical issue.
In 1998, researcher and physician Andrew Wakefield published a small article in The Lancet, claiming to have found the explanation for autism in the measles, mumps and rubella (MMR) vaccine. His theory has since been discredited by dozens of studies and no evidence has been found to support his claims.
Students place anonymous initial votes on whether they support, oppose or are unsure of the motion:
Wakefield deserved to be stripped of his medical licence.
The class is split into two teams and assigned to support or oppose the motion. It can be interesting to manipulate the groups so that they are arguing against their initial thinking.</td></tr>
<tr><td>20 minutes</td><td>Students are given time to research and build their lines of argument. The level of scaffolding prompts can be adapted to meet the needs of the class.
Example prompts
• What is the ethical issue?
• What are the consequences of this issue?
• What evidence might support your argument?
• What might the opposite team try to argue?
• How can you dismantle opposition arguments?</td></tr>
<tr><td>20 minutes</td><td>Debate
• Each group selects one or two speakers to briefly (1–2 minutes) summarize their argument.
• The debate is opened to the floor—a “speaking stick” can be used to prevent students talking over each other. This can be controlled by the teacher or students.
• One or two different speakers briefly (1–2 minutes) summarize their arguments.
• Second vote: students place final individual anonymous votes on whether they support or oppose the motion. These results can be compared to the initial votes to identify the winning team.</td></tr>
</table>

Introduction

The Diploma Programme (DP) biology course has no prescriptive sequence for coverage of the concepts and topics. Teachers are completely free to plan their own route through the course according to their circumstances. This section gives ideas for some contexts and possible routes, which may help teachers to develop their own course outlines.

Pathways through the course

There are many ways to order the biology course content. This section provides examples of possible routes through the course.

Standard level biology roadmap example

Rationale and purpose

This particular order of topics has been developed to support the development of students' experimental skills, allowing students to complete the scientific investigation at the end of year 1. The topics were selected to provide multiple opportunities for students to conduct experiments and to be exposed to a variety of scientific investigations such as fieldwork, analysis of data from databases, use of spreadsheets, and simulations. The roadmap includes links to possible practical investigations that build and strengthen students' experimental techniques. The sequence of topics was built to deepen students' conceptual understanding and consolidate their knowledge throughout the course. This roadmap example is tailored to standard level (SL) class requirements.

Practical investigations

This list of topics and examples of investigations offers opportunities for well-known practical investigations that are accessible for all learners. The content is arranged to provide foundations for students with little exposure to biological concepts.

- A1.1 Water (e.g. water properties experiment by Edgecombe County Center, 2020) and D2.3 Water potential (e.g. osmosis experiments by Royal Society of Biology, 2019a)
- B2.1 Membranes and membrane transport (e.g. investigate the effect of temperature on membrane permeability by Edexcel, 2015a)
- B1.1 Carbohydrates and lipids (e.g. food tests by Education Bureau, 2018) and B1.2 Proteins (e.g. nutritional data analysis by Virtual Metabolic Human, 2019)
- A2.2 Cell structure (e.g. microscopic plant and animal cell experiments by Royal Society of Biology, 2019b) and B2.2 Organelles and compartmentalization
- B2.3 Cell specialization (e.g. surface area-to-volume ratio of jelly cubes experiments by Exploratorium, 2017)

Core biological processes

Enzymatic reactions, photosynthesis and cell respiration are the core biochemical processes that allow cells, organisms and ecosystems to live and function. These examples demonstrate how different reactions and biological systems interact with one another and are interdependent.

- C1.1 Enzymes and metabolism (e.g. factors affecting enzymes, reaction rates by Royal Society of Biology, 2019c)
- C1.3 Photosynthesis (e.g. identification of photosynthesis pigments by Biology Junction, 2017, and enclosed greenhouse experiments by Nuffield Foundation and the Royal Society of Chemistry, 2016)
- C1.2 Cell respiration (e.g. factors affecting cellular respiration in yeast by Vernier, n.d.)

Interdependence

A theme of interdependence can be used to connect the topics of Cell respiration (C1.2) and Transport (B3.2). Cell respiration requires oxygen, and carbon dioxide is a by-product. These gases are delivered to cells via the bloodstream. Other connections can be explored, such as how adenosine triphosphate (ATP) is produced during cell respiration and used in a variety of reactions, such as muscle contractions.

- B3.2 Transport (e.g. measurement of pulse rates by National Health Service, 2021 and incidence of coronary heart diseases using epidemiological data by National Health Service, 2014)
- C3.2 Defence against disease (e.g. antibiotic resistance secondary data analysis by European Centre for Disease Prevention and Control, 2016 and evaluation of data related to the COVID-19 pandemic by Center for Systems Science and Engineering, 2022)
- B3.1 Gas exchange (e.g. measurement of tidal volume, vital capacity using sensors)
- D3.3 Homeostasis (e.g. thermoregulation experiments by BBC, n.d.)
- C3.1 Integration of body systems (e.g. measurement of visual reaction time—online test by Human Benchmark, n.d.)
- C2.2 Neural signalling
- D3.1 Reproduction (e.g. dissection of insect-pollinated flowers by WJEC, n.d.)

Continuity

A theme of continuity can be explored to connect the topics of Reproduction and Nucleic acids. Sexual and asexual reproduction provide continuation of life, which is encoded in nucleic acids.

- A1.2 Nucleic acids (e.g. isolation of DNA from fruits by The Open University, n.d.)
- D1.1 DNA replication
- D1.2 Protein synthesis
- D1.3 Mutation and gene editing (e.g. gene mutation secondary data analysis by Institute of Medical Genetics in Cardiff, 2020)
- D2.1 Cell and nuclear division (e.g. calculation of mitotic index by Edexcel, 2015b)
- D3.2 Inheritance (e.g. data collection on height using a box-and-whiskers plot)

Change

A theme of change can help to connect the topics of Inheritance and Diversity of organisms. Diversity of living organisms is a result of genetic variation and spontaneous mutations. Students can explore how different patterns of inheritance trigger changes in the genetic make-up of organisms.

- A3.1 Diversity of organisms (e.g. developing a dichotomous key by Timme, 1991)
- A4.1 Evolution and speciation (e.g. data analysis of John Endler's experiment with guppies—simulation by Virtual Biology Lab, 2010a) and D4.1 Natural selection (e.g. natural selection—simulations by Annenberg Learner, n.d.)
- B4.1 Adaptation to environment (e.g. factors affecting the distribution of plants or animals by Royal Society of Biology, 2019d)
- B4.2 Ecological niches (e.g. analysis of skulls to infer animals' diets by Pennsylvania Envirothon, 2018.)
- A4.2 Conservation of biodiversity (e.g. analysis of IUCN red list of threatened species by IUCN, 2022)
- C4.1 Populations and communities (e.g. estimation of population size—simulation by Virtual Biology Lab, 2010b)
- C4.2 Transfers of energy and matter (e.g. analysis of the Keeling Curve by American Chemical Society, n.d.)
- D4.2 Stability and change (e.g. rate of deforestation by Global Forest Watch, n.d.) and D4.3 Climate change (e.g. NOAA global temperature data sets by NOAA, 2018)

Higher level biology roadmap example

Rationale and purpose

This particular sequence follows the four levels of organization: ecosystems, organisms, cells and molecules. The journey starts with a big picture (ecosystems) and moves to smaller units of life (organisms, cells and molecules). The topics are arranged to offer multiple opportunities to conduct practical investigations and organize fieldwork at the beginning of year 1. Additionally, the roadmap encourages learners to explore local contexts for the topics covered and gives them opportunities for discussing global issues. Suggested investigation examples are possible ways to incorporate global and local context into learning experiences. The roadmap is tailored for higher level (HL) class requirements.

Global issues, ecosystems and populations

The sequence starts with topics related to current global issues, followed by content related to ecosystems and populations.

- D4.2 Stability and change (e.g. investigating deforestation from global and local perspectives using the Global Forest Watch database by Global Forest Watch, n.d.)
- D4.3 Climate change (e.g. investigating coral reef bleaching using *NOAA coral reef watch operational daily near-real-time global 5-km satellite coral bleaching monitoring* by Data.gov, 2021)
- C4.2 Transfers of energy and matter (e.g. investigation of the net productivity of ecosystems in Europe by Joint Research Centre, 2010)
- B4.2 Ecological niches (e.g. investigation of tooth types and diet by Biology in a Box, 2012)
- C4.1 Populations and communities (e.g. an interactive simulation, by BioInteractive, 2020, that allows students to explore two classic mathematical models describing population change over time: the exponential and logistic growth models)
- B4.1 Adaptation to environment (e.g. a comparison of biomes of the world, MBGnet, 2005)
- A4.2 Conservation of biodiversity (e.g. analysis of endangered species from different ecosystems/ regions/continents using the IUCN Red List by IUCN, 2022)

Biodiversity

Biodiversity is a result of evolutionary processes such as speciation. Examples of speciation can be proposed to make connections between topics and present the theme of unity and diversity of living organisms.

- A4.1 Evolution and speciation (e.g. real-life examples of reproductive barriers by Learn.Genetics, n.d.)
- D4.1 Natural selection (e.g. analysis of antibiotic resistance using data sets by European Centre for Disease Prevention and Control, 2016)
- A3.1 Diversity of organisms (e.g. plant and fungal taxonomy database by Royal Botanical Gardens, Kew, n.d.)
- D3.2 Inheritance, D2.2 Gene expression and D1.3 Mutation and gene editing (e.g. the Human Gene Mutation Database, Institute of Medical Genetics in Cardiff, 2020)
- D3.1 Reproduction and B2.3.10 Adaptations of sperm and egg cells (e.g. human population growth per country database by The World Bank. Data, n.d.)

Reproduction and homeostasis

Reproduction and homeostasis can be connected through the topics of hormonal control of pregnancy, childbirth and menstrual cycle. Negative and positive feedback can be used to picture the theme of continuity and change.

- D3.3 Homeostasis and A1.1 Water and D2.3 Water potential (e.g. analysis of global, regional and national burden and trend of diabetes by Lin et al., 2020).
- C3.1 Integration of body systems and C2.2 Neural signalling and C2.1 Chemical signalling (e.g. data sets of sleeping patterns by National Sleep Research Resource, 2022)
- C3.2 Defence against disease (e.g. data set for consumption of antibiotics in different countries by WHO, 2018)
- B3.2 Transport and B2.3.9 Adaptations of cardiac muscle cells and striated muscle fibres (e.g. databases of heart disease in the USA by U.S. Department of Health & Human Services, 2022, Europe by Wilkins et al., 2017, and worldwide by WHO, n.d.)
- B3.3 Muscle and motility
- B3.1 Gas exchange and B2.3.8 Adaptations of type I and type II pneumocytes in alveoli

Gas exchange

Gas exchange in type I pneumocytes can be further explored to show how transport across membranes occurs, connecting both topics through the theme of form and function.

- B2.1 Membranes and membrane transport
- B2.2 Organelles and compartmentalization
- A2.2 Cell structure and B2.3 Cell specialization, and A2.3 Viruses
- D2.1 Cell and nuclear division

Chromosome structure

The structure of chromosomes can provide a link between nuclear division and nucleic acids. Students can unpack the structure of chromosomes from chromatids and nucleosomes, and finish with the DNA double helix.

- A1.2 Nucleic acids and D1.1 DNA replication and D1.2 Protein synthesis
- B1.2 Proteins
- C1.1 Enzymes and metabolism
- C1.2 Cell respiration (e.g. recent trends in global production and utilization of bio-ethanol fuel—case study by Balat and Balat, 2009)
- C1.3 Photosynthesis (e.g. Free Air CO_2 Enrichment (FACE)—FACE database by Oak Ridge National Laboratory, n.d.)
- B1.1 Carbohydrates and lipids

SL and HL biology roadmap example

Rationale and purpose

This particular order of topics has been prepared for a mixed SL and HL class. It starts with the core topics that are taught in both SL and HL. The content has been divided into nine units that often finish with HL content, to allow teachers to continue teaching only with HL students. Topics are arranged to facilitate students' conceptual understanding of the content. The levels of organization are discussed through the lenses of the themes Unity and diversity, Form and function, Interaction and interdependence, and Continuity and change. Linking questions and activities can be used to make connections between units. The roadmap encourages students to network their knowledge and deepen their understanding through overarching themes, not necessarily through the four levels of life organization.

Interactions, interdependence and function in ecosystems

The focus for this unit is to unpack the theme of interactions, interdependence and function in ecosystems. Students will be looking at connections between biotic and abiotic factors, environmental adaptations, and different forms of nutrition.

- C4.1 Populations and communities
- C4.2 Transfers of energy and matter
- B4.2 Ecological niches
- B4.1 Adaptation to environment

Diversity

The driving theme for this unit is diversity. Students will explore the diversity of living organisms (biodiversity) and biological processes that lead to it.

- A4.2 Conservation of biodiversity
- A3.1 Diversity of organisms
- A4.1 Evolution and speciation

Continuity and change in biological systems

This unit deals with the theme of continuity and change in biological systems. Students will be exposed to various processes that maintain continuity or lead to change in living organisms.

