Contents

Module 3 Biological diversity

Module 4 Ecosystem dynamics

How to use this book

Pearson Biology 11 New South Wales

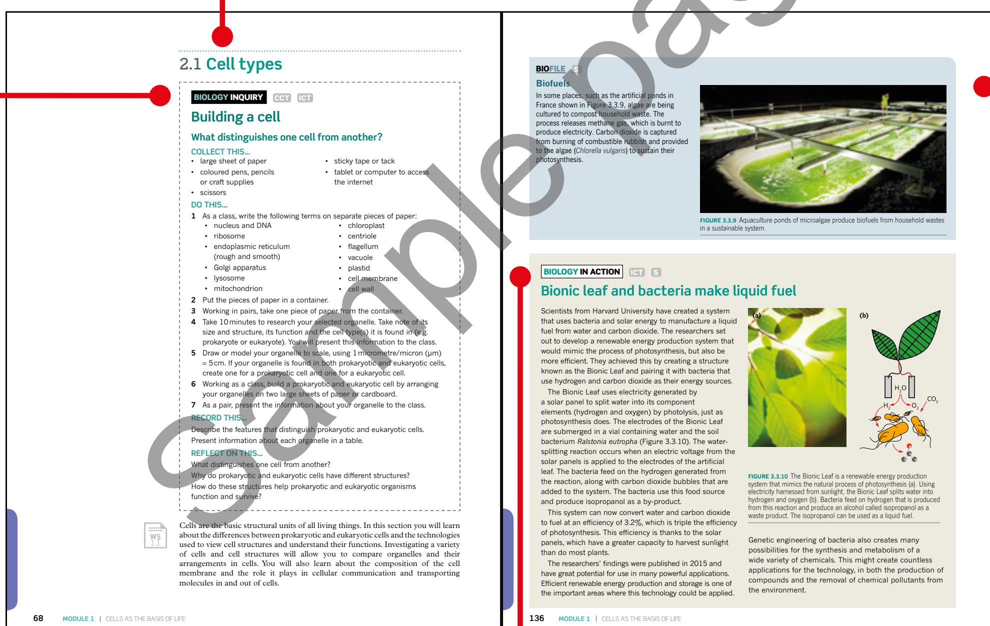
Pearson Biology 11 New South Wales has been written to fully align with the new Stage 6 Syllabus for New South Wales Biology. The book covers Modules 1 to 4 in an easy-to-use resource. Explore how to use this book below.

Chapter opener

The chapter opening page links the Syllabus to the chapter content. Key content addressed in the chapter is clearly listed.

Section

Each chapter is clearly divided into manageable sections of work. Best-practice literacy and instructional design are combined with high-quality, relevant photos and illustrations to help students better understand the idea or concept being developed.



BioFile

BioFiles include a range of interesting and real-world examples to engage students.

Biology Inquiry

Biology Inquiry features are inquiry-based activities that pre-empt the theory and allow students to engage with the concepts through a simple activity that sets students up to 'discover' the science before they learn about it. They encourage students to think about what happens in the world and how science can provide explanations.

Biology in Action

Biology in Action boxes place biology in an applied situation or a relevant context. These refer to the nature and practice of biology, applications of biology and the associated issues, and the historical development of concepts and ideas.

Highlight box

Highlight boxes focus students' attention on important information such as key definitions, formulae and summary points.

SkillBuilder

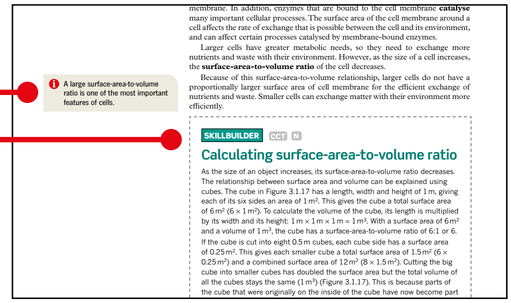
A SkillBuilder outlines a method or technique. They are instructive and self-contained. They step students through the skill to support science application.

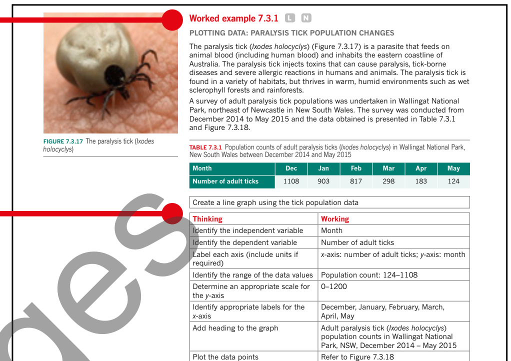
Worked examples

Worked examples are set out in steps that show thinking and working. This format greatly enhances student understanding by clearly linking underlying logic to the relevant calculations.

Each Worked example is followed by a Try yourself activity. This mirror problem allows students to immediately test their understanding.

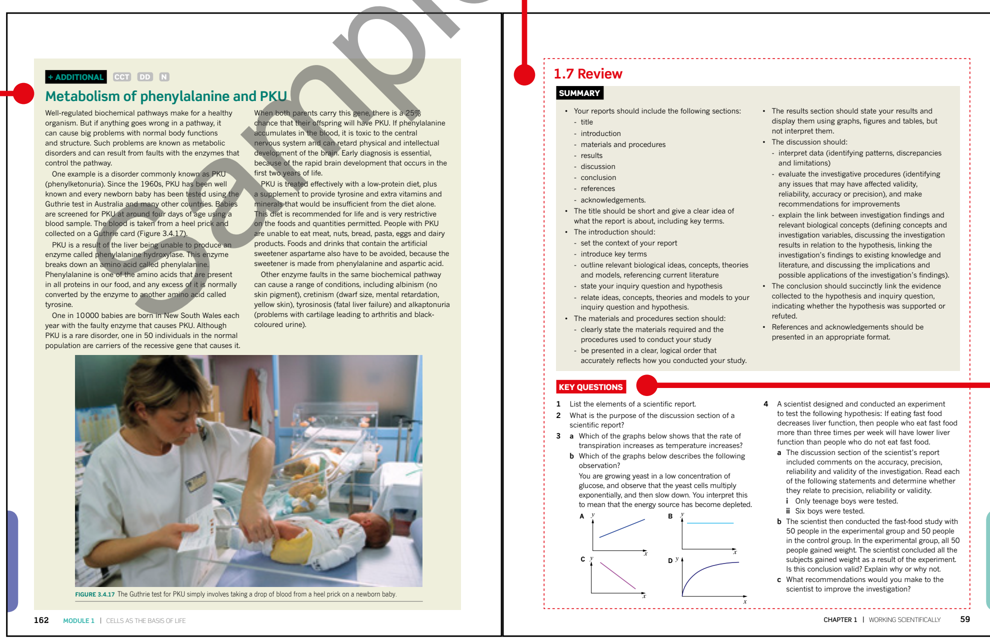
Fully worked solutions to all Worked example: Try yourself activities are available on *Pearson Biology 11 New South Wales* Reader+.





Section summary

Each section has a summary to help students consolidate the key points and concepts of each section.



Additional content

Additional content features include material that goes beyond the core content of the Syllabus. They are intended for students who wish to expand their depth of understanding in a particular area.

Section review questions

Each section finishes with key questions to test students' understanding and ability to recall the key concepts of the section.

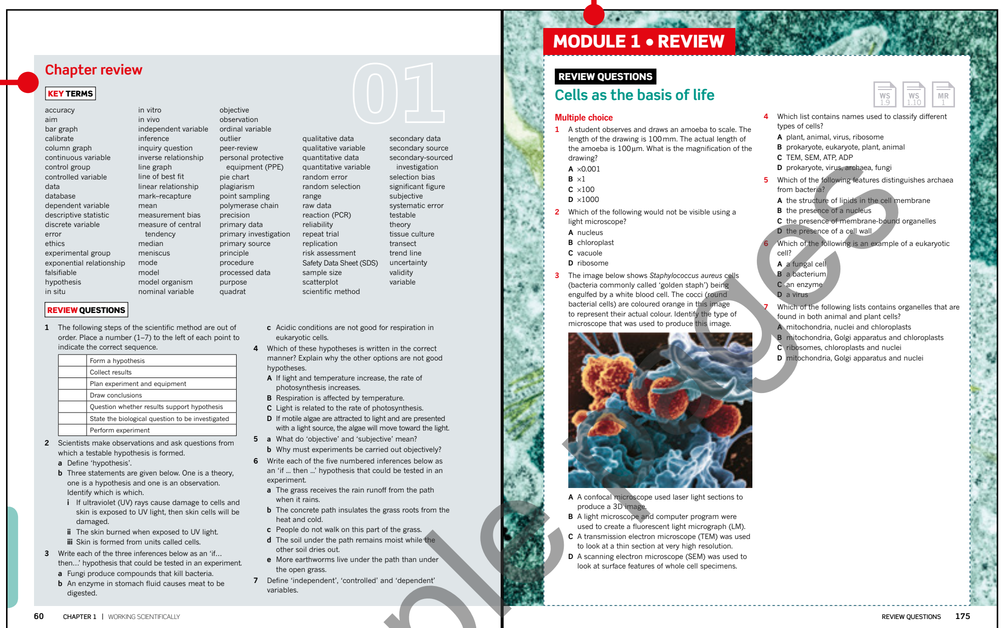
How to use this book

Chapter review

Each chapter finishes with a list of key terms covered in the chapter and a set of questions to test students' ability to apply the knowledge gained from the chapter.

Module review

Each module finishes with a comprehensive set of questions, including multiple choice, short answer and extended response. These assist students in drawing together their knowledge and understanding, and applying it to these types of questions.



Icons

The New South Wales Stage 6 Syllabus 'Learning across the curriculum' and 'General capabilities' content are addressed throughout the series and are identified using the following icons.

AHC A CC CCT DD EU ICT
IU L N PSC S WE

'Go to' icons are used to make important links to relevant content within the same Student Book.

GO TO ➤

This icon indicates the best time to engage with a worksheet (WS), a practical activity (PA), a depth study (DS) or module review (MR) questions in *Pearson Biology 11 New South Wales Skills and Assessment Book*.

WS 3.1

This icon indicates the best time to engage with a practical activity on *Pearson Biology 11 New South Wales* Reader+.

PA 3.2

Glossary

Key terms are shown in **bold** in sections and listed at the end of each chapter. A comprehensive glossary at the end of the book includes and defines all the key terms.

Answers

Comprehensive answers and fully worked solutions for all section review questions, Worked example: Try yourself features, chapter review questions and module review questions are provided via *Pearson Biology 11 New South Wales* Reader+.

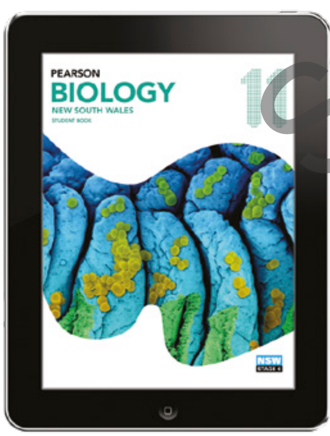
Pearson Biology 11
New South Wales

Student Book

Pearson Biology 11 New South Wales has been written to fully align with the new Stage 6 Syllabus for New South Wales Biology. The Student Book includes the very latest developments and applications of biology and incorporates best-practice literacy and instructional design to ensure the content and concepts are fully accessible to all students.

Skills and Assessment Book

The *Skills and Assessment Book* gives students the edge in preparing for all forms of assessment. Key features include a Biology toolkit, Key knowledge summaries, worksheets, practical activities, suggested depth studies and module review questions. It provides guidance, assessment practice and opportunities to develop key skills.



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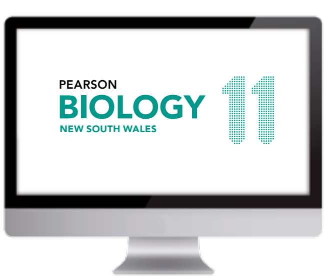

Teacher Support

The Teacher Support available includes syllabus grids and a scope and sequence plan to support teachers with programming. It also includes fully worked solutions and answers to all Student Book and *Skills and Assessment Book* questions, including all worksheets, practical activities, depth studies and module review questions. Teacher notes, safety notes, risk assessments and a laboratory technician checklist and recipes are available for all practical activities. Depth studies are supported with suggested assessment rubrics and exemplar answers.

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CHAPTER 01

Working scientifically

This chapter covers the skills needed to plan, conduct and communicate the outcomes of primary and secondary-sourced investigations. Developing, using and demonstrating these skills in a variety of contexts is important when you undertake investigations and evaluate the research of others.

You can use this chapter as a reference as you work through other chapters. It contains useful checklists for when you are drawing scientific diagrams or graphs, or writing a scientific report. Whenever you perform a primary investigation, refer to this chapter to make sure your investigation is valid, reliable and accurate.

1.1 Questioning and predicting covers how to develop, propose and evaluate inquiry questions and hypotheses. When creating a hypothesis, variables must be considered.

1.2 Planning investigations explains how to identify risks and make sure all ethical concerns are considered. It is important to choose appropriate materials and technology to carry out your investigation. You will also need to confirm that your choice of variables allows for reliable data collection.

1.3 Conducting investigations describes procedures for accurately collecting and recording data to reduce errors. It also describes appropriate procedures for disposing of waste.

1.4 Processing data and information describes ways to represent information and explains how to identify trends and patterns in your data.

1.5 Analysing data and information explains error, uncertainty and limitations in scientific data and helps you to assess the accuracy, validity and reliability of your data and the data of others.

1.6 Problem solving is a guide to using modelling and critical thinking to make predictions and demonstrate an understanding of the scientific principles behind your inquiry question.

1.7 Communicating explains how to communicate an investigation clearly and accurately using appropriate scientific language, nomenclature and scientific notation and draw evidence-based conclusions relating to your hypothesis and research question.

Outcomes

By the end of this chapter you will be able to:

- develop and evaluate questions and hypotheses for scientific investigation (BIO11-1)
- design and evaluate investigations in order to obtain primary and secondary data and information (BIO11-2)
- conduct investigations to collect valid and reliable primary and secondary data and information (BIO11-3)
- select and process appropriate qualitative and quantitative data and information using a range of appropriate media (BIO11-4)
- analyse and evaluate primary and secondary data and information (BIO11-5)

- solve scientific problems using primary and secondary data, critical thinking skills and scientific processes (BIO11-6)
- communicate scientific understanding using suitable language and terminology for a specific audience or purpose (BIO11-7)

Content

By the end of this chapter you will be able to:

- develop and evaluate inquiry questions and hypotheses to identify a concept that can be investigated scientifically, involving primary and secondary data (ACSBL001, ACSBL061, ACSBL096) L
- modify questions and hypotheses to reflect new evidence CCT
- assess risks, consider ethical issues and select appropriate materials and technologies when designing and planning an investigation (ACSBL031, ACSBL097) EU PSC
- justify and evaluate the use of variables and experimental controls to ensure that a valid procedure is developed that allows for the reliable collection of data (ACSBL002)
- evaluate and modify an investigation in response to new evidence CCT
- employ and evaluate safe work practices and manage risks (ACSBL031) PSC WE
- use appropriate technologies to ensure and evaluate accuracy ICT N
- select and extract information from a wide range of reliable secondary sources and acknowledge them using an accepted referencing style L
- select qualitative and quantitative data and information and represent them using a range of formats, digital technologies and appropriate media (ACSBL004, ACSBL007, ACSBL064, ACSBL101) L N
- apply quantitative processes where appropriate N
- evaluate and improve the quality of data CCT N
- derive trends, patterns and relationships in data and information
- assess error, uncertainty and limitations in data (ACSBL004, ACSBL005, ACSBL033, ACSBL099) CCT
- assess the relevance, accuracy, validity and reliability of primary and secondary data and suggest improvements to investigations (ACSBL005) CCT N
- use modelling (including mathematical examples) to explain phenomena, make predictions and solve problems using evidence from primary and secondary sources (ACSBL006, ACSBL010) CCT
- use scientific evidence and critical thinking skills to solve problems CCT
- select and use suitable forms of digital, visual, written and/or oral forms of communication L N
- select and apply appropriate scientific notations, nomenclature and scientific language to communicate in a variety of contexts (ACSBL008, ACSBL036, ACSBL067, ACSBL102) L N
- construct evidence-based arguments and engage in peer feedback to evaluate an argument or conclusion (ACSBL034, ACSBL036) CC DD

1.1 Questioning and predicting

FIGURE 1.1.1 An entomologist (a scientist who studies insects) collects insects from the top of a tropical rainforest tree.

Biology is the study of living organisms. As scientists, biologists extend their understanding using the scientific method, which involves investigations that are carefully designed, carried out and reported. Well-designed research is based on a sound knowledge of what is already understood about a subject, as well as careful preparation and observation (Figure 1.1.1).

When beginning an investigation, you must first develop and evaluate an **inquiry question** and **hypothesis**, and determine the **purpose** of the investigation. It is important to understand that each of these can be refined as the planning of your investigation continues.

- The inquiry question defines what is being investigated. For example: Is the rate of transpiration in plants dependent on temperature?
- The hypothesis is a tentative explanation for an observation that is based on prior knowledge or evidence. For example: If transpiration rates in plants increase with increasing temperature and the air temperature is raised from 20°C to 40°C, then transpiration and water loss from a plant will increase. A hypothesis must be **testable** and **falsifiable** (can be proven false). You'll learn more about hypotheses on page 9.
- The purpose (also known as the **aim**) is a statement describing in detail what will be investigated. For example: To investigate the effect of temperature on the rate of transpiration in plants at 20°C, 30°C and 40°C.

This section will introduce you to developing and evaluating inquiry questions and hypotheses to investigate scientifically.

TYPES OF INVESTIGATIONS

Many different types of investigations can be conducted in biology. You are probably most familiar with practical investigations or experiments. An investigation that you conduct yourself is known as a **primary investigation**, and the **data** and information you collect is called **primary data** or a **primary source**.

Inquiry questions can also be answered by researching and evaluating data that others have collected. Data or information that was collected by someone else is known as **secondary data** or a **secondary source**. An investigation that uses secondary data is known as a **secondary-sourced investigation**.

Examples of different types of investigations are listed in Table 1.1.1 and Table 1.1.2.

TABLE 1.1.1 Examples of primary investigations

	Example tasks
conducting experiments in a laboratory	planning a valid experiment, conducting a risk assessment, working safely, recording observations and results, analysing and evaluating data and information
conducting fieldwork	conducting a risk assessment, working safely, recording observations and results, analysing and evaluating data and information
conducting surveys	writing questions, collecting data, analysing data and information
designing a model	identifying a problem to be modelled, summarising key findings, identifying advantages and limitations of the model

TABLE 1.1.2 Examples of secondary-sourced investigations

	Example tasks
researching published data from primary and secondary sources	finding published information in scientific magazines and journals, books, databases, media texts and labels of commercially available products; analysing and evaluating data and information

Before you start the practical side of your investigation, you must first understand the biological concepts that underlie it.

LEARNING THROUGH INVESTIGATION

Scientists make observations and then ask questions that can be investigated. Using their knowledge and experience, scientists suggest possible explanations for the things they observe. A possible explanation is called a hypothesis. A hypothesis can be used to make certain predictions. Often these predictions can be tested experimentally. This experimental approach to the study of science is called the **scientific method** (Figure 1.1.2).

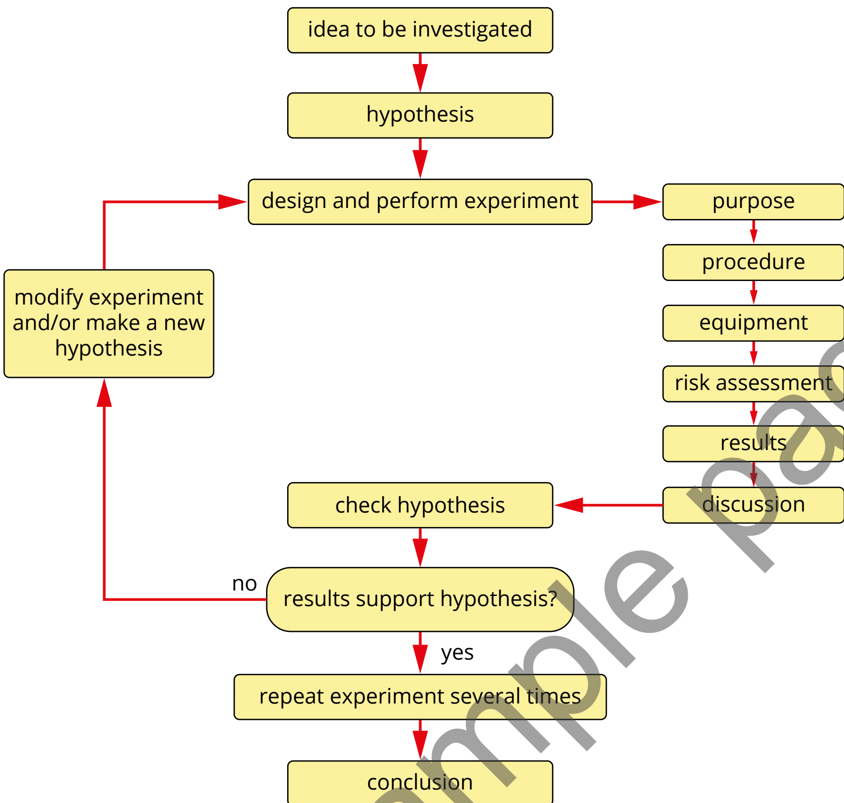

FIGURE 1.1.2 The scientific method is based on asking questions that can be answered experimentally.