- D4.1 Natural selection except for HL content, and A3.2 Classification and cladistics (HL students only)
- D3.2 Inheritance and D4.1 Natural selection HL content

- D2.1 Cell and nuclear division
- D1.3 Mutation and gene editing
- D2.2 Gene expression (HL students only)

Change, continuity and form at the molecular level

The focus for this unit is to picture the theme of change, continuity and different forms at the level of molecules.

- A1.2 Nucleic acids
- D1.1 DNA replication
- D1.2 Protein synthesis
- B1.2 Proteins

Form and function at the molecular and cellular levels

This unit introduces the theme of form and function in living organisms through the lenses of molecules and cells. Students will look at various macromolecules and their functions, cells and their structure, and adaptations of cells to carry out various roles.

- B1.1 Carbohydrates and lipids
- B2.1 Membranes and membrane transport
- A1.1 Water and D2.3 Water potential
- B2.2 Organelles and compartmentalization
- A2.2 Cell structure
- B2.3 Cell specialization
- A2.1 Origins of cells (HL students only)

Form and function in body systems

In this unit, the same theme of form and function is continued, but explored from a different perspective. Students will have an opportunity to learn different forms of adaptations, forms of cells, and systems that make body systems work together.

- B3.1 Gas exchange
- B3.2 Transport
- B3.3 Muscle and motility (HL students only)

Interaction and interdependence in organisms and body systems

Students will revisit the theme of interaction and interdependence and explore it from a perspective of organisms and body systems.

- C3.1 Integration of body systems
- C2.2 Neural signalling
- C2.1 Chemical signalling (HL students only)

Continuity and change in organisms and body systems

The leading theme for this unit is continuity and change in organisms and body systems. Students will be introduced to defence mechanisms to further explore interactions between the human immune system and pathogens.

- D3.3 Homeostasis
- D3.1 Reproduction
- C3.2 Defence against disease
- A2.3 Viruses (HL students only)

Interactions and interdependence at the molecular level and linked to global issues

In this last unit, students will look at the theme of interactions and interdependence at the level of molecules, and connect them with global issues such as global warming, carbon accumulation in the atmosphere and afforestation. As a result, students will gain a better understanding of cause-and-effect relationships in living and non-living systems.

- C1.1 Enzymes and metabolism
- C1.2 Cell respiration
- C1.3 Photosynthesis
- D4.3 Climate change
- D4.2 Stability and change

Lesson example

Downloadable resource

Lesson example: Chemical and neural signalling (PDF)

Unit planners

Sample unit planners

All DP teachers are required to engage in explicit planning. However, the IB does not prescribe a particular format of unit planner that teachers should use. Nonetheless, the process of planning may be supported by using one of the template DP unit planners developed for DP teachers. These DP unit planners are not intended to mandate or restrict what DP teachers can or cannot do. Rather, they are intended to inspire and support teachers to think more about not only what they are teaching, but also how they are teaching.

Examples of DP unit planners are provided in the resource *Approaches to teaching and learning in the Diploma Programme*. This section of this support material also includes examples of completed unit plans for the DP sciences. These examples are intended to help teachers to reflect on their own planning and are not intended to be model plans or to prescribe how unit planning should be undertaken.

Downloadable resources

DP biology sample unit planner 1: Ecological interactions (PDF)

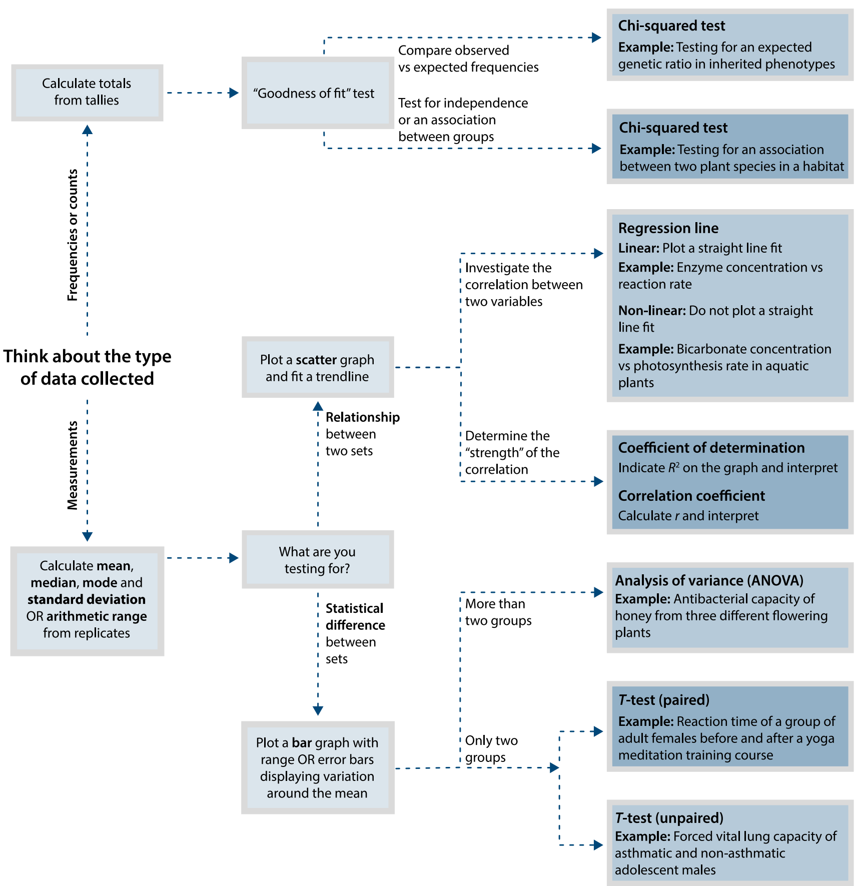
DP biology sample unit planner 2: Water, membranes and cells (PDF)

Mathematical skills for practical investigations

Introduction

The following mathematical functions are regularly incorporated into practical investigative writing in Diploma Programme (DP) biology. Teachers should aim to scaffold their experimental programme so that students are exposed to a sufficient range of mathematical and statistical proficiencies as to allow them to carry out successfully the correct analytical aspects of their scientific investigation. The aim of this resource is to provide both a description and rationale for common mathematical functions. Therefore, this resource could be used by both teachers and students. Student activities, including task sheets, model answers and guidance, are provided in other teacher support material (TSM) resources for the chi-squared test, *t*-test and presentation of standard deviation as error bars in graphing with a spreadsheet. Teachers are reminded to read recent subject reports for further feedback and instruction in practical components of the DP biology course. Other statistical functions not mentioned in this resource may be relevant to scientific investigations. As with the investigations themselves, there is no "one-size-fits-all" statistical approach, and this in itself is worth acknowledging. A basic flow chart, such as the one shown, can be used by students to select a statistical tool appropriate for their data. This flow chart can also be downloaded as a PDF.

Flow chart for selecting a statistical tool



Downloadable resource: Flow chart for selecting a statistical tool (PDF)

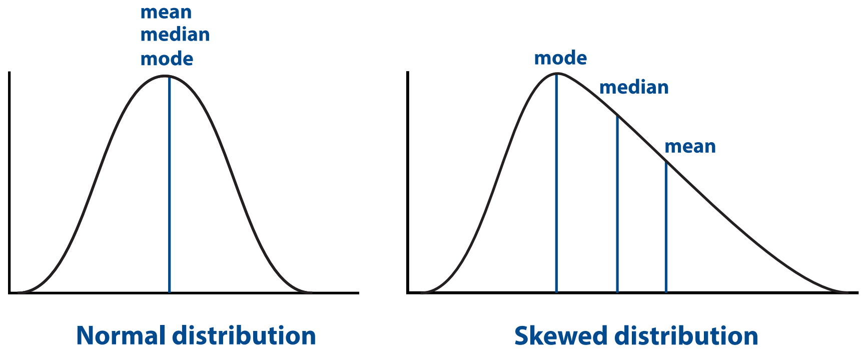
Arithmetic mean

The arithmetic mean (also known as the "mean" or $\bar{x}$) is an average of data points and displays the "central tendency" of a data set. It is a powerful way to represent a tendency as it considers both the number of times each measurement occurs and the range. Typically, the greater the sample size, the more accurate the mean value. This is why students are encouraged to replicate measurements, especially in biology, as natural variation associated with living systems leads to a greater variation in measurements compared to other science disciplines such as physics or chemistry, given that they are more likely to be concerned with physical phenomena.

Median and mode

It may be appropriate to use the median or mode instead of the arithmetic mean to display the central tendency of skewed data (data that are not normally distributed), as depicted in the figure showing the differences between a normal distribution and a skewed distribution. Students could be encouraged to calculate and display the median and mode along with the mean to show their data are normally distributed. When using statistical tools such as standard deviation or t-test, it is assumed that the distribution is normal.

Differences between a normal distribution and a skewed distribution



Arithmetic range

The arithmetic range (or range) is a measure of the spread of data. It is the difference between the largest and smallest observed values in a data set. Outliers, or data that are unusually large or unusually small, can impact the range. Describing the variability of data in a data set allows students to make judgements about reliability, and this judgement is expected in data analysis and evaluation criteria. A high range would suggest an unreliable set of data, as it shows a lack of consistency, the presence of outliers or a wide spread of the data. Arithmetic range is a statistical tool that must be employed if students are interested in establishing the central tendency but have fewer than five replicates for a measured variable. When five or more replicates exist, students must instead calculate and display the standard deviation to show variability.

Standard deviation

The standard deviation (also known as SD, s or σ) is a powerful indicator of the variability of a data set, as it considers both the spread of data and the proximity of data points to their mean. In DP biology, standard deviation is the tool by which students are expected to judge the reliability of a mean value. It should only be calculated and displayed for sets of data that show normal distribution and for data sets with a minimum of five repeat measurements (also known as “replicates” or “trials”). If students have insufficient data, they must use the arithmetic range. As standard deviation shows the spread of data, or how tightly data points are clustered around the mean, it can be used as an indicator of reliability. As biologists often investigate phenomena that are associated with living systems, there is typically a wider spread in data around a mean than, say, in chemistry or physics, where measurements do not vary as much. This is why biologists are not expected to propagate error (uncertainties) to the extent that chemists or physicists are within the DP sciences. As the greatest source of variability in measurements is usually the living system itself, standard deviation plays a central role in data analysis and evaluation criteria. Students are expected to show their understanding of this aspect in their written interpretation. Not calculating the standard deviation when it is warranted or calculating the standard deviation with insufficient replicate measurements is a common mistake in practical work in biology and could impact the data analysis, evaluation and conclusion criteria.

Correlation coefficient

The correlation coefficient (also called “Pearson’s correlation coefficient” or r) measures linear correlation or the degree to which a pair of continuous variables is related. It can allow a student to determine the “goodness of fit” of their trend line as well as whether the relationship is positive or negative. However, the correlation coefficient is only really applicable for data that fit a linear relationship, as displayed in a scatter plot with a straight line trend line. The correlation coefficient takes a value between positive and negative one (+1 and −1, respectively), where 1 denotes a perfect linear correlation and 0 shows no correlation. Students can use descriptors such as “weak”, “moderate” or “strong” to describe the fit based on the value of the correlation coefficient, as shown in the table on descriptions for fit.

Descriptions for fit based on the value of the correlation coefficient

Degree of correlation	Explanation
Perfect	a value close to 1 or −1 shows near-perfect correlation
Strong	a value between ± 0.50 and ± 1 displays strong correlation
Moderate	a value between ± 0.30 and ± 0.49 displays moderate correlation
Weak	a value below ± 0.29 is said to denote weak correlation
No correlation	a value of 0 or close to 0 denotes no correlation

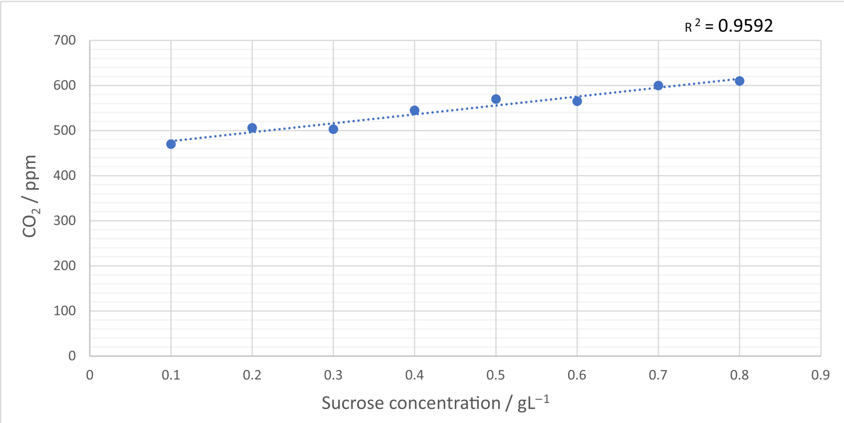
[Source: Statistics Solutions, 2019]

In order to calculate the correlation coefficient, students may employ a graphic display calculator or a spreadsheet program to show their calculation steps. They do not need to display multiple steps in the working out of this statistic, although some evidence of process would be reasonable to expect for the data analysis criteria.