To determine whether their predictions are accurate or not, a scientist carries out carefully designed experiments. If the results of an experiment do not fall within an acceptable range, the hypothesis is rejected. If the predictions are found to be accurate, the hypothesis is supported. If, after many different experiments, one hypothesis is supported by all the results obtained so far, then this explanation can be given the status of a **theory** or **principle**.

There is nothing mysterious about the scientific method. You might use the same process to find out how unfamiliar technology works if you had no instructions. Careful observation is usually the first step.

OBSERVATION

Observation includes using all your senses and the instruments available to allow closer inspection of things that the human eye cannot see. Through careful inquiry and observation, you can learn a lot about organisms, the ways they function, and their interactions with each other and their environment. For example, animals function very differently from plants. Animals usually move around, take in nutrients and water, and often interact with each other in groups. We find them in water, on land and flying in the air. Some are fast, efficient predators (Figure 1.1.3).

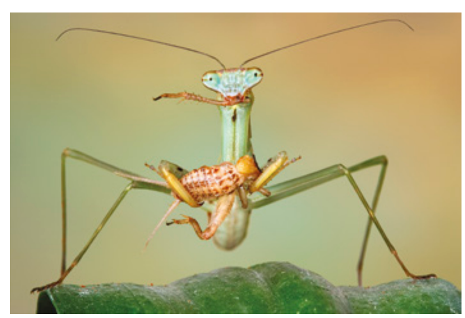

FIGURE 1.1.3 The praying mantis is a fast, efficient predator. Its green colouration and leaf-like shape give it the deadly advantage of camouflage. These features of the praying mantis can be observed and investigated.

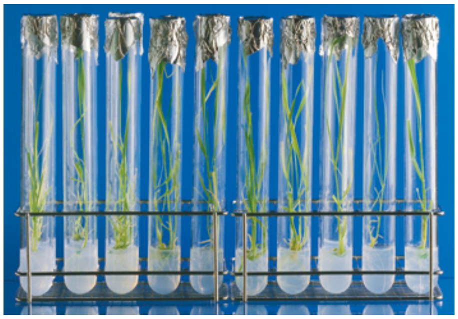

FIGURE 1.1.4 Laboratory procedures, such as plant tissue culture, rely on careful observations and data collection to understand the requirements for plant growth. Laboratory investigations then provide new information that can be applied to plants growing in the field.

Plants, meanwhile, are usually green, stationary and turn their leaves towards the light as they grow. Sometimes they lose all their leaves, and then grow new ones. Many develop flowers and fruit for reproduction. All of these things can be learnt from simple observation.

The idea for a primary investigation of a complex problem arises from prior learning and observations that raise further questions. For example, indoor plants do not grow well without artificial lighting. This suggests that plants need light to photosynthesise. By researching this aspect of photosynthesis, new knowledge can be used in other applications, such as **procedures** for growing plants in the laboratory for genetic selection and modification for crop improvement (Figure 1.1.4).

INQUIRY QUESTIONS

How observations are interpreted depends on past experiences and knowledge. But to enquiring minds, observations will usually provoke further questions, such as those given below.

- How do organisms gain and expend energy?
- Are there differences between cellular processes in plants, animals, bacteria, fungi and protists?
- How do multicellular organisms develop specialised tissues?
- What are the molecular building blocks of cells?
- How do species change and evolve over time?
- How do cells communicate with each other?
- What is the molecular basis of heredity, and how is this genetic information decoded?

Many of these questions cannot be answered by observation alone, but they can be answered through scientific investigations. Lots of great discoveries have been made when a scientist has been busy investigating another problem. Good scientists have acute powers of observation and enquiring minds, and they make the most of these chance opportunities.

Before conducting an investigation, you need an inquiry question to address. An inquiry question defines what is being investigated. For example, what is the relationship between a plant's exposure to sunlight and the rate of the plant's growth?

Choosing a topic

When you choose a topic, consider the following suggestions.

- Choose an inquiry question you find interesting.
- Start with a topic for which you already have some background information, or some clues about how to perform the experiments.
- Check that your school laboratory has the resources for you to perform the experiments or investigate the topic.
- Choose a topic that can provide clear, measurable data.

GO TO ➤ Section 1.3 page 20

You will learn more about useful research techniques in Section 1.3.

Asking the right questions

In science, there is little value in asking questions that cannot be answered. An experimental hypothesis must be testable. If you consider a question such as 'How do bats navigate at night?', then the statement 'Bats use thought waves to navigate' is not possible to test. Instead, a testable hypothesis might be 'If bats use hearing to navigate, then they will not be able to navigate if they cannot hear'.

In 1793, Italian scientist Lazzaro Spallanzani wondered about this question, and set about testing the hypothesis. He found that if he plugged their ears, the bats collided into obstacles, but if the plugs had a hole that allowed the bats to hear, then they flew normally. He concluded that bats used their ears to detect obstacles and prey at night. It wasn't until 1938 that English physiologist Hamilton Hartridge detected the ultrasonic signals made by bats, thereby allowing us to understand how bats use their hearing to navigate.

You must also ask the right questions to get answers that are relevant to the problem you are examining. For example, there is no point in asking how long bats live when you are studying how they navigate, as the information you obtain will not be useful for testing your hypothesis.

Developing your inquiry question

It is important to work out exactly what an inquiry question is asking you to do. You need to:

- identify a 'guiding' word, such as *who*, *what*, *where*, *why*
- link the guiding word to command verbs, such as *identify*, *describe*, *compare*, *contrast*, *distinguish*, *analyse*, *evaluate*, *predict*, *develop* and *create*.

Some examples of inquiry questions are provided in Table 1.1.3.

TABLE 1.1.3 Examples of inquiry questions for primary or secondary investigations

Guiding word	Example inquiry questions	What are you being asked to do? What are the command verbs?
what	**What** distinguishes one cell from another?	Identify and describe specific examples, evidence, reasons and analogies from a variety of possibilities. *Identify* and *describe*.
where	**Where** are blue triangle butterflies distributed?	Identify and describe, giving reasons for a place or location. *Identify* and *describe*.
how	**How** do selection pressures within an ecosystem influence evolutionary change?	Identify and describe in detail a process or mechanism. Give examples using evidence and reasons. *Identify* and *describe*.
why	**Why** is polypeptide synthesis important?	Identify and describe in detail the causes, reasons, mechanisms and evidence. *Identify* and *describe*.
would	**Would** there be life if elements did not form compounds?	Evaluate evidence. Justify your answer by giving reasons for and against (using evidence, analogies, comparisons). *Evaluate* and *justify*.
is/are	**Is** there a relationship between evolution and biodiversity? **Are** there more species to be discovered?	Evaluate evidence. Justify your answer by giving reasons. *Evaluate* and *justify*.
on what basis	**On what basis** are new species named?	Identify and describe examples. Distinguish between reliable and unreliable evidence. *Identify, describe* and *distinguish*.
can	**Can** population genetic patterns be predicted with any accuracy?	Analyse and evaluate evidence. Justify your answer by giving reasons. Create a diagram to support your answer. Suggest possible alternatives. *Analyse, evaluate, justify* and *create*.
do/does	**Do** non-infectious diseases cause more deaths than infectious diseases? **Does** artificial manipulation of DNA have the potential to change populations forever?	Evaluate evidence. Justify using reasons and evidence for and against. Compare and contrast. *Evaluate, justify, compare* and *contrast.*
should	**Should** we manage and conserve biodiversity?	Identify and evaluate pros and cons, implications and limitations. Make a judgement. Critically assess evidence and develop an argument to support your position. Use reliable evidence to justify your conclusion. *Identify, evaluate, assess, develop* and *justify*.
might	What **might** we do if fishery stocks run out?	Evaluate evidence. Justify your answer by giving reasons for and against (using evidence, analogies, comparisons). Create a graph and predict the outcomes of different scenarios. *Evaluate, justify, compare, create* and *predict.*

Once you come up with a topic or idea of interest, the first thing you need to do is conduct a literature review. This means reading scientific reports and other articles on the topic to find out what is already known, and what is not known or not yet agreed upon. The literature also gives you important information you can use for the introduction to your report and ideas for experimental procedures.

A literature review is an analysis of secondary data or information. While you are reviewing the literature, write down any questions or correlations you find. Compile a list of possible ideas. Do not reject ideas that initially may seem impossible, but use these ideas to generate questions.

When you have defined an inquiry question, you first need to evaluate it. Then, you will be able to come up with a hypothesis, identify the measurable variables, design your investigation and experiments, and suggest a possible outcome.

Evaluating your inquiry question

Stop to evaluate your inquiry question before you start planning the rest of your study. You might need to refine your question further or conduct some more investigations before deciding whether the question is suitable as a basis for an achievable, worthwhile investigation. Use the following list when evaluating your inquiry question:

- Relevance—your question must be related to your chosen topic. For your practical investigation, decide whether your question will relate to cellular structure or organisation, or to structural, physiological or behavioural adaptations of an organism to an environment.
- Clarity and measurability—your question must be able to be framed as a clear hypothesis. If the question cannot be stated as a specific hypothesis, then it is going to be very difficult to complete your research.
- Time frame—make sure your question can be answered within a reasonable period of time. Ensure your question isn't too broad.
- Knowledge and skills—make sure you have a level of knowledge and a level of laboratory skills that will allow you to explore the question. Keep the question simple and achievable.
- Practicality—check the resources you require, such as reagents and laboratory equipment, are going to be available. You may need to consult your teacher. Keep things simple. Avoid investigations that require sophisticated or rare equipment. Common laboratory equipment may include thermometers, photometers and light microscopes.
- Safety and ethics—consider the safety and ethical issues associated with your question. If there are any issues, determine if these need to be addressed.
- Advice—seek advice from your teacher on your question. Their input may prove very useful. Your teacher's experience may lead them to consider aspects of the question that you have not thought about.

DEFINING YOUR VARIABLES

The factors that can change during your experiment or investigation are called the **variables**. An experiment or investigation determines the relationship between variables, measuring the effects of one variable on another. There are three categories of variables:

- **independent variable**—a variable that is controlled by the researcher (the variable that is selected and changed)
- **dependent variable**—a variable that may change in response to a change in the independent variable, and is measured or observed
- **controlled variables**—the variables that are kept constant during the investigation.

You should have only one independent variable. Otherwise, you could not be sure which independent variable was responsible for changes in the dependent variable. Variables and controlled experiments are discussed further in Section 1.2.