Coefficient of determination

A squared correlation coefficient (denoted as r^2 or R^2), also known as the “coefficient of determination”, shows how well a trend line matches the plotted data points. The r^2 value is often used to judge the “goodness of fit” of a trend line through plotted data, as seen in the figure displaying the relationship between concentration of sucrose and mean CO_2 evolved from respiring *Saccharomyces cerevisiae*. A value of 1 displays a perfect fit and 0 implies no discernible fit at all. Students can use descriptors such as “weak”, “moderate” or “strong” to describe the fit of their trend line based on the value of their coefficient of determination, as mentioned above. Students graphing data using a spreadsheet program can opt to display the coefficient of determination on their graph, as shown in the figure on the relationship between concentration of sucrose and mean CO_2 evolved from respiring *Saccharomyces cerevisiae*. Thus, this statistical tool is simple to use and accessible. It is reasonable to assume that students investigating a correlation between two variables would have carried out “sufficient” processing of data, with calculations of mean and standard deviation, as well as the correct application of a trend line, rather than using the coefficient of determination alone. Although not required, once calculated, students could be encouraged to include a significance test for their correlation, to provide more robust processing and to expand the scope for analysis and interpretation.

Relationship between concentration of sucrose and mean CO_2 evolved from respiring Saccharomyces cerevisiae



Students need to ensure that they interpret correlation coefficients correctly and refer to goodness of fit rather than assuming that the statistic infers the "reliability" or "accuracy" of their data. This is often a cause for misinterpretation and affects the data analysis criteria. The coefficient of determination may be displayed for linear and logistic (logarithmic) regression but should not be plotted for polynomial or geometric relationships. Unlike the correlation coefficient, the coefficient of determination cannot show whether a trend is positive or negative.

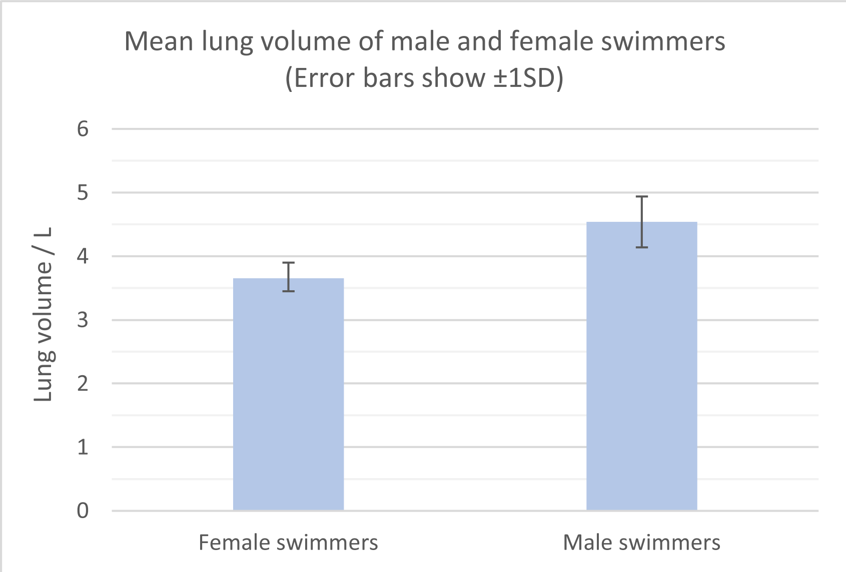
Error and range bars

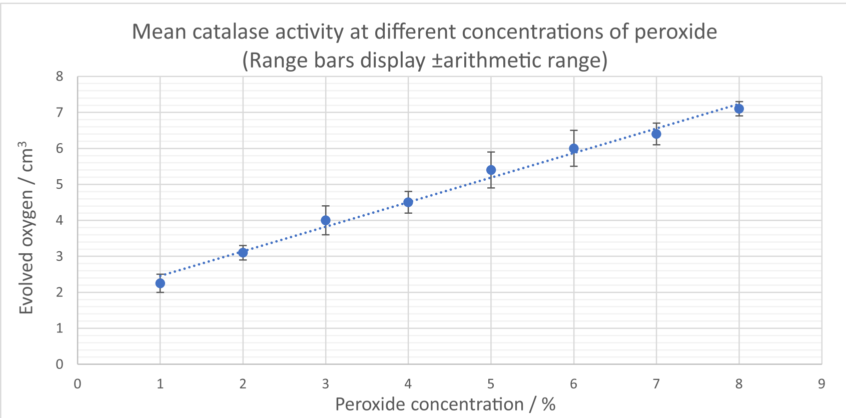
Error and range bars are graphical representations of the variability of a data set. In other words, they represent an impression of our confidence in any average values calculated. Range bars simply show the maximum and minimum values of a data set. Error bars commonly represent ± 1SD or ± 2SDs from the mean, though they can also be used to show other measures of confidence such as the standard error of the mean (SEM) or 95% confidence interval (95% CI). In all circumstances, clear labelling is important with respect to identifying the type of bars used, and the reasons for this choice should be made clear as appropriate. Error and range bars are best displayed using vertical bars extended above and below a data point plotted on a graph. Horizontal error bars can also be used to display the uncertainty in reported measurements, but this is not expected or customary in investigations involving biology.

As arithmetic range and standard deviation quantify variability but do not account for sample size, they should not be used to assess statistical significance with regard to the overlap of error bars. Observing whether standard deviation error bars overlap or not, for example, conveys nothing about whether the difference is, or is not, statistically significant. As SEM and 95% CI statistics take both variability and sample size into account, statistical significance can be deduced by the overlap or lack of overlap between discrete sets of data. In either case, additional statistical tools, including t-test or analysis of variance (ANOVA), are usually expected to confirm this. In DP biology, range and error bars are expected for graphs displaying means for discrete data sets, and their correct application affects the data analysis and evaluation criteria in practical work. They are also useful, but not mandatory, for graphs displaying continuous data or correlations.

Graphs are provided to show examples of range and error bars plotted for discrete (bar graph) and continuous (scatter plot) data using Microsoft Excel.

Examples of error bars and range plotted for discrete (bar graph) and continuous (scatter plot) data





The following are important points to note.

- The descriptive titles of each graph specifically refer to the parameters displayed by the error bars. This is an expected practice and affects the data analysis criteria for practical work.
- Each bar is unique in length. This is because each mean has its own specific range or standard deviation value. If they are the same length, the statistic has been incorrectly displayed.
- To date, the spreadsheet program Google Sheets does not have the functionality to allow users to customize range or error bars sufficiently. Other spreadsheet programs, such as Excel (Windows or macOS) and Numbers (macOS), can do this. If accurate, manually drawn range or error bars are acceptable.

Downloadable resources

Examples of resources for a teachers' toolkit or for use in formative assessment.

- Displaying standard deviation as error bars: Student task sheet (PDF)
- Error bars: Student model with guidance (PDF)

T-test

T-test provides the basis by which to judge whether or not the difference between the means of two data sets is statistically significant. When something is considered statistically significant, it means that there is a strong statistical probability that it is not caused by chance alone. This test is easy to perform, can be used with relatively small data sets (a sample size of $n \geq 10$ for a given variable is permissible, although larger sample sizes are preferable) and distinguishes small differences between means. However, *t*-test is only valid for certain situations. The following criteria must be met for *t*-test validity.

- It is a two-group test only. It is not appropriate for multiple data sets.
- It is an appropriate comparison for means from discrete data sets (e.g. species A vs species B).
- It can only be applied to measurements (it is not suitable for counts or frequencies).
- The sample size of each data set must have a minimum of five replicates/repeats/trials. As mentioned above, larger samples are more likely to yield greater significance. Also, care must be taken by students in planning investigations, so as to collect sufficient data to represent 10 hours of allotted practical work.
- Standard deviations of means should be similar.
- The data must show a normal distribution. This can be evidenced when the mean, median and mode are closely aligned, as shown in the figure on the differences between a normal distribution and a skewed distribution in "Median and mode".

Statistical tools such as *t*-test would normally be presented after a graphical display of processed data and before the conclusion and evaluation sections in investigative writing.

There are a number of ways to calculate this statistical function, and each method has different expectations in terms of what is presented/communicated in investigative writing. For further guidance on the expectations of what to include in investigative writing if using a spreadsheet program (e.g. Microsoft Excel) for *p* or performing a manual calculation for *t*, consult the following *t*-test activity with the accompanying example.

Downloadable resources

Examples of resources for a teachers' toolkit or for use in formative assessment.

- *T*-test: Student task sheet (PDF)
- *T*-test: Student model with guidance (PDF)

Chi-squared test

"Chi" (χ) is a Greek letter and, for the record, is pronounced as "kai" (not "chee"). The chi-squared (χ^2) test is a statistical tool that allows students to interpret observed differences between data sets as statistically significant. The χ^2 test is easy to perform, but this statistical tool is only valid for certain situations. The following are χ^2 test criteria that must be met for validity.

- The χ^2 test should only be used with counts or frequencies (it is, therefore, not suitable for measurements).
- It should not be used with derived values (such as a percentage or density derived from counts).
- The χ^2 test should be used to compare a set of observed (experimental) results to a set of expected or theoretical results.
- The minimum sample size should be 20 ($n = 20$). This statistical test is invalid when sample sizes are too small. Larger samples are likely to yield greater significance. Students need to consider the amount of data they should collect to account for 10 hours of practical investigation.
- This statistical tool is not valid if any of the categories has a frequency of 0 (0 counts).
- Students must be able to group the data into distinct/discrete categories (such as "a" or "b").

Within the DP biology syllabus, students may come across more than one application of this statistical function. Each application has different expectations in terms of processing and what is presented/communicated in an investigation. Students need to be informed that the mathematical processes are different for each application, although some mathematical conventions are similar.

As there is no "function" for χ^2 in a spreadsheet program, it must be calculated manually, using a graphic display calculator, or in stages in a spreadsheet program (e.g. Microsoft Excel or Numbers). Some biology textbooks present a sequential breakdown of the equation in a spreadsheet so that students may display their mathematical process logically and clearly. Such tables may be used when illustrating data processing. An example of such a breakdown when performing the χ^2 test is provided in the table on χ^2 analysis of phenotype frequencies for wing type in a monohybrid cross between heterozygous *Drosophila melanogaster* parents.

χ^2 analysis of phenotype frequencies for wing type in a monohybrid cross between heterozygous Drosophila melanogaster parents

Phenotypes	Observed frequency (O)	Expected frequency (E)	$(O - E)$	$(O - E)^2$	$\frac{(O - E)^2}{E}$
Vestigial wings	22	25	–3	9	0.36
Wild wings	78	75	3	9	0.12
Column totals	100	100	-	-	$\chi^2 = 0.48$

The formulae below display χ^2 and a sample calculation using the same data set presented in the table.

Either the table or the formulae would be appropriate to display χ^2 test processing in a student investigation.

$$X^2 = \sum \frac{(O - E)^2}{E}$$

$$X^2 = \sum \frac{(22 - 25)^2}{25} + \sum \frac{(78 - 75)^2}{75}$$

$$= 0.48$$

Statistical tools such as the χ^2 test would normally be presented after a graphical display of processed data and before the conclusion and evaluation sections in investigative writing.

Downloadable resources

Examples of resources for a teachers' toolkit or for use in formative assessment.

- Chi-squared test: Student task sheet (PDF)
- Chi-squared test: Student model with guidance (PDF)

Errors and uncertainties

The examples that follow are only illustrations of the depth required to address uncertainties and errors. They do not represent all the ways and means to deal with uncertainties and errors.

The significance of errors and uncertainties

Data collection and data analysis are central to the scientific process. All data are limited in the information they convey; this means that there is uncertainty in every measurement. This uncertainty is expressed as a range of possible values within which the true value lies.

Moreover, experimental design always involves some weaknesses and assumptions that may give rise to errors. These uncertainties and errors have an impact on the validity of scientific findings, and so they must be carefully communicated and considered in the evaluation of the results.

Students should, therefore, be encouraged to record uncertainties and errors, and to consider their impact on the results of **all** their experimental work during the course. The criteria for the internal assessment component of the course also include these skills.

The resources here explain the steps involved in handling errors and uncertainties, so that these processes can be integrated into students' learning. Experimental data continually expand the boundaries of science, but an awareness of the limits of that knowledge is crucial to its application.

Types and sources of error

There are two types of errors: systematic and random.

Systematic errors

The first category of errors concerns systematic errors, which:

- are errors due to identifiable causes in the experimental design
- give results that are consistently higher or lower than the true value
- are not reduced by repetition of the experiment
- can, in principle, be reduced by modifications to the experiment.

Examples of causes of systematic error include:

- error caused by poor insulation during thermochemical experiments
- error caused when measuring gas volume by collection over water, assuming the gas is insoluble.

Random errors

The second category of errors involves random errors, which:

- arise from the limit of the precision of the experimental apparatus
- lead to measurements that are equally likely to be higher or lower than the true value
- can be minimized by measurement repetition and averaging the measurements, leading to cancelling out of the variation
- can be reduced with the use of more precise measuring equipment
- can be quantified in all measurements and are expressed as a ± range of values.

The following are examples of measurements showing a decrease in random error and thus an increase in precision (the term "precision" is explained in the following section).