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Qualitative and quantitative variables

Variables are described as either qualitative or quantitative. There are also further subsets in each category of variables.

- **Qualitative variables** (or categorical variables) can be observed but not measured. They can only be sorted into groups or categories such as flower colour or leaf shape. Qualitative variables can be nominal or ordinal.
  - **Nominal variables** are variables in which the order is not important; for example, eye colour.
  - **Ordinal variables** are variables in which order is important and groups have an obvious ranking or level; for example, a person's body mass index.
- **Quantitative variables** can be measured. Height, mass, volume, temperature, pH and time are all examples of quantitative data. Discrete and continuous variables are types of quantitative variables.
  - **Discrete variables** consist of only integer numerical values, not fractions; for example, the number of nucleotides in a sequence of DNA.
  - **Continuous variables** allow for any numerical value within a given range; for example, the measurement of height, temperature, volume, mass and pH.

You will learn more about data and variable types in Section 1.4.

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HYPOTHESES

A hypothesis is a tentative explanation for an observation that is based on evidence and prior knowledge. A hypothesis must be testable and falsifiable. It defines a proposed relationship between two variables.

Developing your hypothesis

To develop a hypothesis, you need to identify the dependent and independent variables. A good hypothesis is written in terms of the dependent and independent variables: e.g. If x is true and I test this, then y will happen.

For example:

IF there is a positive relationship between light and the rate of photosynthesis, and the rate of photosynthesis is estimated by measuring the oxygen output of a plant, THEN the oxygen output of a plant will be higher when it is in the light than when it is in the dark.

- The 'if' at the beginning of the hypothesis indicates that the statement is tentative. This means that it is uncertain and requires testing to confirm. This first part of the hypothesis is based on an educated guess and refers to the relationship between the independent and dependent variable (e.g. IF there is a positive relationship between light and the rate of photosynthesis). In this example, light is the independent variable and the rate of photosynthesis is the dependent variable.
- When writing a hypothesis, consider how it will be tested. The outcome of the test needs to measurable (e.g. by measuring a plant's oxygen output when it is in the dark and when it is exposed to light).
- A hypothesis should end with a statement of the measurable, predicted outcome (e.g. the oxygen output of a plant will be lower when it is in the dark than when it is exposed to light).

A good hypothesis can be tested to determine whether it is true (verified or supported), or false (falsified or rejected) by investigation. To be testable, your hypothesis needs to include variables that are measurable.

> Hypotheses can be written in a variety of ways, such as 'x happens because of y' or 'when x happens, y will happen'. However they are written, hypotheses must always be testable and clearly state the independent and dependent variables.

Writing a hypothesis from an inference

Scientists often develop a hypothesis by **inference** (reasoning) based on preliminary observations. For example, in summer, the colour of grasses usually changes from green to brown or yellow. One observation is that grass growing near the edges of a concrete path stays green for longer than grass further from the edges (Figure 1.1.5).

FIGURE 1.1.5 The grass closer to the concrete and in between the cracks of the concrete is green. This is an observation from which a hypothesis can be developed.

A valid inference is one that explains all the observations. The following inferences may explain why grass growing near the edge of the concrete path remains green in summer.

- Inference 1: The grass receives the runoff water from the path when it rains.
- Inference 2: The concrete path insulates the grass roots from the heat and cold.
- Inference 3: People do not walk on the grass growing near the edge of the path.

For Inference 1, the hypothesis might be: 'If grass needs water to remain green, then grass that doesn't receive rainwater runoff will turn brown while grass that receives rainwater runoff will remain green.'

Creating a table like Table 1.1.4 will help you evaluate your inquiry question, the variables you might consider, and the potential hypothesis you could use to guide your investigation.

TABLE 1.1.4 Summary table of inquiry question, variables and potential hypothesis

Inference	Research question	Independent variable	Dependent variable	Controlled variables	Potential hypothesis
Plants growing in soil with fertiliser added are taller than plants growing in soil without fertiliser added.	Does fertiliser make plants grow taller?	fertiliser	plant height	type of plant, soil, temperature, water and sunlight	If fertiliser makes plants grow taller and fertiliser is added to the soil, then plant X will grow taller.

PURPOSE

The purpose (also known as the aim) is a statement describing what will be investigated. The purpose should directly relate to the variables in the hypothesis, and describe how each variable will be studied or measured. The purpose does not need to include the details of the procedure.

Determining your purpose

To determine the purpose of your investigation, first identify the variables in your hypothesis.

Example 1:

- Hypothesis: If transpiration rates in plants increase with increasing air temperature and the air temperature is increased, then the rate of transpiration in plants will also increase.
- Variables: temperature (independent) and transpiration rate (dependent).
- Purpose: To compare the rate of transpiration of corn seedlings in air temperatures of 15°C, 25°C, 35°C and 45°C over 24 hours.

Example 2:

- Hypothesis: If bees are more attracted to the colour red than to the colour blue, then red flowers will attract more bees than blue flowers.
- Variables: colour of flowers (independent) and number of bees attracted to a flower (dependent).
- Purpose: To compare the number of bees visiting red flowers to the number of bees visiting blue flowers over a period of time.

1.1 Review

SUMMARY

- Well-designed experiments are based on a sound knowledge of what is already understood or known and careful observation.
- An investigation that you conduct yourself is known as a primary investigation, and the data you collect is called primary data.
- An investigation that uses data collected by someone else is known as a secondary-sourced investigation.
- Scientific investigations are undertaken to answer inquiry questions.
- Inquiry questions define what is being investigated.
- A primary investigation determines the relationship between variables by measuring the results.
- The scientific method is an accepted procedure for conducting experiments.
- The three types of variables are:
  - independent—a variable that is controlled by the researcher (the one that is selected and changed)
  - dependent—a variable that may change in response to a change in the independent variable, and is measured or observed
  - controlled—the variables that are kept constant during the investigation.
- The hypothesis is a tentative explanation for an observation based on previous knowledge and evidence. A hypothesis must be testable and falsifiable.
- Scientific investigations are undertaken to test hypotheses. The results of an investigation may support or reject a hypothesis, but cannot prove it to be true in all circumstances.
- The purpose is a statement that describes in detail what will be investigated.

KEY QUESTIONS

1 What is the scientific method based on?
  A observation
  B subjective decisions
  C manipulation of results
  D generalisations

2 It is important to evaluate and revise your inquiry question and hypothesis when conducting an investigation. What are three things to consider when evaluating your inquiry question?

3 Which of the following is an important part of conducting an experiment?
  A disregarding results that do not fit the hypothesis
  B making sure the experiment can be repeated by others
  C producing results that are identical to each other
  D changing the results to match the hypothesis

4 Write a hypothesis for each of the following purposes:
  a to test whether carrot seeds or tomato seeds germinate quicker
  b to test whether sourdough, multigrain or white bread goes mouldy the fastest
  c to test whether Trigg the dog likes dry food or fresh food better

5 Select the best hypothesis, and explain why the other options are not good hypotheses.
  A If light and temperature increase, then the rate of photosynthesis increases.
  B Transpiration is affected by temperature.
  C Light is related to the rate of photosynthesis.
  D If temperature positively affects the rate of photosynthesis, then a plant's output of oxygen will increase as temperature increases.

6 **a** State the meaning of the term 'variable'.
  b Copy and complete the table below with definitions of the types of variables.

Independent variable	Controlled variable	Dependent variable

7 Identify the independent, dependent and controlled variables that would be needed to investigate each of the following hypotheses:
  a If the rate of transpiration is positively affected by temperature, then an increase in temperature will lead to an increase in the rate of transpiration in plants.
  b If photosynthesis is dependent on light and there is no light, then there will be no photosynthesis in the leaves of a plant.
  c If a lid on a cup prevents heat loss from the cup and a cup of hot chocolate has a lid on it, then it will stay hot for a longer period of time.
  d If the amount of wax in a candle increases burn time and a thin candle and a thick candle are lit at the same time, then the thin candle will melt faster.

1.2 Planning investigations

FIGURE 1.2.1 A microbiologist in the field collecting soil samples to test for bacteria in the East Kimberley, Western Australia

Once you have formulated your hypothesis, you will need to plan and design your investigation. Taking the time to carefully plan and design a practical investigation before beginning will help you to maintain a clear and concise focus throughout (Figure 1.2.1). Preparation is essential. This section is a guide to some of the key steps that should be taken when planning and designing a practical investigation.

WRITING A PROTOCOL AND SCHEDULE

Once you have determined your inquiry question, variables, hypothesis and purpose, you should write a detailed description of how you will conduct your experiment. This description is also known as a **protocol**. You should also create a work schedule that outlines the time frame of your experiments, being sure to include sufficient time to repeat experiments if necessary. Check with your teacher that your protocol and schedule are appropriate, and that others will be able to repeat your experiment exactly by following the protocol you have written.

Test your protocol, and evaluate and modify it if necessary. When writing your protocol, consider the time, space, equipment, resources and teacher or peer support you will need to conduct your investigation. Quantitative results are preferable for high-quality, reproducible science. Therefore, if possible, you should use procedures that enable you to count, measure or grade what you observe.

EVALUATING THE PROCEDURE

The procedure (also known as the method) is the step-by-step procedure followed to carry out the investigation. When detailing the procedure, make sure it will allow for a valid, reliable and accurate investigation.

Procedures must be described clearly and in sufficient detail to allow other scientists to repeat the experiment. If other scientists cannot obtain similar results when an experiment is repeated and the results averaged, then the experiment is considered unreliable. It is also important to avoid personal bias that might affect the collection of data or the analysis of results. A good scientist works hard to be **objective** (free of personal bias) rather than **subjective** (influenced by personal views). The results of an experiment must be clearly stated and must be separate from any discussion of the conclusions that are drawn from the results.

Experiments and their results must be validated. This means they must be able to be repeated by other scientists.

In science, doing an experiment once is not usually sufficient. You can have little confidence in a single result, because the result might have been due to some unusual circumstance that occurred at the time. The same experiment is usually repeated several times and the combined results are then analysed using statistics. If the statistics show that there is a low probability (less than 5%, referred to as $P < 0.05$) that the results occurred by chance, then the result is accepted as being significant.

Validity

Validity refers to whether an experiment or investigation is actually testing the set hypothesis and purpose. Is the investigation obtaining data that is relevant to the question? For example, if you think you have measured a variable but have actually measured something else, then the results are invalid. Factors influencing validity include:

- whether your experiment measures what it claims to measure (i.e. your experiment should test your hypothesis)
- whether the independent variable influenced the dependent variable in the way you thought it would (i.e. the certainty that something observed in your experiment was the result of your experimental conditions, and not some other cause that you did not consider)
- the degree to which your findings can be generalised to the wider population from which your sample is taken, or to a different population, place or time.

Controls

It is difficult—sometimes impossible—to eliminate all variables that might affect the outcome of an experiment. In biology, such variables might include time of day, temperature, amount of light, season and level of noise. A way to eliminate the possibility that random factors affect the results is to set up a second group within the experiment, called a **control group**. The control group is identical to the first group (the **experimental group**) in every way, except that the single experimental (independent) variable that is being tested is not changed. This is called a controlled experiment. Because it allows us to examine one variable at a time, a controlled experiment is an important way of testing a hypothesis.

To ensure an investigation is valid, it should be designed so that only one variable is changed at a time. The remaining variables must remain constant, so that meaningful conclusions can be drawn about the effect of each variable.

To ensure validity, carefully evaluate the:

- independent variable (the variable that will be changed), and how it will change
- dependent variable (the variable that will be measured)
- controlled variables (the variables that must remain constant), and how they will be maintained.

The experimental conditions of the control group are identical to the experimental group, except that the variable of interest (the independent variable) is also kept constant in the control group.

In an experiment, controlled (fixed) variables are kept constant. Only one variable (the independent variable) is changed. The dependent variable is then measured to determine the effect of that change.

Randomisation

Random selection of your sample improves the validity of your investigation by reducing **selection bias**. Selection bias occurs when your sample doesn't reflect the wider population that you wish to generalise your results to. For example, if you were scoring phenotypes in large trials of genetically selected or genetically modified crop plants, choosing plants at random locations throughout the field would be more valid than choosing plants only at the edges of the field.

Reliability

Reliability (sometimes called repeatability) is the ability to obtain the same averaged results if an experiment is repeated (Figure 1.2.2). Because a single measurement or experimental result could be affected by errors, **replicating** samples within an experiment and running **repeat trials** makes an investigation more reliable. To improve reliability, you should:

- specify the materials and procedures in detail
- include replicate (several) samples within each experiment
- take repeat readings of each sample
- run the experiment or trial more than once.

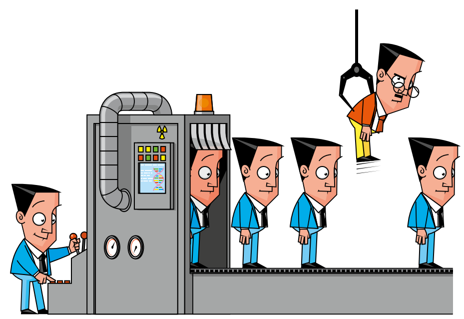

FIGURE 1.2.2 If you can reproduce your results using the same experimental procedures, then they are reliable.

MODIFYING THE PROCEDURE

Your procedure may need to be modified during the investigation. The following actions will help to determine any problems with your procedure and how to modify them.

- Record everything.
- Be prepared to make changes to the approach.
- Note any difficulties encountered and the ways they were overcome. What were the failures and successes? Every test can help you understand more about the investigation, no matter how much of a disaster it may first appear.
- Do not panic. Go over the theory again and talk to your teacher and other students. A different perspective can lead to a solution.

If you don't get the data you expected, don't worry. As long you can critically and objectively evaluate the investigation, identify its limitations and propose further investigations, then the work is worthwhile.

ISSUES TO CONSIDER IN SCIENTIFIC RESEARCH

Scientific research is part of human society and often has social, economic, legal and ethical implications. You need to address these implications when planning your research.

Social issues

Social issues relate to implications for individuals, communities and society. People often fear what they do not understand, so they tend to fear new scientific advances and technology.

When considering social issues, it is important to think about how technology will affect different groups of people. For example, in vitro fertilisation allows couples with fertility issues to have children. However, it is currently very expensive, meaning couples from a lower socioeconomic background may not be able to afford it.

Economic issues

All scientific research is subject to economic limitations, because all research requires money. Some research might also have important implications for local, national or global economies.

An important economic issue for scientific research relates to costs and benefits. Valuable scientific research might never be funded because it is unlikely to produce measurable benefits in the short term. For example, rare diseases usually receive less research funding than common diseases, because they affect fewer and often poorer people, and the return on an investment in research is likely to be small.

It is also important to consider who is paying for the research. For example, a company funding research into the benefits of its products will be more interested in positive results than negative results. This could result in bias when reporting the results—especially if the company reports the results, rather than the researcher.

Legal issues

The most common legal issue that researchers face is the need to obtain permits under relevant legislation. For example, in New South Wales, a legal permit is required to collect plants, trap animals or conduct any other sort of research on public land. In some parts of Australia, permission is also required from the traditional owners or custodians of land. Legal issues might also be relevant if there are risks involved in using the results of research, or when new research could lead to conflict between the people involved in the outcome.

Ethical considerations

Scientific research involving humans or animals must be approved by an ethics committee before it can commence. All research involving animals in Australia must comply with the *Australian Code of Practice for the Care and Use of Animals for Scientific Purposes*.

However, there might still be public concern about some types of research. For example, many people have raised concerns about the prospect of being able to genetically modify humans before birth, leading to 'designer babies', in which parents could choose features such as the child's sex or eye colour. The use of live animals in research (e.g. for testing the safety of pharmaceutical products) is also an issue for many people.

ETHICS APPROVAL

Ethics is a set of moral principles by which your actions can be judged as right or wrong. Every society or group of people has its own principles or rules of conduct. Scientists have to obtain approval from an ethics committee and follow ethical guidelines when conducting research that involves animals—including, and especially, humans.

If you work with animals as part of your studies, your school should have already obtained a special licence to cover this, and should be following the New South Wales Government's guidelines for the care and use of animals in schools. These guidelines recommend that schools consider the '3Rs principle':

- Replacement—replacing the use of animals with other materials and procedures where possible
- Reduction—reducing the number of animals used
- Refinement—refining techniques to reduce the impact on animals.

You should treat animals with respect and care. The welfare of the animal must be the most important factor to consider when determining the use of animals in experiments. If at any time the animal being used in your experiment is distressed or injured, the experiment must stop.

RISK ASSESSMENT

While planning for an investigation in the laboratory or outside in the field, you must consider the potential risks—for both your safety and the safety of others.

Everything we do involves some risk. **Risk assessments** identify, assess and control hazards. A risk assessment should be done for any situation that could hurt people or animals, whether in the laboratory or out in the field. Always identify the risks and control them to keep everyone safe.

To identify risks, think about:

- the activity that you will be carrying out
- where in the environment you will be working, e.g. in a laboratory, school grounds or a natural environment
- how you will use equipment, chemicals, organisms or parts of organisms that you will be handling
- the clothing you should wear.

The following hierarchy of risk control (Figure 1.2.3) is organised from the most effective risk management measures at the top of the pyramid to the least effective at the bottom of the pyramid.

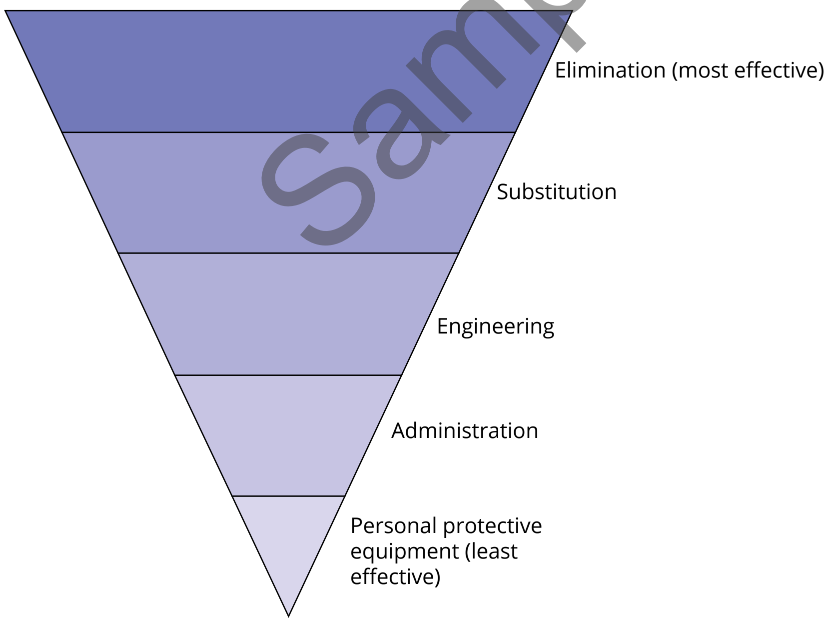

FIGURE 1.2.3 The hierarchy of risk control in this pyramid is marked from top to bottom in order of decreasing effectiveness.

Take the following steps to manage risks when planning and conducting an investigation:

- Elimination—Eliminate dangerous equipment, procedures or substances.
- Substitution—Find different equipment, procedures or substances that will achieve the same result, but have less risk.
- Engineering—Modify equipment to reduce risks. Ensure there is a barrier between the person and the hazard. Examples include physical barriers, such as guards in machines, or fume hoods when working with volatile substances.
- Administration—Provide guidelines, special procedures, warning signs and safe behaviours for any participants.
- **Personal protective equipment (PPE)**—Wear safety glasses, lab coats, gloves, respirators and any other necessary safety equipment where appropriate, and provide these to other participants.

1.2 Review

SUMMARY

- Write a protocol and schedule to plan your investigation. Test your protocol, and evaluate and modify it if necessary.
- The procedure of your investigation is a step-by-step procedure that must ensure that the investigation is valid, reliable and accurate.
- Validity refers to whether an experiment or investigation is actually testing the set hypothesis and purpose.
- Reliability or repeatability is the ability to obtain the same averaged results when an experiment is repeated.
- Controlled experiments allow us to examine only one factor at a time (the independent variable), while reducing the effects of all other variables.
- The procedure of your investigation may need to be modified during the investigation process.
- The social, economic, legal and ethical implications of scientific research must be considered when planning research.
- Social issues relate to implications for individuals, communities and society.
- Economic issues relate to costs and benefits.
- Legal issues may relate to researchers needing to obtain permits under relevant legislation.
- Scientific research involving humans or animals must be approved by an ethics committee before it can commence.
- The three Rs should be applied in any investigation that requires the use of animals:
  - Replacement—replacing the use of animals with other materials and procedures where possible
  - Reduction—reducing the number of animals used
  - Refinement—refining techniques to reduce the impact on animals.
- Risk assessments that identify, assess and control hazards should be done before undertaking laboratory or fieldwork.

KEY QUESTIONS

1 Why is it important to plan before you conduct your scientific investigation?

2 a Explain what is meant by the term 'controlled experiment'.
  b Using an example, distinguish between independent and dependent variables.