Examples of measurements showing a decrease in random error thus an increase in precision

5.2 g ± 0.1 g

5.13 g ± 0.01 g

5.312 g ± 0.001 g

decreasing random error

increasing precision

Accuracy and precision

Accuracy is how close a measured value is to the correct value. Experiments with smaller systematic errors are more accurate.

Precision indicates how many significant figures there are in a measurement. Data with smaller random errors are more precise.

For example, the normal boiling point of water is 100°C. Measurements from two experiments are provided in the table on boiling point versus uncertainty.

Measurements from two experiments on boiling point of water vs uncertainty

	Boiling point (°C)	Uncertainty
Experiment 1	99.5°C	± 0.5°C
Experiment 2	98.15°C	± 0.05°C

Experiment 1 is more accurate but less precise. Experiment 2 is less accurate but more precise. (Note the consistency in the number of decimal places between each measurement and its uncertainty. The term "uncertainty" is explained in the next section.)

Estimating and recording uncertainty in raw data

All raw data should be given with an associated uncertainty (random error). As it is the last digit that is uncertain, the uncertainty must be expressed to the same number of decimal places as those in the measurement.

Example 1

34.0 cm^3 ± 0.5 cm^3

34.10 cm^3 ± 0.05 cm^3

It can sometimes be difficult to determine the uncertainty associated with a measurement as several factors may influence the reading. Examples include the reaction time of the experimenter when measuring time, or judging the colour change at the end point of an indicator during a titration. These may not be quantifiable but should be noted as additional sources of error.

In general, random error can be estimated as follows.

- The uncertainty for a specified temperature is often stated by the manufacturer of the instrument or glassware.
- Where not stated, for digital equipment, the uncertainty is the smallest scale division (sometimes known as "the least count").
- Where not stated, for analogue equipment, the uncertainty is half the smallest division.

Example 2

For example, consider the following data obtained from experiments to measure the mass of two samples using a digital balance. According to the table on data from the two-decimal point balance, the uncertainty is ± 0.01 g.

Uncertainty in measurements when using a two-decimal point balance

	Mass (g ± 0.01 g)
Sample 1	1.23
Sample 2	0.95

However, as the table on data from the three-decimal point balance shows, the uncertainty is ± 0.001 g.

Uncertainty in measurements when using a three-decimal point balance

	Mass (g ± 0.001 g)
Sample 1	1.233
Sample 2	0.954

Note that when the same apparatus is used for a set of data, the uncertainty can be recorded in the column header, as it is the same for each reading.

Example 3

As the figure of the glassware shows, the smallest division (or least count) is 0.1 cm^3. In this case, the uncertainty is taken as ± 0.05 cm^3.

Therefore, the volume of air in the glassware is expressed as 48.80 cm^3 ± 0.05 cm^3.

Example of uncertainty in measurement of volume when using analogue glassware

Teacher and student responsibilities

This section outlines the actions and responsibilities of both teachers and students during the scientific investigation. The teacher is the mentor who provides guidance and support to students during the process, so that students can demonstrate the necessary inquiry skills described in the sections "Approaches to learning", "Approaches to teaching" and "Skills in the study of biology".

Teachers are encouraged to accompany and guide students in this journey, allowing them to make their own decisions with confidence, replicating the processes undertaken by scientists. Topics that have some personal significance will encourage students into more innovative approaches.

Teacher responsibilities

General responsibilities

Teachers must provide "non-decision-making" guidance and support. They must develop a range of strategies to ensure ongoing authenticity of the student work, which may include:

- discussing with students their initial proposals and the investigative methods to be used
- being present and supervising students during data collection
- discussing the content of the work with students and the conclusions being drawn
- scrutinizing the draft and final versions of the work, e.g. by comparing a student's writing style with that of their other work, or using web-based applications to detect plagiarism.

Specific responsibilities

While facilitating the scientific investigation, teachers have the following responsibilities.

Prior to student development of a research question, teachers must:

- explain the aims and requirements of the scientific investigation, ensuring that the criteria are well understood by students
- ensure that students have developed the required skills for their scientific investigation and for authoring their reports
- encourage students to explore ideas and ask questions that relate to topics studied during the course
- remind students that different types of investigation could be carried out, e.g. hands-on investigations, fieldwork, use of databases and online simulation
- ensure that approximately 10 hours are allocated for the design and implementation of the scientific investigation.

During student development of a research question, teachers must:

- discuss with students the appropriateness of their research question for a report with a 3,000-word limit
- counsel students on whether the projected research is suitable for the biology course and feasible in terms of time, resources, and safety, ethical and environmental considerations
- ensure that each student develops their own research question
- ensure that the investigative method proposed by each student is adequate to obtain valid and sufficient data.

During initial collaborative work, teachers must:

- guide students in organizing themselves into groups

- ensure that each group consists of no more than three students.

In this phase, the school, the teacher and the students share responsibility for ensuring that each student's input is assessed only on the work they carry out for their own investigation.

During the investigation, teachers must:

- supervise the work and data collection carried out by students. If students are collecting data outside the classroom, sufficient steps should be established to ensure authenticity of student work
- monitor student progress in data collection and processing
- where necessary, show students how to operate equipment, or guide them in the steps needed to carry out tasks such as statistical analysis, graphical analysis and navigating a database. However, the teacher should not choose equipment, the method of analysis or the database for students.

During report writing, teachers must:

- remind students of the requirements of the written report—it should be relevant and concise, with references—and of the assessment criteria
- ensure that students understand concepts related to academic integrity, e.g. authenticity and intellectual property. In the case of collaborative work, the difference between collaboration and collusion must be made clear
- read and comment on students' draft investigative reports. The teacher's comments should aim to help students identify issues and shortfalls according to the assessment criteria, but they must not directly offer solutions
- ensure that the internally assessed work is entirely that of each student, and that any information incorporated from external sources is appropriately cited and acknowledged.

Student responsibilities

General responsibilities

- First and foremost, the work submitted must be a student's own.
- Individually, each student must:
    - formulate a research question
    - establish a research methodology
    - identify variables
    - collect and analyse the data
    - draw conclusions.
- Students must also understand and actively apply concepts related to academic integrity, such as authenticity, respect for intellectual property, and citing and referencing according to accepted systems.

Specific responsibilities

Prior to the development of a research question, students must:

- understand that the internal assessment is compulsory for both standard level (SL) and higher level (HL) students
- read and understand the assessment criteria.

During development of a research question, students must:

- choose a suitable topic in biology for the scientific investigation
- formulate and develop their own research question, even if working in small collaborative groups
- consult with the teacher to ensure that the proposed scientific investigation is feasible. The research question must be focused, non-trivial and testable

- design a method that is suitable to address the research question and allows collection of valid and sufficient data
- seek teacher guidance to learn how to set up and use equipment, and to be sure that their methodology is appropriate considering the time and resources available.

During the investigation, students must:

- follow experimental guidelines, and local ethics, safety and environmental regulations
- follow school and teacher recommendations and stipulations
- record all observations and measurements.

During the report writing phase, students must:

- present a concise draft version of the report to the teacher
- use subject-specific terminology and conventions
- acknowledge all sources of information, with adequate references
- consider teacher recommendations regarding the draft version of their report, before submitting the final version
- confirm that the report submitted is their authentic work, and constitutes the final version of that work.

Scheduling and planning the internal assessment

As stated in the *Biology guide*, "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".

Each school is free to decide the stage of the course most appropriate to carrying out the scientific investigation, when students have developed sufficient skills and subject content.

Factors to consider in scheduling and planning include:

- the experimental skills and concepts to be developed during the two-year course
- the 10 hours to be allocated to the work, e.g. when these should be scheduled
- the number of students being assessed, all of whom will need guidance and supervision
- coordination with teachers of other Diploma Programme (DP) subjects, to avoid excessive student workload
- school calendars, local regulations and other DP assessment activities
- accessibility to any outdoor environment (if applicable)
- the types of investigation chosen by the students:
    - laboratory work
    - fieldwork
    - investigations using simulations, databases and modelling
- the IB submission deadline indicated in *Diploma Programme Assessment procedures* (updated annually).

Student preparedness

Over the course of their studies, student preparedness for the internal assessment is developed through multifaceted learning opportunities.

Developing approaches to learning skills in biology

Table 3 in the *Biology guide* describes the approaches to learning skills that students must experience during the course. Through these experiences, the approaches to learning skills—thinking, communication, social, research and self-management—can be practised and developed before the scientific investigation is attempted.

Formative practical experiences

The section "Skills in the study of biology" in the *Biology guide* describes the experimental techniques, technology and skills that students must attain to support the inquiry process. Students develop their scientific skills and techniques, and their understanding of scientific methodologies, using a range of active learning processes through which they experience the syllabus content. Throughout the course, this involves carrying out different formative practical activities, investigations, experiments, fieldwork and assignments. It is essential that students are given the opportunity to ask a range of research questions with differing methodologies. These experiences will be applied to the scientific investigation through the inquiry process, which includes the stages of designing the investigation, collecting and processing data, concluding and evaluating. This is also an opportunity to reinforce the *IB sciences experimentation guidelines* and academic integrity guidance, as well as giving guidance on how to cite and include references.

Presenting and explaining the internal assessment criteria

The internal assessment criteria are introduced in class activities throughout the first year of the course. Applying the criteria to smaller assignments, whether individual or collaborative, is another way to familiarize students with the criteria. Students should have sufficient opportunities to unpack the requirements for each criterion.

Student planning

An important success factor for the internal assessment is for students to organize themselves according to the time and resources available. For example, major tasks can be broken down into stages, each one with an agreed deadline. A staged process may involve the following.

Ideation sessions

Ideation sessions can be very useful for students to develop a culture of asking questions based on personal interests, observations and subject content within the syllabus. Ideation sessions can also be valuable in revising the *IB sciences experimentation guidelines*.

Students should be encouraged to choose a topic of interest for the scientific investigation.

Developing a research question

Each student should read about their topic of interest to gather background information that will lead to meaningful study. They should record details of all the websites and literature they consult.

Students can then formulate a focused research question identifying the relevant variables, including those that need to be controlled. After a question is formulated, the teacher spends time with each student to verify that the research question is testable, and that variables have been correctly identified. For example, it may be necessary to select a suitable range of values for the independent variable.

Deciding on a methodological procedure

Each student decides on the most appropriate method to ensure the collection of relevant and sufficient data that address the research question and allow for a valid conclusion to be drawn. Each student provides a list of materials and equipment required for the investigation.

The teacher evaluates the suitability of the student's proposed methodology to answer the research question. If asked, teachers may (for example) need to show how equipment is used, how a technique should be followed, or how a statistical analysis and graphical analysis are carried out.

Collecting data

Each student agrees with the teacher when and where data are to be collected. The teacher should verify that all safety, ethics, environmental and experimental guidelines are followed. They should also monitor the progress of the investigation and supervise the work being carried out by the student as part of the ongoing authenticity check.

For large cohorts of students, a staggered process could be organized.

Writing a draft report

Each student agrees with the teacher on the handover deadline for a draft report. The teacher reads it and provides holistic feedback on the work, without editing the draft. Teacher comments should be broad and general. This is the last opportunity for the teacher to:

- emphasize the importance of a relevant and concise report
- emphasize the correct use of references
- ensure that the work is commensurate with the level of the course
- ensure that the work meets the criteria against which it will be assessed.

Delivering the final report

The student agrees with the teacher on the final handover deadline. Students should revise the contents of the work and make any necessary amendments or improvements before submitting the final version.

Each student must confirm that the scientific investigation is their own authentic work and is their final version. As stated in the *Biology guide*, "the requirement to confirm the authenticity of work applies to the work of all students, not just the sample work that is submitted to the IB for the purpose of moderation".

Internal assessment deadlines

Further work is necessary after the students have submitted their final report. Teachers must therefore take the following steps into consideration while scheduling the work.

Assessment of the reports

The final report from each student about their work must be read, assessed using the internal assessment criteria and authenticated by the teacher.

It is strongly recommended that comments are made on the work. This aids in awarding the correct level for each criterion. During the process of external moderation, comments help examiners understand the reasoning behind the marks given by the teacher.

Internal standardization

Internal standardization is essential to ensure that works are marked consistently within the school for a given examination session. If only one teacher is teaching biology, standardization across science subjects is recommended.

Submission of marks to the IB

After the marks of all the students are entered, a randomized set of works are selected for moderation. Teachers work with heads of department and DP/Career-related Programme (CP) coordinators to make sure marks are submitted prior to the deadline published in *Diploma Programme Assessment procedures* (updated annually).

Submission of works to the IB

The works of the students chosen by the IB for external moderation must be uploaded before the deadline, following the procedures indicated in *Diploma Programme Assessment procedures.*

Activities to develop skills for the inquiry process

Asking questions worth answering

The process of investigating is an opportunity for students to use time and resources to answer a research question. It is the teacher's responsibility to give students opportunities to ask meaningful questions and to steer them away from trivial ones.

Teachers must challenge students to ask questions:

- that are not easily answered using an online search engine
- that are not versions of previously written practical reports
- for which answers are not found in their textbook
- for which the answers are not self-evident from the syllabus.

Some strategies for teaching students to ask questions worth answering include the following.

Exploring unanswered questions

Try asking questions and leading the discussion. For example:

- The question "Why does the amylase inside seeds not digest starch before germination?" can be asked when studying plants or during a study of enzymes or digestion. The answer is that some seeds contain amylase inhibitors (Kneen, Sandstedt, 1943).
- We know heavy metals inhibit enzymes, but what about other metal ions?

Scheduling a lesson on just research questions

A video about a subject (e.g. about what plants can sense) could be used as an activity for students to practise asking research questions.

Downloadable resource
Asking questions from videos (PDF).
This is an example of a lesson about plants.

Reminder: What makes a good research question? The examiner notes say explorations of the relationship between variables should:

- identify the independent variable
- indicate the range of the independent variable
- identify the dependent variable (and/or derived dependent variable)
- describe the material being studied
- include a methodology
- include the scientific name of the organism, where relevant.

Collecting stories

Stories can help to develop students' skills for the inquiry process. They can act as real-world inspiration that helps students think of areas to explore. The following are examples from IB teachers.

Example 1

My Lebanese students told me that their parents grew mint in their gardens to make fresh mint tea. Each family seemed to have their favourite flowers to grow along with the mint plants—running their own domestic versions of an experiment on the effects of companion plants. Ask students to look up the idea of companion plants (e.g. She Said Sunflower, 2019; Zhang et al., 2003) and suggest three research questions from their reading.

Example 2

My Indonesian friends put their mangoes in rice to help them ripen (something I had never seen while growing up in India). What else can ripen fruits, and how might students investigate a question like this? After some background reading (e.g. Gandhi et al., 2016; Nutrition You Can Trust, n.d.), ask students to develop a method.

Example 3

Every place I visited seemed to have their favourite vitamin C source, with parents often saying fruit X had Y times the vitamin C of oranges. For example in India, we are fans of amla; in Southeast Asia, guava is a favourite source; my Japanese students were sure it would be yuzu. Here I ask students to discuss possible methodologies that they could use to analyse food samples to investigate these claims. Students could then do some background research (e.g. Islamic Publications, n.d.; Japan National Tourism Organization, n.d.; Medindia, 2019), devise a research focus and draft the introduction, materials and method.

Running a "skills circus"

A session involving different activities can help refresh and develop students' practical inquiry skills. Here are two examples.

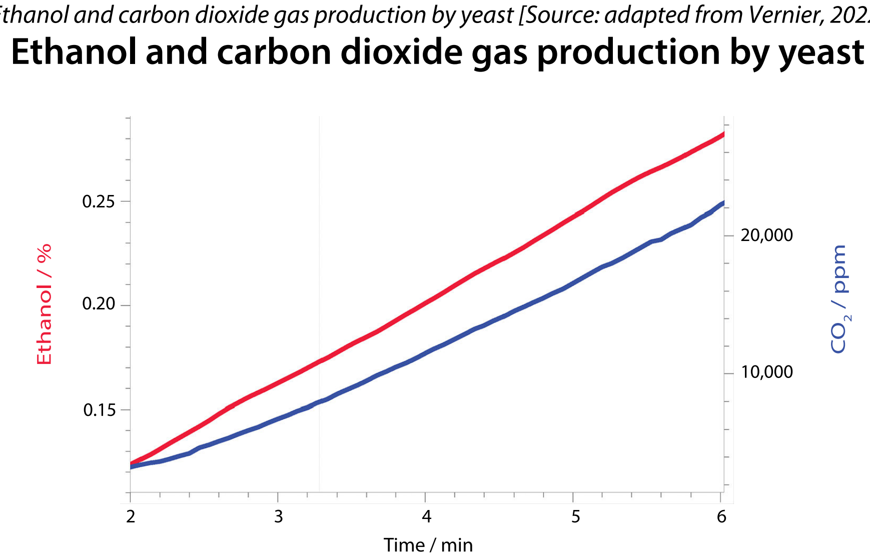
Activity 1—For different laboratory experiments that students have carried out over the past year, gather the apparatus and other materials they used and set it out on laboratory benches. Students then try to use the apparatus to refresh their memories of investigations they undertook. They can use any resource to refresh their memories.

For experiments, also ensure students follow the guidance given in *IB sciences experimentation guidelines* and *Managing safety in science laboratories and workshops*.

Activity 2—Each student receives a graph of experimental results. Their challenge is to set up the correct apparatus and other materials that would be needed to replicate the results shown on the graph.

For example, if given the graph below, students would set up a fermentation laboratory experiment with two different probes and use glucose solutions as their samples.

Ethanol and carbon dioxide gas production by yeast [Source: adapted from Vernier, 2022]



Playing a variable lotto

Variable lotto is a low-stakes, high-feedback exercise. The following example involving chance choice with scientific variables aims to develop experimental design skills.

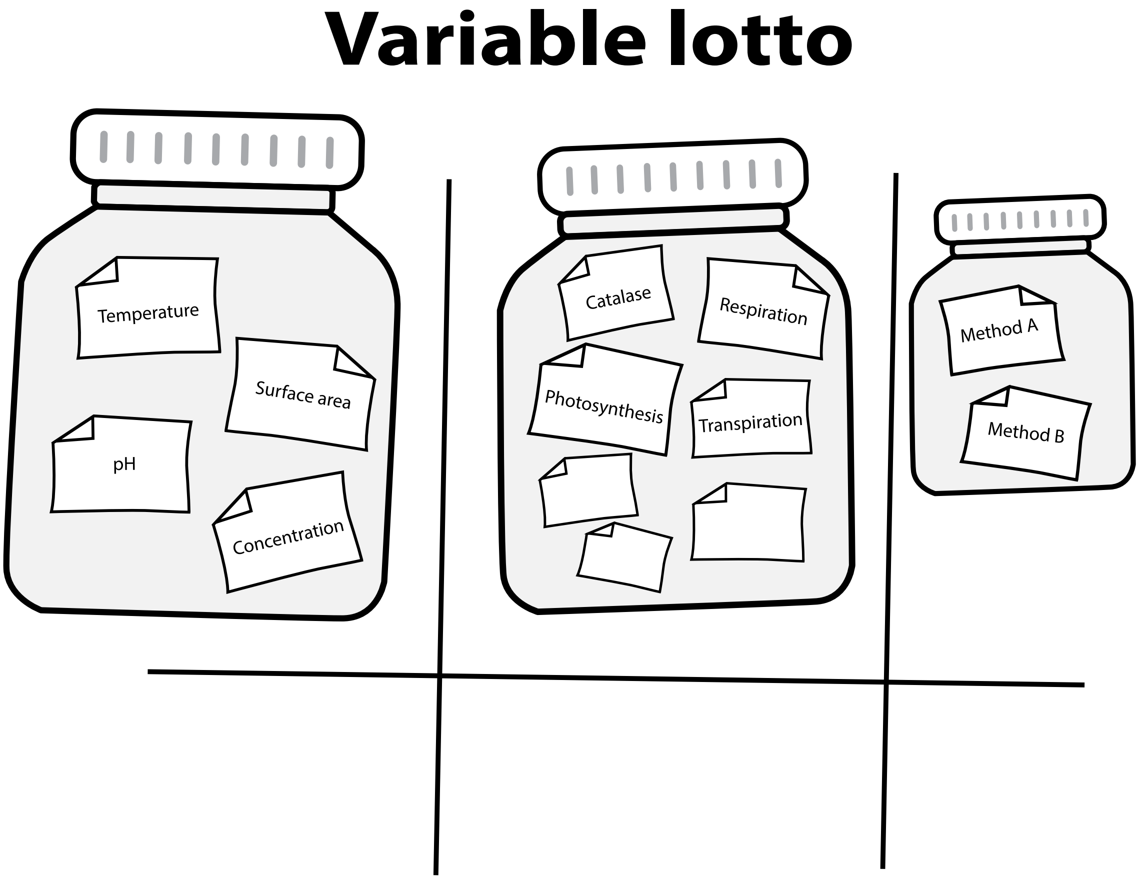
Prepare three beakers or jars containing folded pieces of paper (see the figure) marked with:

- a range of possible independent variables (jar 1)
- various dependent variables (jar 2)

- the letters A and B, referring to different methodologies (jar 3).

Students take a piece of paper from each jar. This shows them the laboratory experiment they will need to design for the next lesson.

An example of a variable lotto



Examples of lotto outcomes

- Effect of temperature on *Elodea* photosynthesis using method A, bubble counting
- Effect of surface area on *Elodea* photosynthesis using method B, measurement using a dissolved oxygen probe

Describe, explain, evaluate, predict

For a graph or set of graphs, students take turns describing what they observe, then explain the results. They then evaluate other factors, such as possible weaknesses in the study, or how the data are presented. Finally, they attempt to make predictions from the data given, or extrapolate to suggest how the experiment that produced the data could be extended further.

For each graph, students:

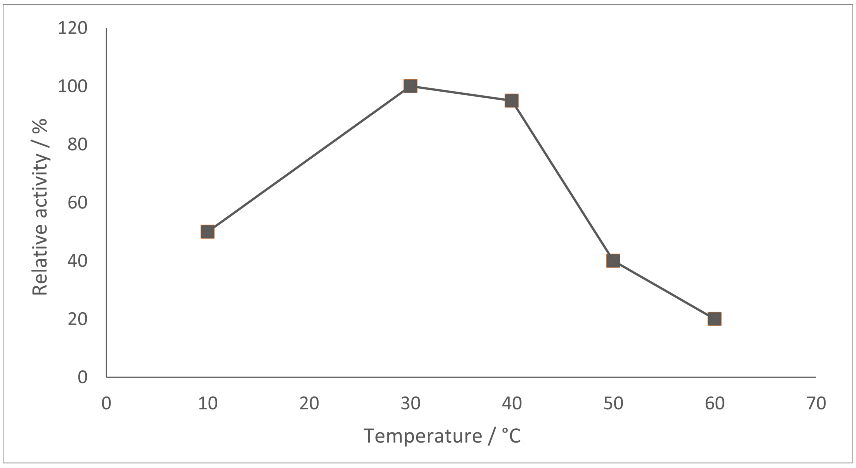
1. suggest an explanation
2. suggest an alternative explanation
3. design experiments to eliminate the alternative explanation.

Some example graphs follow. The first graph includes some answers that students could suggest.

Catalase decomposition of hydrogen peroxide

In this graph, the results are expressed as relative activity, a percentage of the highest reaction rate measured.

Catalase decomposition of hydrogen peroxide [Source: adapted from Al-Bar, 2012]

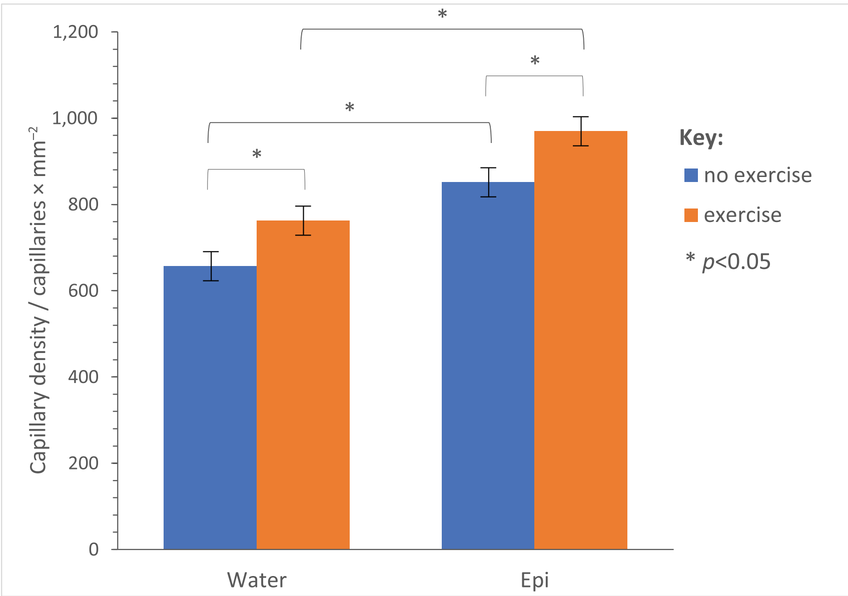


- **Explanation**: Most collisions between enzymes and substrates happen between 10°C and 30°C, and enzymes denature at temperatures higher than this.
- **Alternative explanation**: The spontaneous breakdown of hydrogen peroxide happens more quickly at higher temperatures, or the probe stops working at temperatures higher than 40°C.
- **Possible methods to eliminate alternative explanation**: If this was just the spontaneous breakdown of hydrogen peroxide at higher temperatures, the same trend would be seen in the absence of the enzyme. The student could include a series of test tubes, one for each of the given temperatures, that contain everything but the catalase. There should be no similar increase of reaction rate at temperatures between 10°C and 25°C.

Effects of epicatechin (Epi) on the aerobic capacity of muscles

In this graph, the results show the effects of epicatechin (Epi), a substance in dark chocolate, on the aerobic capacity of leg muscles of mice.