3 A student conducted an experiment to find out whether a bacterial species could use sucrose (cane sugar) as an energy source for growth. She already knew that these bacteria could use glucose for energy. Three components of the experiment are listed. Next to each one, indicate the type of variable described.
  a presence or absence of sucrose
  b measurement of cell density after 24 hours
  c incubation temperature, volume of culture, size of flask

4 List four issues that need to be considered when planning a scientific investigation.

5 What are the 3Rs that should be considered when using animals in research?

6 Why are risk assessments performed?

1.3 Conducting investigations

Once you have finished planning and designing your practical investigation, the next step is to undertake your investigation and record the results. As with the planning stages, you must keep key steps and skills in mind to maintain high standards and minimise potential errors throughout your investigation.

This section will focus on the best procedures for conducting a practical investigation and systematically generating, recording and processing data.

SAFE WORKING PRACTICES AND MANAGING RISKS

Personal protective equipment

Everyone who works in a laboratory wears clothing and equipment to improve safety (Figure 1.3.1). This is called personal protective equipment (PPE) and includes:

- safety glasses
- shoes with covered tops
- disposable gloves for handling chemicals or organisms
- an apron or a lab coat to prevent spills from coming into contact with your clothes and skin
- ear protection if there is risk to your hearing.

FIGURE 1.3.1 A lab coat, gloves and safety glasses are essential items of personal protective equipment in the laboratory.

Science outdoors

Scientific research often involves outdoor fieldwork in potentially hazardous situations (Figure 1.3.2). Every potential risk, and ways to minimise them, must be considered when planning fieldwork. Table 1.3.1 shows some common risks associated with fieldwork and measures that can be taken to minimise them.

FIGURE 1.3.2 These botanists are well prepared for fieldwork in an alpine environment. They are wearing warm clothing, waterproof jackets, long pants and protective boots. They are carrying food, water and everything they might need in an emergency in their backpacks, and they are working in a group rather than alone.

TABLE 1.3.1 Common risks associated with fieldwork

Risk	Measures to minimise risk
sunburn	wear a hat, sunglasses and long-sleeve top; apply sunscreen regularly
hot weather	wear light, loose-fitting clothing; drink water regularly to avoid dehydration
cold weather	wear warm clothing, such as a polar-fleece jacket and woollen hat
insect and animal bites	apply insect repellent; watch where you walk, and do not put your hand in a hole or hollow without checking it first; bring a first-aid kit
sprained ankle, blisters	wear sturdy, well-fitting boots with thick socks
wet weather	carry waterproof clothing
getting lost	work in a group, never alone; carry a map, compass, torch, GPS and mobile phone or two-way radio
bushfire	check fire conditions before you leave; do not work in the field when danger is rated high or more; carry a radio to listen for bushfire warnings

Chemical safety

Some chemicals used in laboratories are harmful. When you are working with chemicals in the laboratory or at home, it is important to keep them away from your body. Laboratory chemicals can enter the body in three ways: ingestion, inhalation and absorption.

- Ingestion—chemicals that have been ingested (eaten) may be absorbed across cells lining the mouth or enter the stomach, and may then be absorbed into the bloodstream.

- Inhalation—chemicals that are inhaled (breathed in) can cross the thin cell layer of the alveoli in the lungs and enter the bloodstream.
- Absorption—some chemicals can pass through the skin and enter the body.

When working with any type of chemical, you should:

- identify the chemical codes and be aware of the dangers they are warning about
- become familiar with chemical **Safety Data Sheets (SDS)**
- use PPE
- wipe up any spills
- wash your hands thoroughly after use.

Chemical codes

The chemicals in laboratories, supermarkets, pharmacies and hardware shops have a warning symbol on the label. These symbols are a chemical code indicating the nature of the contents (Table 1.3.2).

TABLE 1.3.2 Some of the different warning labels you might see on chemicals

Symbol	Meaning and examples	Symbol	Meaning and examples
	Biological hazards are living organisms, such as bacterial cultures, that may pose a threat of infection or irritation. To dispose of these, place in a biohazard bag ready for autoclaving (sterilisation at 121°C), or soak contaminated paper towel in ethanol or bleach. Clean contaminated surfaces with 70% ethanol or bleach.		Organic peroxides, including hydrogen peroxide, are powerful bleaching agents that cause skin and hair to turn white. They can irritate and damage skin and eyes.
	Corrosive chemicals can dissolve or eat away substances, including tissues such as your skin or airways. Examples include bleach, acids and bases (e.g. hydrochloric acid, acetic acid, sodium hydroxide), some stains used for microscopy, and biochemical reagents for detecting protein and sugars.		Irritants cause discomfort, pain or itchiness. Examples include urea, some microscopy stains and acetic acid.
	Poisons can cause injury or death if ingested, inhaled or absorbed. Examples include ninhydrin, methanol, Lugol's iodine, hydrochloric acid and formalin/formaldehyde.		Flammable liquids include alcohols, such as ethanol, acetone and glacial acetic acid.

Safety data sheets (SDS)

Every chemical substance used in a laboratory has an SDS. An SDS contains important information about how to safely handle, store and dispose of the chemical, as well as first-aid information for teachers and technicians about each chemical you commonly use in the laboratory. It also provides employers, workers and emergency crews with the necessary information to safely manage the risk of hazardous substance exposure.

An SDS states:

- the name of the hazardous substance
- the chemical and generic names of certain ingredients
- the chemical and physical properties of the hazardous substance

- health hazard information
- how to store the chemical safely
- precautions for safe use and handling
- how to dispose of the chemical safely
- the name of the manufacturer or importer, including an Australian address and telephone number.

First aid

Minimising the risk of injury reduces the chance of requiring first-aid assistance. However, it is still important to have someone with first-aid training with you during practical investigations. Always tell your teacher or laboratory technician if an injury or accident happens.

RESEARCH TECHNIQUES

Many research techniques are used in scientific investigations. Throughout your studies, you may be required to undertake investigations through a combination of laboratory work and fieldwork.

Laboratory work

Techniques that you may use in a biology laboratory include:

- microscopy—to observe cells, tissues and microscopic organisms (Figure 1.3.3). You'll learn more about microscopy in Chapter 2.
- cell and **tissue culture**—growing cells and tissues to investigate their growth rates, responses and other biological processes (Table 1.3.3)
- investigating biochemical processes, such as cellular respiration and photosynthesis. You'll learn more about these processes in Chapter 3.
- investigating enzymatic reactions. Enzymes are covered in detail in Chapter 3.

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TABLE 1.3.3 Growing cells for biology investigations

	Bacteria and yeast are cultured in appropriate liquid nutrient broth or nutrient agar plates.
	Algae and protists can be grown in suitable protist medium in sterile glassware. Algae are grown in good light conditions. Protists prefer the dark.
	In plant tissue culture, small segments of stem or leaf are surface sterilised to remove contaminants. Cells or tissues of plants are cultured on nutrient agar over days or weeks.

FIGURE 1.3.3 *Paramecium caudatum* viewed under a light microscope. *Paramecium* is a large unicellular protist that is commonly used as a model organism in classrooms and laboratories.

- spectrophotometry or colorimetry—to measure light absorbance to quantify biological reactions (Table 1.3.4, Figure 1.3.4)
- chromatography—to investigate pigments and other biological products (Figure 1.3.5)
- electrophoresis—to separate proteins and DNA by size, and investigate DNA fragments amplified using the **polymerase chain reaction (PCR)** (Figure 1.3.6)
- PCR—to make many copies of sections of DNA for sequencing
- DNA sequencing and analysis—to understand the inheritance of traits, the function of genes and the genetic diversity and structure of populations. You'll learn more about the use of biochemical data in Chapter 10.
- immunology—to investigate human responses to invading pathogens and disease.

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Tools to support your practical investigations

Table 1.3.4 lists some tools you might use during your investigations.

TABLE 1.3.4 Tools that can be used in practical investigations

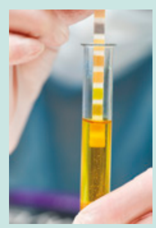
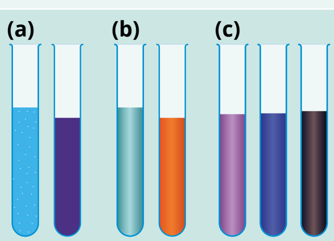
Simple indicator of pH	Measuring pH or temperature	Measuring solutes
Tool: a dipstick test for the full pH range. A strip with pH-sensitive coloured pads is dipped into a solution, and then read against a reference colour chart after a defined time. **Purpose:** to measure the pH of a solution.	**Tool:** electronic meters and probes. **Purpose:** to measure pH or temperature.	**Tool:** strip tests for measuring glucose, protein and other solutes: • Multistix® tests for several substances • UriScan® tests glucose and protein • Glucostix® tests glucose only **Purpose:** usually designed for urine testing. Coloured pads on the strip are dipped into urine or other solutions; the colour develops and is read against a reference chart. Detection is often based on an enzyme reaction within the pad.
		
Data loggers for a range of measurements	**Biochemical/chemical tests to detect molecules**	**Measuring absorbance, optical density or turbidity**
Tools: common types of probes and capabilities in data loggers include: • pH • temperature • oxygen concentration • carbon dioxide concentration • absorption colorimeter • concentration of various compounds. **Purpose:** data loggers enable data collection over long periods.	**Tools include:** **a** biuret reagent* for detecting protein (purple) **b** Benedict's reagent* for detecting reducing sugars, such as glucose, maltose, fructose; not sucrose (red) **c** iodine–potassium iodide (IKI)* reagent for detecting starch (blue/purple). **Purpose:** to detect different biochemical reactions.	**Tool:** colorimeter or spectrophotometer. **Purpose:** to quantitate colour reactions, or measure turbidity for monitoring cell growth.
		
	* Some tests are qualitative; quantitative or semi-quantitative results may be achieved if combined with standards and absorbance readings.	

FIGURE 1.3.5 Thin-layer chromatography (TLC) plate in a beaker, showing separated components (colours). TLC is performed on a sheet of glass, plastic or foil coated in a thin layer of adsorbent material.

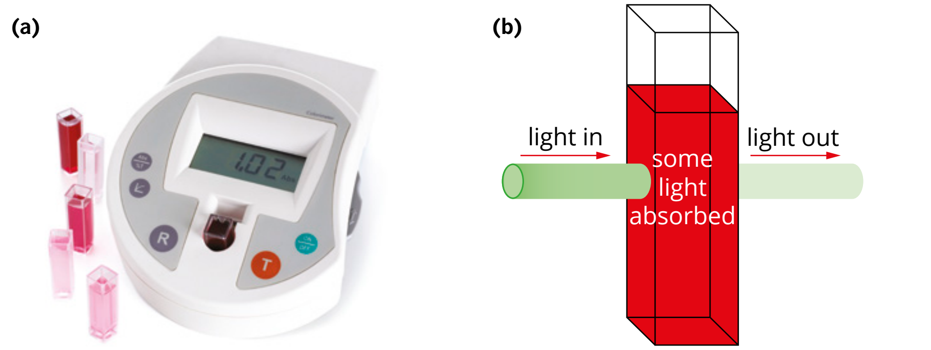


FIGURE 1.3.4 A colorimeter or spectrophotometer (a) reads absorbance of light. A sample is placed in a cuvette and placed in the instrument. Light of a particular wavelength is shone through the sample (b). The meter reads the amount of light absorbed by the sample. A sample with higher concentration gives a higher absorbance reading.