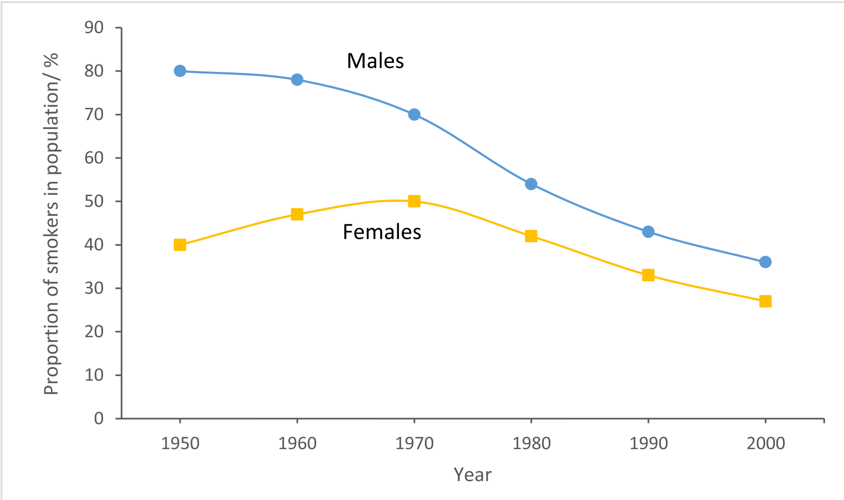
Blood capillary density in mice leg muscles [Source: adapted from Nogueira et al., 2011]

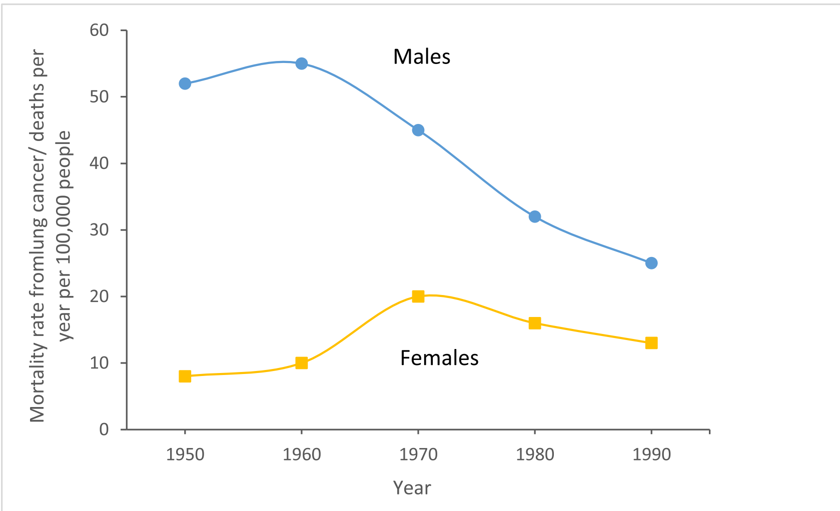


Tobacco smoking and mortality due to lung cancer

In these graphs, the results show the trends in tobacco smoking and mortality due to lung cancer. The results are from a sample of the population aged 35 to 59 and living in the United Kingdom from 1950 to 2000.

Tobacco smoking and mortality due to lung cancer [Source: adapted from Peto, et al., 2000]





Tobacco smoking and chronic obstructive pulmonary disease

The table shows the numbers of individuals in each chronic obstructive pulmonary disease (COPD) class and their mean forced expiratory volume (FEV1) for a Swedish study of 349 people. COPD is characterized by progressive airflow limitation. Classification of COPD as mild, moderate or severe is based on measurement of FEV1, which is the maximum volume of air that can be exhaled in one second.

[Source: adapted from Lindberg et al., 2012]

	Normal	Mild COPD	Moderate COPD	Severe COPD
Never smoked	96	12	6	0
Ex-smokers	95	29	19	3
Regular smokers	32	18	17	2
Occasional smokers	11	8	1	0

	Normal	Mild COPD	Moderate COPD	Severe COPD
FEV1 / litres	2.9 ± 0.68	2.6 ± 0.60	2.0 ± 0.46	1.3 ± 0.24

Using mentor texts when writing the scientific investigation

Mentor texts can be an effective tool to help students learn the specific requirements of disciplines and subject-specific tasks. Teachers know that each discipline has its own specific demands. Students will enter DP biology classes with some writing skills, but teachers will still need to find ways to familiarize students with the internal assessment criteria. They will also need to introduce students to specific conventions expected in science writing, and teach them some of the subject-specific vocabulary required for this task (Pytash, Morgan, 2014).

Mentor texts are often pieces of work that students can read to identify very specific sentences or phrases, and whether they were effective or ineffective. They can then "integrate what they learned from this process into their own writing" (Thompson, Reed, 2019). A mentor text will show students, not just tell them, how to write well, allowing them to envision the kind of writer they can be as they develop their skills (Dorfman, Cappelli, 2017).

One way this exercise varies from the use of mentor texts with younger students is that it does not use a "perfect" exemplary piece of work. Students are invited to find strengths and weaknesses in the mentor text based on teacher clarification of the rubric.

Sample mentor text lesson

In this lesson, taught over two days, students will read two unrelated investigations from the *Biology assessed student work*. While neither of these investigations is perfect, they scored highly enough that students will be able to identify strengths, as well as areas for improvement.

This lesson is best taught after students have collected some data in a laboratory experience, for example a simple enzyme experiment that generated data for which they can draw a conclusion.

The activity, "Assessing mentor texts" (PDF), guides teachers and students through these texts and marking rubrics specifically for the "Conclusion" and the "Evaluation" criteria, but the lesson format is fairly straightforward and can be modified to include other sections.

1. The teacher introduces each internal assessment criterion individually by going over the rubrics, the clarifications and then some more focused points.
2. Students read an assigned section of the mentor text, usually no more than two or three pages of student work. Individually, they mark up where they believe aspects of the conclusion criterion have been achieved, or where they believe there are omissions.
3. Students discuss their findings in groups and give feedback to the class about what markband they would assign this student for that criterion.
4. The teacher then uses a marked-up copy of the mentor text to go over what makes an effective conclusion.
5. Students then spend 15 minutes writing their own conclusions individually.
6. The next day, students continue reading, discussing and marking the evaluation section. The teacher then uses the marked-up copy of the mentor text to go over what makes an effective evaluation.
7. Students then spend 15 minutes writing their own evaluations individually.

Note: It is understood that while the data in biology may support the research question, the results may also be inconclusive.

General advice

Calculating the overall criterion mark

Deciding on an overall mark for a criterion can seem challenging, but it is less so when a clear methodology is used.

- When marking a student's report, read the complete report first to get a general impression of the work before deciding on the marks to be awarded.
- Evidence for a single criterion will inevitably appear in several places in a report—it is not expected that students will respond to the criteria in a linear or standard way. Read the report several times, marking the report overall against each criterion.
- A best-fit approach must be used to decide the appropriate mark for each criterion. The overall mark awarded for a criterion is *not* an arithmetic mean of the different strands. Rather, it is a holistic judgement reflecting the overall standard of work the student has demonstrated for that criterion.
- Read the level descriptors for each criterion (starting with the lowest level) until you arrive at a descriptor that most appropriately describes the level reached by the student's work.
    - If a piece of work seems to be between two descriptors, read both descriptors again. Choose the descriptor that more appropriately describes the student's work.
    - Consider how well the application of command terms has been addressed, as described in the *Biology guide*.
- It is not necessary that all level descriptors are met within a single markband for a mark to be awarded.
- Mark positively—give credit for what the student has done; do not penalize what they could have done or should have done. Record only whole numbers when giving marks; partial marks (fractions and decimals) are not acceptable.

Markbands, level descriptors and strands for the "Research design" criterion

Research design

This criterion assesses the extent to which the student effectively communicates the methodology (purpose and practice) used to address the research question.

Marks	Level descriptor
0	The report does not reach the standard described by the descriptors below.
1–2	• $\boxed{\text{The research question is stated without context.}}$ • Methodological considerations associated with collecting data relevant to the research question are stated. • The description of the methodology for collecting or selecting data lacks the detail to allow for the investigation to be reproduced.
3–4	• $\boxed{\text{The research question is outlined within a broad context.}}$ • Methodological considerations associated with collecting relevant and sufficient data to answer the research question are described. • The description of the methodology for collecting or selecting data allows for the investigation to be reproduced with few ambiguities or omissions.
5–6	• $\boxed{\text{The research question is described within a specific and appropriate context.}}$ • Methodological considerations associated with collecting relevant and sufficient data to answer the research question are explained. • The description of the methodology for collecting or selecting data allows for the investigation to be reproduced.

First strand

In this "Research design" criterion there are three **strands**.

The first strand concerns the research question. The second and third strands are the next two items in the markband.

Each strand repeats in each markband, incrementally differentiated each time.

In "Research design" the three strands appear three times each, in markbands 1–2, 3–4, 5–6.

Awarding zero for a criterion

It is rare that a student's report should be awarded a zero, but there are specific circumstances in which this is appropriate.

- In the case of an incomplete report if there is no evidence at all for a criterion, a zero is awarded.
- If there is some evidence of some effort to address a criterion, the work should only be awarded zero if the response is incomprehensible or totally irrelevant to the criterion.

If one strand of a criterion scores a zero when the other strands do not—If a strand is not addressed at all, or the student's work does not reach the required standard for scoring in that strand, the appropriate score is zero. However, if the other strands are found to match the higher markbands, the overall mark for the criterion should reflect the student's achievement, that is, not over-penalizing the zero-scoring strand.

Investigations not focused entirely on biology

The internal assessment is not an opportunity for an interdisciplinary study—the focus should be on biology.

If a teacher is concerned about the focus of the investigation proposed by a student, they can visit My IB to consult other experienced teachers and examiners for clarification. It remains the teacher's responsibility to make sure each student's internal assessment report is appropriate for assessment in biology.

Collecting sufficient data

Designing the collection of sufficient data

Students should be creative or demonstrate initiative in the design, implementation or presentation of their investigation. It is not expected that every investigation will generate a lot of data. The data collected should be commensurate with the 10 hours' work required for the scientific investigation overall. Student guidance is necessary, especially at the outset of the scientific investigation.

There is no single standard for determining that data collected in an investigation is insufficient: some biology investigations will generate data more quickly than others. The amount of data collected that addresses a methodology will be determined by the nature of the investigation and the time available. The number of repeats should be selected with a clear rationale.

For example, a catalase investigation will generate data more quickly than a photosynthesis investigation, depending on the data collection methods involved.

Some limitations may only become apparent during data processing. It is strongly recommended that the student considers the appropriateness of data as they are being collected. Carrying out rough processing while collecting data may help the student identify issues. This allows them to modify the range, interval or frequencies as well as collect additional data.

The report should be an account of what happened, and the outcomes may not be those predicted. The report should include details of problems encountered when collecting data. It should also describe issues faced by the student during their trials and how the student responded to them. One possibility is that a potentially feasible investigation fails to provide sufficient data, through no fault or inexperience of the student. The data may be rough and possibly inconclusive. The student should be adaptable, and express this in their account of the method.

Sufficient data are necessary for adequate processing to be evidenced. Interpreting the results and arriving at a conclusion will require care and attention if the results are inconclusive. For example, standard deviations need to be calculated from samples of five repeats or more. For an effective *t*-test, at least 10 replicates are needed. To calculate the standard error of the mean, 30 or more replicates is considered acceptable. Nevertheless, it is still possible to have fewer replicates and express variation as a range.

The impact of the amount of data collected on other criteria

Insufficient data and poor consideration of uncertainties may impact students' marks for all the criteria.

The amount of data collected will impact the type of processing that can be done.

If, through no fault of the student, insufficient data are collected, the only viable processing may be to calculate the mean and the range. This is straightforward and could perhaps correlate with a test of significance. If the processing carried out is commensurate with the level expected to address the research question, the work could achieve the highest marks available.

Insufficient data will impact on the conclusion and the evaluation of the investigation. It is important to look for evidence in the report that the student is aware that the amount of data is limiting the conclusion. Note too that if the data are limited the processing will also be limited, and the interpretation will be impacted too. The teacher should counsel the student to follow a process that will be productive with the time and materials available. If there is no good reason why more data could not have been collected, the mark for data analysis could be impacted.

If the data are more plentiful, students are permitted to include standard deviation or standard error. When attempting to interpret the criteria, challenges may arise where students have differing levels of data-processing skills. Investigations with more data or larger data sets may inherently reveal a larger number of flaws in processing. In these cases, carefully consider the student's approach rather than penalizing small errors in the processing. Large errors in processing are a different matter, because they will influence interpretation and the conclusion. Errors carried forward should be applied where appropriate.

Using databases, simulations and models

For work involving databases, simulations and models, the same design rules apply. The source of the data needs to be identified clearly, its reliability established, and its sufficiency and relevance to answering the research question considered. Students using databases and simulations should provide the necessary screenshots, including web addresses or the program name, to clearly demonstrate appropriate data collection and manipulation in support of their methodology. Databases and simulations that are free or behind paywalls are acceptable.

When using secondary data sources, more independent variables can be included, because sufficient data can be collected rapidly.

The student will need to explain how the data sampling is controlled and how it is extracted or filtered. They should explain their selection and the decisions taken for extracting data, and consider using a series of screenshots to illustrate the method. When using databases and simulations, the student must include screenshots or pictures to illustrate the methodology.

Investigations based on tables found in published articles are rarely suitable, because the authors have often already made decisions that the students themselves should make.

Repetitions that result in the same value each time receive minimal credit. In this case, the student can use additional simulations or databases to gather sufficient data to answer the research question. The student must explain how and why the specific simulation was used, and the methodology for collecting data.

Investigations based on computational analysis should include tools that calculate properties accurately, rather than those limited to visual representations.

Downloadable resources

- Working with databases: Student worksheet (PDF)
- Working with simulations: Student worksheet (PDF)

Communication style and report length

The structure of the internal assessment report is the student's responsibility. The IB offers no guidelines here, except that the report should be clear, concise and focused, and demonstrate relevant scientific skills. A cover page and a table of contents are often distractions and should not be included. A clear and informative title reflecting the research question and a first paragraph should inform the reader about the investigation.

There is no fixed style for presenting the method. Both prose and recipe style are acceptable. This is a biology investigation, not an assessment of language skills. The use of the passive voice or a personal style should not impact the marks given. Neither should errors of expression, spelling and grammar, unless these result in ambiguity, contradictions, or amount to incomprehensible content. The structure, scientific relevance and conciseness of the report are more important than the language used. This is particularly important considering that many students are not working in their preferred language.

Assessment is always based on evidence from the student's report, and this evidence needs to be clearly communicated in scientific terms. Effective communication is not a criterion on its own; it is an essential part of all four criteria.

- Effective communication is explicit in the research design criterion. The student needs to communicate the methodology (the purpose and practice) and the context of their investigation.
- Effective communication is an aspect of the data analysis criterion, where the recording and processing of data should be clear, precise and accurate in relation to the research question.
- Effective communication is also implicit in the conclusion and evaluation criteria, where an answer to the research question must be justified and where evidence of an evaluation needs to be expressed.

The report should be a maximum of 3,000 words. The word count does not include data tables, sketches, graphs, headings, references or bibliographies. Where a large amount of data has been collected, only a sample of the data should be included. If a report is clear, concise and focused, 3,000 words (maximum) will be more than adequate. If the report exceeds this limit, examiners are not compelled to read further.

The presentation of scientific names should use the recognized conventions: italics and correct use of case in letters (e.g. *Homo sapiens*).

Citations, bibliographies and academic integrity

If the student is quoting broadly accepted facts or theories, citations are generally not needed. However, if a specific fact is quoted, a citation would be expected. For example, the fact that enzymes have an optimal pH can be considered general knowledge in this subject, but the fact that alpha-amylases have an optimum pH of 6.8 would require a citation.

Citations can be in-text, in footnotes on each page, in endnotes, or written as references in a bibliography. The citations should allow sources to be traced, for example the URL and retrieval dates for online sources. They should be limited to sources that have been used in the investigation, either for ideas, content quoted or images copied. The style of citation is up to the student, but they should follow a clear and consistent method of referencing. The bibliography can be used to record the full reference details.

Academic integrity is important to IB educational philosophy and, indeed, to any academic pursuit. Honesty is the hallmark of scientific inquiry. When writing their reports, the student must clearly distinguish between their words or ideas and those of others.

If a teacher believes some of a report's content may have been taken from a source without adequate citation, this may be a case of malpractice. The teacher must discuss this with the student, to clarify how and why the content came to be presented in the report.

If an examiner is not satisfied that the report is the student's own work, the IB will instigate an inquiry on suspected malpractice.

For further guidance, refer to the IB's *Academic integrity policy* and *Effective citing and referencing*.

Appendices

All information relevant to the investigation must be presented within the report. Appendices will not be read by the examiner. The only appendices permissible and sometimes necessary are consent forms for students participating in data collection.

The full raw data is no longer required in an appendix if there is too much to fit in the actual report. The teacher should have seen the full raw data and made a comment in the work to that effect. The sample data used in the report should be taken at regular intervals so it covers the range of the independent variable.

Research design

This criterion assesses the extent to which the student effectively communicates the methodology (purpose and practice) used to address the research question.

Research question and context

The teacher should check that the:

- research question is unique to the student
- independent variable is present or the two variables being correlated are present
- dependent variable or derived dependent variable is present
- variables are quantifiable
- scientific name of the organism is used (where relevant)
- background context or theory is relevant and focused
- context of the independent and dependent variables is relevant and focused
- choice of data sources, in the case of databases, is explained and their reliability is commented on.

Deciding on the research question

The research question needs to be unique to the student. In the case of group work, the teacher should verify this. Both the research question and the background context provided need to be considered.

All students (whether standard level (SL) or higher level (HL)) can explore topics outside the syllabus. Students should avoid research questions where the answer is known to them beforehand.

The research question may not necessarily include the actual dependent variable but a derived value. For example, for the question "What is the effect of X on the rate of Y?", the rate would be derived from the measured values. The link between the dependent variable and the investigation—the context—would need to be established in the background. This may not be the case for simulations that may result in derived values such as rates. In these cases, the rate would be the raw data.

For certain investigations there would be no independent variable, for example investigating the relationship between the distribution of two species in a named ecosystem.

When a more general research topic is being investigated, the student needs to express it in a form that clearly states the quantities and their relationship, thus guiding an appropriate investigation method.

General accounts of the broad area of study will not achieve the highest marks (e.g. a general overview of enzyme activity). Students should focus their background reading on the exact research question. The background may provide information that will lead the student to identify variables.

The student needs to explain the relationship of the dependent variable to the system being investigated. For example, the context and background for an investigation on catalase could note that the presence of this enzyme leads to the production of oxygen gas, and that the dependent variable measures this. The way the measurement is taken—by pressure sensor, oxygen probe or flotation of filter paper discs—would be part of the methodology.

If the investigation's background is too broad and/or lacks specifics, the student's work will not reach the top markband in the first strand.

Students are permitted to present more than one independent variable, but there must be a clear link between them. They should also carefully consider if including more than one variable will allow the investigation to reach the expected depth, considering the word limit.

Students are permitted to formulate a hypothesis for the outcome of the investigation, though this is not obligatory. A hypothesis can help to set the research question in context. This should not be in the form of the null and alternative hypotheses unless for statistical analysis.

Methodological considerations

The teacher should check:

- that the method can generate data that may answer the research question
- the type of data collected
- the protocol for collecting relevant data
- that a preliminary or trial investigation is described and assessed
- the description of measuring the dependent variable
- the range and intervals of the independent variable
- the sampling rate
- the method of controlling or monitoring each variable
- the discussion of other factors that would need to be controlled
- the techniques used to ensure adequate control (fair testing)
- the use of control experiments
- the quantity of data collected, including sufficient repetitions given the nature of the system investigated
- that provision is made for qualitative observations.

Protocols, methods and procedures

The protocol will be a record of the method used, including an account of trialling. It should not be a proposed plan. Students will probably use standard protocols for determining the dependent variable; the protocols should be cited.

The method employed will depend on the nature of the investigation and may be limited by time or materials. The student's method needs to make reasonable provision for the collection of sufficient data to answer the research question in a 10-hour period of investigative work. This 10-hour period may include a certain amount of designing and trialling, followed by redesign, which could be time consuming. The quantity of data collected needs to be realistic. The student must consider time constraints during design. If the investigation requires more time than that allocated, the teacher should provide the necessary scaffolding.

The reader needs to understand how the methodology and procedures were implemented, and how the equipment and other materials were used. There needs to be enough information so that the reader could, in principle, repeat the investigation. The procedure should be clear and detailed enough to be reproduced.

Defining and explaining variables

A table can be used to list and explain the variables. It is not necessary for the variables to be identified explicitly and separately (e.g. using subheadings).

The dependent variable needs to be accurately defined and explained.

The rationale for the range and intervals used for the independent variable needs to be explained in the context of the investigation. In many experiments the sampling rate needs to be considered to ensure that meaningful but not excessive data are collected. This can often be best determined during trialling.

The method should identify which variables can be controlled and how this is achieved. It should also identify which variables cannot be controlled but need to be monitored (confounding variables). For example, students need to control the lighting and background when taking visual observations (e.g. when using testing strips or comparing test tubes).

Room temperature may not vary very much during an experiment, but in temperature-sensitive investigations it needs to be recorded. Merely setting the room's thermostat or air conditioning is not sufficient to control room temperature for an experimental set-up.

In biology, students often forget that the environmental conditions are important for investigations on human physiology or behaviour.

A student whose work indicates several trials should not be penalized for not mentioning repeat measurements in their methodology.

Students should reflect on the quality of the data while carrying out the investigation, including some rough data processing to detect issues that can be addressed.

Risk assessment

The teacher should check for:

- safe handling of chemicals or equipment
- safe handling of microbes
- application of *IB sciences experimentation guidelines*
- judicious consumption of materials
- use of consent forms where human volunteers are involved
- appropriate disposal of waste
- consideration of impact and safety on field sites
- consideration of safety and environmental concerns.

Teachers have a responsibility to ensure that their students carry out safe, ethical investigations and that the students also consider the environmental impact of these.

Risk assessment is an important part of experimental design. However, issues concerning safety, ethics and environmental impact may not apply to the same degree for each investigation. The impact of risk assessment on the mark awarded for the criterion will depend on whether there are significant safety, ethical and environmental factors that are, or need to be, considered by the student. It should be clear that these risks have been mitigated. Stating an issue indicates the student is aware of it, but not necessarily that the issue has been addressed. If an investigation has no safety, ethics or environmental considerations, the student should include a statement to this effect.

For work with databases, simulations or modelling systems, safety and environmental concerns will not be relevant. However, ethical issues can arise for the use of databases, and it is to the student's credit if they are raised.

Evidence of the use of informed consent forms will be expected where investigations involve human subjects. Use of a consent form is good ethical practice, but it is not evidence that safety issues have been considered.

Examiners who encounter experimental set-ups that constitute a severe risk to safety or the environment will refer these to the IB. The relevant school may then be contacted.

Describing the data collection method

The teacher should check for:

- a logical sequence
- the presence of essential information
- unnecessary repetition
- the sketches, diagrams, charts and photographs used to illustrate the investigation
- the use of screenshots to explain how the data were captured (in the case of investigations using databases and simulations)
- correct use of scientific terms (spelling is not penalized if there is no ambiguity)

- correct conventions for scientific names
- the selection of measuring instruments
- brand names of items used as variables (e.g. fertilizers, sunscreens, milk).

Students need to present information in enough detail for the reader to understand readily how the methodology was implemented, such that they could, in principle, repeat the investigation.

Illustrations and lists

Students should consider illustrating their investigation using annotated sketches, diagrams, charts and photographs of the experimental set-up. These can help to describe the investigation, with minimal impact on the word count.

Illustrations should only be included when they add value. For example, fieldwork should always include some form of site description. This could include maps, diagrams or photographs with appropriate annotations.

A list of materials is useful but not obligatory. Details of the materials can be included in the method if appropriate.

Data analysis

This criterion assesses the extent to which the student's report provides evidence that the student has recorded, processed and presented the data in ways that are relevant to the research question.

Communication of the recording and processing of data

The teacher should check for:

- collection of sufficient and relevant data to address the research question
- appropriate qualitative observations (images/drawings correctly labelled)
- concise presentation (of text, tables, calculations, graphs, other illustrations)
- use of correct scientific units and their symbols
- appropriate formatting of data: units are correct and uncertainties are identified; a consistent number of decimal places
- clear and precise processed data that address the research question
- a sample calculation or the use of screenshots where appropriate
- relevance of graphs (e.g. with best-fit lines or curves).

Units and decimal places

International System of Units (SI) or other metric units (e.g. mL or cm^3, L or dm^3 for volumes) are acceptable. Non-decimal system units (e.g. °F, cups, inches) are not appropriate and should be converted.

A correct and consistent number of decimal places, based on the degree of precision, is expected. Minor errors in data tables can be accepted if, overall, the student is trying to maintain consistent decimal places between the raw data, any degrees of precision expressed and the processed data. In biology, students are not expected to use significant figures conventions; if they do, these should be used correctly.

Recording and processing data

The presentation of the analysis will depend upon the data-processing tools being used. Percentages, means, standard deviations or ranges at the end of the column or row of data they represent are sufficient evidence of processing. For more complex processing (e.g. using spreadsheets), screenshots including the formula used are acceptable. For other less orthodox processing, a worked example is necessary.

For statistical analysis the student will need to make a statement of null hypotheses and alternative hypotheses. This is required even if the student is using a graphic display calculator or a statistical program for calculations. However, there is no need to state a null and alternative hypothesis at the beginning of an experiment.

Providing examples of full calculations is superfluous or irrelevant when using dedicated software programs. A program such as Microsoft Excel gives only the p-value for the t-test. Therefore students cannot include the t-statistic in a probability table because this is built into the program. Excel also calculates the degrees of freedom. Students do not need to present these, but they do need to be aware of the impact of sample size. Students should state the source (e.g. Microsoft Excel 2016). However, the processing and reasoning must be clear so that the validity of the calculations and interpretations can be verified.

Note: Interpretation of the data as it relates to the research question is assessed in the "Conclusion" criterion.