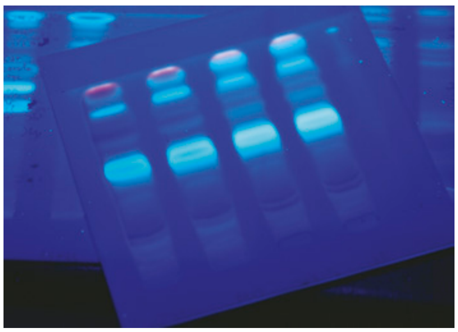


FIGURE 1.3.6 Gel electrophoresis uses an electric current to separate fragments of protein and DNA. Fragments of different sizes separate as they travel through the gel, because smaller fragments travel faster than larger fragments.

Fieldwork

Biological investigations often include fieldwork. For example, you may want to determine the type and number of living organisms in an area. There are many different ways to do this, including quadrats and transects. Whatever way you use, it is important to always leave the environment the way you found it (Figure 1.3.7).

FIGURE 1.3.7 When working in the field, a good principle to work by is: take only photographs, leave only footprints.

In natural environments, it is usually impossible to count all the individuals of a species. Even just counting the living things in your school would take a very long time. Sampling gives us a good idea of the organisms in an ecosystem without needing to count each one.

When sampling in the field, you should always consider the time and equipment available, the organisms involved and the impact the sampling may have on the environment.

Some common sampling techniques used to investigate species in the field are:

- **point sampling**—counting organisms at selected points
- **quadrats**—a square, rectangular or circular area that is surveyed as a representative of a larger area
- **transects**—a straight line along which vegetation is sampled
- water sampling—water is collected in a container and organisms are counted
- **mark–recapture**—animals are captured, marked and then released. When animals are observed or recaptured, their mark is used to identify them.

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Chapter 11 outlines these sampling techniques in more detail, and describes when they are best used in the field.

IDENTIFYING AND REDUCING ERRORS

When an instrument is used to measure a physical quantity and obtain a numerical value, the aim is to determine the true value. However, the measured value is often not the true value. The difference between the true value and the measured value is called the **error**. This error in the measured value is the result of errors in the experiment, and can be one of two main types: systematic errors and random errors.

Systematic errors

A **systematic error** (or bias) is a consistent error that occurs every time you take a measurement. Systematic errors are not easy to spot, because they do not appear as a single difference in the dataset. Instead, repeated measurements give results that differ by the same amount from the true value. There are many different types of systematic errors, but the most common types are selection bias and **measurement bias**.

Selection bias

Selection bias occurs when your sample is not representative of the population being studied. This can have several different causes, including sampling bias and time-interval bias. Sampling bias occurs when your sample has not been selected randomly. Time-interval bias occurs when you stop your study too early, because you think the results support your hypothesis.

Measurement bias

Measurement bias is usually a result of instruments that are faulty or not calibrated, or the incorrect use of instruments. Both of these produce inaccurate results. For example, if a scale under-reads by 1%, a measurement of 99 mm will actually be 100 mm. Another example would be if you repeatedly used a piece of equipment incorrectly throughout your investigation, such as reading from the top of the **meniscus** instead of the bottom when using a measuring cylinder or graduated pipette (Figure 1.3.8).

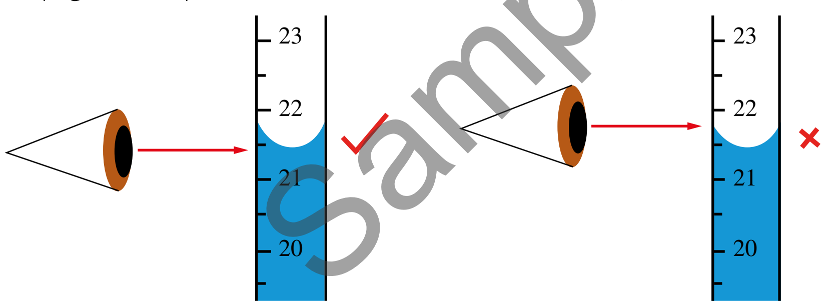

FIGURE 1.3.8 When measuring liquid levels in cylinders and pipettes, measure the value at the bottom of the meniscus of the liquid, as shown in (a), not at the top, as shown in (b).

A meniscus is the curved upper surface of liquid in a tube.

Reducing systematic errors

The appropriate selection and correct use of **calibrated** equipment will help you reduce systematic errors. Because systematic errors are difficult to identify, it is also a good idea (if you have time) to repeat your measurements using different equipment.

Appropriate equipment

Use equipment that is best suited to the data you need to collect. Determining the units and scale of the data you are collecting will help you to select the correct equipment. For example, if you need to measure 10 mL of a liquid, using a 10 mL graduated pipette or a 20 mL measuring cylinder will give more accurate readings than when using a 200 mL measuring cylinder, because the pipette or smaller cylinder will have a finer scale.

FIGURE 1.3.9 A student measures the pH level of tartaric acid using a pH meter. To ensure an accurate reading, the student would first have calibrated the meter using standard solutions of known pH.

Calibrated equipment

Accurate measurement requires properly calibrated equipment. Before you carry out your investigation, make sure your instruments or measuring devices are properly calibrated and functioning correctly (Figure 1.3.9). Your school laboratory may have a set of standard masses that can be used to calibrate a balance or scale. A pH meter should have a set of standard pH solutions (e.g. at pH 4, pH 7 and pH 9) that you can use to check the meter readings and adjust the meter if necessary.

Correct use of equipment

Make sure you have been trained to use equipment correctly. Write the instructions in detail so you can follow them exactly each time, and practise using the equipment before you start your investigation. Improper use of equipment can result in inaccurate, imprecise data with large errors, which compromises the validity of the data. An example of incorrect use of a balance would be if it was not placed on a level surface, or if it was used in a room with strong air currents or vibrations.

Random errors

Random errors (also called variability) are unpredictable variations that can occur with each measurement. Random errors can occur because instruments are affected by small variations in their surroundings, such as changes in temperature. All instruments have a limited precision, so the results they produce will always fall within a range of values.

Reducing random errors

To reduce random errors, you need to take more measurements or increase your sample size. You can then calculate the average (the mean), which is a more accurate representation of the data.

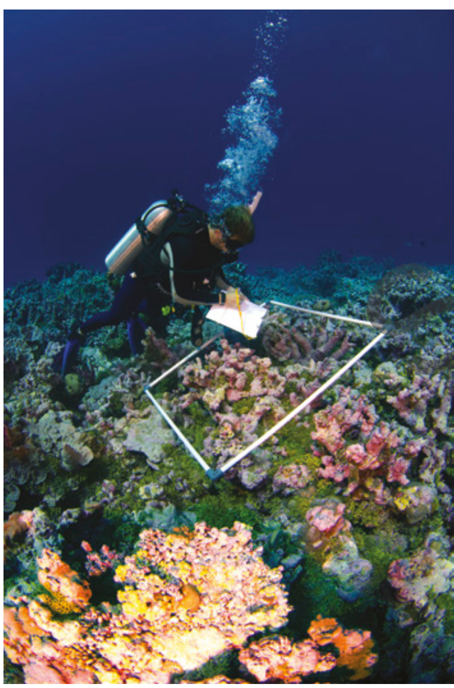

FIGURE 1.3.10 This marine biologist is keeping a logbook, recording observations of each coral in the square quadrat.

More measurements

The impact of random errors can be minimised by taking more measurements and then calculating the average value. In general, more measurements will improve the accuracy of the measured value. The minimum number of measurements you should take is three, but you may need more depending on the type of investigation you are conducting. If one reading differs greatly from the rest, mention this in your results and discuss possible reasons for the difference. If you think it is the result of an error, do not include it in your results, because it will skew (bias) the result.

Sample size

Increasing the **sample size** reduces the effect of random errors, which in turn makes your data more reliable. For example, if you are investigating the effects of light intensity on the rate of photosynthesis in *Elodea* (a genus of aquatic plants), do not test your hypothesis on just one stem. Test several stems (minimum three). If two stems photosynthesise and one does not, it is reasonable to conclude that one stem was unhealthy or the conditions incorrect. Using a large number of samples will reduce the likelihood of your results being skewed.

DATA COLLECTION

The measurements or observations that you collect during your own investigation are your primary data (Figure 1.3.10). Keep in mind that different types of data can be collected in a scientific investigation. When planning your investigation, you should consider the type of data you will collect and how best to record it. Data can be raw or processed, and qualitative or quantitative.

Keeping a logbook

During your investigation, you must keep a logbook that includes every detail of your research. The following checklist will help you remember to record:

- your ideas when planning your investigation
- clear protocols for each stage of your investigation (e.g. what standard procedures you will use)
- all materials, procedures, experiments and raw data
- instructions or tables noting exactly what needs to be recorded
- experimental/observation protocols that you will follow exactly each time
- tables you draw up ready for data entry (see Table 1.3.5)
- all notes, sketches, photographs and results (directly into logbook—not on loose paper)
- any incidents or errors that may influence results.

Raw and processed data

The data you record in your logbook is **raw data**. This data often needs to be processed or analysed before it can be presented. If an error occurs in processing the data, or you decide to present the data in a different format, you will always have the recorded raw data to refer back to.

Raw data is unlikely to be used directly to validate your hypothesis. However, it is essential to your investigation, and plans for collecting your raw data should be made carefully. Consider the formulas or graphs you will be using to analyse your data at the end of your investigation. This will help you to determine the type of raw data you need to collect to test your hypothesis.

For example, you might want to study the effect of nutrient concentration on tomato production in a hydroponic garden. To do this, you might collect two sets of raw data: the concentration of nutrient solution applied to each plant, and the total mass of tomatoes harvested from each plant. Once you have determined the data you need to collect, prepare a table to record it (e.g. Table 1.3.5).

You can then process this data further. For example, the nutrient might be very expensive, so you might be interested in the ratio of tomato mass to nutrient concentration. This value (shown in the last column in Table 1.3.5) is **processed data**. Processed data is obtained by applying a calculation or formula to raw data.

Primary data is data that you collect yourself. Secondary data is data that someone else has collected.