Correctly tabulated data should have appropriate titles and numbers, or they should be set in a context that makes them unambiguous. Within the text of the report, they should be referenced using, for example, Figure 1 or Graph 1. Where relevant, there should be concise column headings and units in the column headers with their uncertainties. It is not necessary to provide separate tables for raw data and processed data.

If large amounts of data have been collected, students are permitted to present only a representative sample of the raw data, to facilitate comprehension. Data taken directly from an electronic device are raw data and require further processing to constitute processed data. For example, a device that determines "rate" produces raw data. If software automatically constructs a graph, the graph itself is acceptable as raw data. Details about how results were obtained, and information about quantities, units and precision, should be mentioned in the text. The gradient of or area under the graph may then be used for further calculations.

Inadequate labelling of a graph (axes, legends, titles) will impact data analysis. The type, size, proportions and scaling of the graph impact not only presentation, but also the graph's usefulness in data analysis.

Descriptions of qualitative observations are expected to accompany the raw data where applicable. Their importance will depend on the nature of the investigation.

Considering uncertainties

The teacher should check for:

- degrees of precision in the instruments used
- consideration of errors and uncertainties
- consistency in the reported uncertainties
- variation in the material used, as shown by standard deviations, standard errors, trend lines, R^2 values, uncertainty bars
- significance testing
- ranges (maximum value minus minimum value)
- an appropriate response to outlier data.

Note: The processing of data to obtain an uncertainty value is assessed in the third strand (relevant processing of data) of the "Data analysis" criterion. Consideration of the impact of uncertainties is assessed in the "Conclusion" criterion because (in part) this criterion assesses the relevance of the conclusion to the analysis.

It is not expected that students will necessarily cover all of the above parameters. This is merely a guide to the ways a student may evidence that they have considered the impact of uncertainty on the analysis.

Uncertainties in measurements

Measurement uncertainties can be obtained from an instrument's graduations, manufacturer specifications (for electronic devices) or the read-out for least count. The realistic use of an instrument also needs to be considered. For example, a handheld stopwatch used to measure the time of an event will not have a precision of 0.001 seconds, even if the stopwatch can provide such a read-out—human reaction times are not this fast. Students should justify the size of uncertainty based on the nature of the experiment.

Stating uncertainties for counts (± 1) is not necessary. However, this may be necessary for data derived from these counts. For example, the percentage germination of a sample of 25 seeds will have a margin of error of ± 4%, while measuring human heart rate by palpation for 15 seconds will have an error margin of ± 4 beats per minute. Nevertheless, the propagation of uncertainties is not systematically expected in biology.

Where relevant, measurement uncertainties should appear in the column headings along with the units, unless there is reasonable justification for data to have different values of uncertainty within a column.

Uncertainties are also expressed graphically using scatter plots with trend lines. These may also include uncertainty bars and R^2 values. Box-and-whisker plots may also be used.

Statistical tests that generate significance levels are also measurements of uncertainty. For some tests such as the *t*-test, chi-squared test or analysis of variance (ANOVA), establishing the probability level (*p*-value) is part of their outcome. For correlation coefficients it is an additional step that needs to be considered. If used, ANOVA (*F*-test) should be accompanied by a post-hoc test (e.g. a Tukey test) so that the significance of the difference between the treatments can be determined.

Outliers

Data identified as possible or probable outliers should not be systematically omitted from calculations. Outliers are actual measured results and therefore need to be considered. Removing them so that the results "fit better" with expectations or with a general model is not good practice. This is manipulation of data and it is unscientific. Instead, students could consider presenting the outcome with the outliers included and excluded, thereby revealing their impact.

Outliers may be identified statistically from the data. A common definition is that they are greater than 1.5 times the interquartile range below the first quartile, or more than 1.5 times the interquartile range above the third quartile. **A student considering excluding these should provide a justification**. This is especially true of data in Diploma Programme (DP) biology scientific investigations, as the sample size is usually small ($n \leq 30$) or very small ($n < 15$). However, if observations can explain an outlier, or if a weakness in the method is identified and corrected, then these data can be justifiably removed.

Processing of data

The teacher should check for:

- processing that is efficiently presented and at the DP level for the topic
- appropriate processing tools
- realistic trend lines in presented data
- statistical analysis with a justification for the choice of a test
- appropriate graphing techniques including adequate scale, title and labelled axes
- correct calculations and graphing.

Processing is the transformation of raw data to arrive at a conclusion. Mathematical skills are important, and this is stressed in the nature of science (NOS) aspect of this course; however, this is not a mathematics course.

Graphing, even that of raw data, is part of processing, especially if it is used to derive values such as gradients for rates.

Graphing raw data when the graphing of *processed* data would be more appropriate can be considered insufficient, or even irrelevant; but it is not wrong.

The types of graphs produced by the student should be appropriate to the data being analysed.

Dot-to-dot plotting of data is acceptable. Going further by placing a trend line on the data can be a useful step in processing and interpretation, for example for comparison with an accepted model. A trend line can be especially helpful if uncertainty bars accompany it, or a correlation coefficient (*r*) or the coefficient of determination (R^2 value).

To be confident that a trend line can be drawn on data points, sufficient data need to be obtained. Given the variability in biological systems, this is very difficult at this level. A trend line may be used to show how the limited data collected fit a given model. Examples include the optimum pH for an enzyme or light saturation of a photosynthetic system. Do not penalize a student for producing a dot-to-dot graph where there are continuous variables.

In biology, *r*-values are useful because biologists are often looking for correlations. R^2 values are also useful: they allow evaluation of how well a trend line fits the data. Note that *r*, the correlation coefficient, is not the same as R^2, the coefficient of determination.

Standard deviation or standard error can be useful, assuming there are a sufficient number of replicates to calculate one; otherwise, ranges are acceptable for maximum and minimum values. Standard deviations may be calculated on sample sizes as low as 5. The standard error of the mean is influenced more by sample size, so it should be reserved for samples greater than 30.

Students carrying out statistical tests need to appreciate that the sample size is important. As a rule, $n>30$ is considered a large sample, 15–30 a small sample and 5–14 a very small sample. For tests like the t-test, $n<10$ is usually considered too small. Some tests, such as the Mann–Whitney U-test, can handle very small samples, but generally sample size should be at least 10 for the calculation of a statistical test.

Conclusion

This criterion assesses the relevance of the conclusion to the research question, to the analysis presented and to the accepted scientific context.

Relevance of the conclusion

The teacher should check for:

- a valid explanation of trends in the results
- a conclusion that addresses the research question in the proposed context
- evidence that sense has been made of the data and/or results, leading to a conclusion that is realistic
- references to a hypothesis (if one has been stated)
- interpretation of statistical calculations (e.g. significance testing)
- the impact of errors on results
- interpretation of the significance of statistical test results if used
- a discussion of the impact of uncertainties
- a discussion of the reliability of the data (which may indicate an appreciation of the strengths of the data)
- whether the data support any hypothesis that has been proposed.

The student must discuss whether the data address the research question or not. The data collected and processed may not demonstrate clear patterns or trends. The data may also be inconclusive. For some investigations, the data may partially support a conclusion, but not necessarily lead to a strong one.

Students should ensure they do not introduce bias in the interpretation to form conclusions that are not supported by their data.

Where relevant, terms such as “optima”, “maxima” (plateau) and “intercepts” should be used.

Considering uncertainties in the conclusion

Measures of variation, such as the range or the standard deviation, can indicate the reliability of the results.

Students should show an appreciation of the limitations of their sample size in the interpretation of their results. As the sample size gets smaller the impact of uncertainties becomes greater. Increasing sample size will generally increase the accuracy.

Other indicators of uncertainty may be used, such as the coefficient of determination, the R^2 value. This will reveal if a trend line, whether straight or curved, fits the data well.

In biology, random uncertainties from biological material will probably be the most significant source of variation. The interpretation of statistical tests will therefore be important. For significance tests that generate a p-value, 0.05 (5%) is considered as the critical value below which the results can be said to have significance. Above this level the results could be due to random chance. The IB is aware that the p-value is a controversial issue among scientists. But it is still used to judge whether one fails to reject the null hypothesis or accepts the alternative hypothesis.

The conclusion and the scientific context

The teacher should check for:

- a relevant scientific context, with references from the literature that help explain the investigation's outcomes
- reliable scientific sources, referenced with sufficient detail to be traced (e.g. retrieval dates for online sources)
- comparison with general models and a proposed explanation in the context of biology.

There may be no accepted value for comparison (e.g. certain ecological studies). In this case, the student must determine if the result is reasonable.

Evaluation

This criterion assesses the extent to which the student's report provides evidence that weaknesses and limitations in the investigative methodology have been assessed, and improvements have been suggested.

Methodological weaknesses and limitations

The teacher should check for:

- methodological and procedural weaknesses and limitations
- evaluation of the relative impact of weaknesses and limitations
- evidence supporting the identified weaknesses and limitations
- a clear understanding of the topic in the suggested context and of the methodology used.

There is no expectation that a student will address all aspects relating to methodological weakness and limitations. Nevertheless, when evaluating the results of an investigation, students should explain the relative impact of those that are significant. They can do this in a qualitative way, identifying minor and major weaknesses by explaining how the issue would affect the results.

Discussion of methodological weaknesses needs to consider both the issues in the methodology and their effect on the quality of the data. Weaknesses do not include errors due to careless manipulation skills or hypothetical events for which there is no evidence.

Discussion of limitations acknowledges that experiments will only go so far in answering the research question. Even if conditions are perfect, an experiment will still have its shortcomings. For example, a simulation may have few methodological weaknesses, but it will have some limitations.

The degree of impact of these weaknesses and limitations on the outcome of the investigation needs to be judged qualitatively.

The reliability of the results needs to be judged in the light of the uncertainties that have been established.

Instruments that are faulty or that have not been calibrated correctly cause systematic errors. These errors, which affect accuracy, can also be caused by human error.

Random uncertainties are unpredictable in size and direction. Measures of uncertainty (e.g. range or standard deviation) in populations can be used to judge their impact on the results. The precision (measurement uncertainty) of instruments varies due to random errors. Judging the degree of impact of each measuring instrument on the results is an important task in science. The propagation of uncertainties is not required or expected. So, this judgement will remain quite qualitative.

The act of measuring can also influence the results. Taking a measurement can affect the environment of an experiment significantly. For example, a cold thermometer placed in a test tube of warm water will cool the water. An experimenter observing and recording the behaviour of animals may influence their behaviour.

In investigations using databases, the student should not refer to the validity of the sources because this should have been done in research design. However, there are issues in the curation of databases, and a reflection in this regard adds value to the conclusion. Problems resulting from experimental and theoretical values present the same challenges.

Suggesting improvements to the investigation

The teacher should check for:

- realistic and relevant improvements
- a clear understanding of the topic in the suggested context and the methodology used.

Suggested improvements should be realistic and relevant to the investigation. The improvements must be related to the weaknesses or limitations that have been identified, and should be feasible in a school environment or field course. They need to be based on the identified weaknesses that are relevant to the research question and methodology.

The student should avoid generalities such as “take more measurements” or “use a more precise measuring method”. Only if these generic issues are connected to specific issues can they be seen as improvements to weaknesses.

During the design phase, changing to a more precise instrument may not be an option if the choice of instruments is limited. In an enzyme investigation at home, using a number of different household items to establish the pH is a weakness. (Using buffers would be an improvement.) The range of pH used may fail to establish the optimum pH. This is a limitation, so extending the range would be an improvement.

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Updates to the publication

This section outlines the updates made to this publication over the past two years. The changes are ordered from the most recent to the oldest updates. Minor spelling and typographical corrections are not listed.

Changes for November 2024

Mathematics > Mathematical skills for practical investigations

"Introduction"

Introduction of revised or improved content.

The flow chart for selecting a statistical tool has been revised to provide more clarity for selecting the correct test. The same changes have been made in the downloadable resource "Flow chart for selecting a statistical tool (PDF)".

Changes for August 2024

Throughout the publication

Alignment of language with other IB documentation.

The term "independent investigation" was replaced with "scientific investigation".

The term "Student's *t*-test" was replaced with "*t*-test".

Enhancing learning and teaching > International-mindedness

"Exploring international-mindedness"

Correction of error in the previous version.

The broken link to "Template: An activity to promote international mindedness in biology (PDF)" was fixed.

Facilitating the internal assessment > Activities to develop skills for the inquiry process

"Tobacco smoking and mortality due to lung cancer"

Introduction of revised or improved content.

The paragraph preceding the graphs was amended to better match the content.

Unpacking the internal assessment > General advice

"Collecting sufficient data"

Introduction of revised or improved content.

In the section "Using databases, simulations and models", more guidance was added for teachers to understand the requirements of the internal assessment reports when students have used databases or simulations.

In the downloadable resource “Working with databases: Student worksheet (PDF)”, the term “potentially impact” was replaced with “affect”. The terms “function/dependent variable” and “functional part/dependent variable” were replaced with “dependent variable”.

“Communication style and report length”

Amendment in response to stakeholder feedback.

In the section “Appendices”, more guidance was added for teachers to understand what should (or should not) be present in an appendix of an internal assessment report.