TABLE 1.3.5 An example of the kind of table used in a logbook for primary (raw) data collection

Plant tray no.	Total tomato mass (kg)	Nutrient concentration (g/L)	Mass per unit concentration (kg per g/L)
1	1.25	5.0	0.250
2	2.81	10.0	0.281
3	4.64	15.0	0.309
4	5.02	20.0	0.251
5	5.84	25.0	0.234

SOURCING INFORMATION

You might source information to learn more about your research topic, prepare a literature review, research experimental procedures or investigate a broader issue. Every time you source information, consider whether it comes from primary or secondary sources. You should also consider the advantages and disadvantages of using resources such as books or the internet.

Primary and secondary sources

Primary and secondary sources provide valuable information for research. Primary sources of information are from investigations that you have conducted yourself, while secondary sources are information from investigations that have been conducted by others. Table 1.3.6 compares primary and secondary sources.

TABLE 1.3.6 Summary of primary and secondary sources of information

	Primary sources	Secondary sources
Characteristics	• first-hand records of events or experiences • written at the time the event happened • original documents	• interpretations of primary sources • written by people who did not see or experience the event • reworked information from original documents
Examples	• results from your experiments • reports of your scientific discoveries • photographs, specimens, maps and artefacts that you collected	• textbooks • scientific journal/magazine articles • biographies • newspaper articles • magazine articles • documentaries • interviews with experts • websites that interpret the scientific work of others

FIGURE 1.3.11 You will find reputable science magazines in your school library.

Using books and the internet

The resources you use affect the quality of your research. **Peer-reviewed** scientific journals are the best sources of information, but some are only accessible with a subscription. Books, magazines and internet searches will be your most commonly used resources for information. However, you should be aware of the limitations of these resources (Table 1.3.7). Reputable science magazines you might find in your school library include *New Scientist*, *Cosmos*, *Scientific American* and *Double Helix* (Figure 1.3.11).

TABLE 1.3.7 Advantages and disadvantages of book and internet resources

	Book resources	Internet resources
Advantages	• written by experts • authoritative information • have been proofread, so information is usually accurate • logical, organised layout • content is relevant to the topic • contain a table of contents and index to help you find relevant information	• quick and easy to access • allow access to hard-to-find information • access to information from around the world; millions of websites • up-to-date information
Disadvantages	• may not have been published recently—information may be outdated	• time-consuming looking for relevant information • a lot of 'junk' sites and biased material • search engines may not display the most useful sites • cannot always tell if information is up to date • difficult to tell if information is accurate • hard to tell who has responsibility for authorship • information is not ordered • less than 10% of sites are educational

Secondary sources of information include books, journals, magazines, newspapers, interviews, television programs and the internet. You should aim to use a wide range of data sources when performing your secondary-sourced investigations. Secondary sources may have a bias, so you need to determine if they are accurate, reliable and valid sources of information. You will learn about assessing the accuracy, reliability and validity of secondary data in Section 1.5.

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Biological databases

Many open-access **databases** of biological information are available on the internet. They include databases of gene and protein sequences, biochemical pathways and cellular signalling. Other open-access databases provide a large body of information for investigating the living world, biosciences and molecular biology. They include databases from museums and research institutions, and include the records of specimens, fauna and flora, biodiversity and fossil collections (Table 1.3.8). They may include images, raw data and geographic distributions of species that can be compared when investigating biological change and continuity over time (Figure 1.3.12).

TABLE 1.3.8 Useful databases for investigating biological diversity

Examples of biological databases	Type of data, information or applications
Encyclopedia of Life World Register of Marine Species Atlas of Living Australia	species information, biodiversity, taxonomy, phylogeny
Museums Victoria	species data, classification, geographic distribution over time, skull image databases, biological data, fossils
Australian Museum—Learning Resources	evolution and extinction of Australian mammals; human evolution with 3D virtual skulls
American Museum of Natural History Smithsonian Museum of Natural History	research and collections with links to various resources, e.g. palaeobiology, bioinformatics
The Paleobiology Database Fossilworks	databases of fossils, geographic distributions, timescales, analysis tools, maps

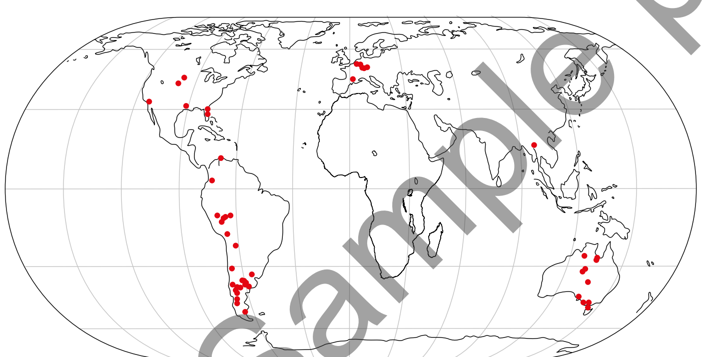

FIGURE 1.3.12 This map shows the distribution of marsupials in the Miocene geological period. It was constructed using a palaeontology database with search and mapping tools.

Referencing secondary-sourced information

As you conduct your investigation, it is important to make note of any secondary-sourced information that you use. This will then be included in your written report. You will learn more about writing scientific reports and referencing in Section 1.7.

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Categorising the information and evidence you find while you are researching will make it easier to locate information later and to write your final report. Categories you might use while researching could include:

- research procedures
- key findings
- evidence
- relevance to your research
- issues to consider (e.g. social or ethical issues)
- people affected by the research
- future concerns.

Record information from resources in a clear way so you can retrieve and use it later.

1.3 Review

SUMMARY

- Everyone who works in a laboratory wears personal protective equipment (PPE), such as safety glasses, disposable gloves and a lab coat.
- Laboratory chemicals can enter the body in three ways:
  - ingestion
  - inhalation
  - absorption.
- Chemical codes indicate the nature of the contents of solutions, powders and other reagents that are used in the laboratory (e.g. flammable, corrosive, poisonous).
- Every chemical substance used in a laboratory has a safety data sheet (SDS).
- Many different techniques are used in the laboratory, such as microscopy, cell culture and DNA sequencing.
- Many different techniques are used in the field, such as point sampling, mark–recapture, transects, quadrats and water sampling.
- Reduce random errors by:
  - having a large sample size
  - repeating measurements.
- Reduce systematic errors by:
  - selecting appropriate equipment
  - properly calibrating equipment
  - using equipment correctly
  - repeating experiments.
- Record all information objectively in your logbook, including your data and procedures.
- Raw data is the data you collect in your logbook.
- Processed data is raw data that has been mathematically manipulated.
- Primary sources of information are first-hand records of investigations that you conducted yourself.
- Secondary sources of information are records of primary sources conducted or written about by someone else, such as a scientific journal or magazine article.

KEY QUESTIONS

1. Explain the difference between ingestion, inhalation and absorption.
2. What does SDS stand for? Explain the reasons for having an SDS for each of the chemicals used in the laboratory.
3. If you spilled a chemical substance with the following label on yourself, what would be the appropriate thing to do?

4. Suggest some procedures you could use for detecting carbon dioxide generation during respiration in yeast, water plants or algae.
5. Which materials or procedure(s) from the list below could you use for the experiments listed in the following table? Copy and complete the table by writing the letter(s) into the right-hand column.
   A biochemical test
   B bacterial culture
   C glucose test strip
   D pH meter, indicator or pH stick
   E data logger—temperature probe
   F plant tissue culture
   G data logger—oxygen probe
   H staining and microscopy
   I spectrophotometer/colorimeter

	Materials or procedure(s)
i measure oxygen released in photosynthesis	
ii test the effectiveness of antibiotics on the rate of bacterial growth	
iii quantitatively measure protein concentration in an enzymatic reaction	
iv identify phagocytosis in ciliate protozoa	
v measure glucose in an enzyme experiment	

6. Two sets of data are given below. Both sets contain errors. Identify which set is more likely to contain a systematic error and which is more likely to contain a random error.
   Dataset A: 11.4, 10.9, 11.8, 10.6, 1.5, 11.1
   Dataset B: 25, 27, 22, 26, 28, 23, 25, 27
7. What is the difference between raw and processed data?
8. Decide whether each of the following is a primary or a secondary source of information.
   a a newspaper article about genetically modified human embryos
   b an experiment to investigate molecular changes within cells treated with hormones
   c an interview with a fisheries molecular scientist about using DNA analysis for tracking tiger sharks
   d a website with information about genetic engineering

Chapter review

01

KEY TERMS

accuracy
aim
bar graph
calibrate
column graph
continuous variable
control group
controlled variable
data
database
dependent variable
descriptive statistic
discrete variable
error
ethics
experimental group
exponential relationship
falsifiable
hypothesis
in situ
in vitro
in vivo
independent variable
inference
inquiry question
inverse relationship
line graph
line of best fit
linear relationship
mark–recapture
mean
measurement bias
measure of central tendency
median
meniscus
mode
model
model organism
nominal variable
objective
observation
ordinal variable
outlier
peer-review
personal protective equipment (PPE)
pie chart
plagiarism
point sampling
polymerase chain reaction (PCR)
precision
primary data
primary investigation
primary source
principle
procedure
processed data
purpose
quadrat
qualitative data
qualitative variable
quantitative data
quantitative variable
random error
random selection
range
raw data
reliability
repeat trial
replication
risk assessment
Safety Data Sheet (SDS)
sample size
scatterplot
scientific method
secondary data
secondary source
secondary-sourced investigation
selection bias
significant figure
subjective
systematic error
testable
theory
tissue culture
transect
trend line
uncertainty
validity
variable

REVIEW QUESTIONS

1 The following steps of the scientific method are out of order. Place a number (1–7) to the left of each point to indicate the correct sequence.

	Form a hypothesis
	Collect results
	Plan experiment and equipment
	Draw conclusions
	Question whether results support hypothesis
	State the biological question to be investigated
	Perform experiment

2 Scientists make observations and ask questions from which a testable hypothesis is formed.

a Define 'hypothesis'.

b Three statements are given below. One is a theory, one is a hypothesis and one is an observation. Identify which is which.

i If ultraviolet (UV) rays cause damage to cells and skin is exposed to UV light, then skin cells will be damaged.

ii The skin burned when exposed to UV light.

iii Skin is formed from units called cells.

3 Write each of the three inferences below as an 'if… then…' hypothesis that could be tested in an experiment.

a Fungi produce compounds that kill bacteria.

b An enzyme in stomach fluid causes meat to be digested.

c Acidic conditions are not good for respiration in eukaryotic cells.

4 Which of these hypotheses is written in the correct manner? Explain why the other options are not good hypotheses.

A If light and temperature increase, the rate of photosynthesis increases.

B Respiration is affected by temperature.

C Light is related to the rate of photosynthesis.

D If motile algae are attracted to light and are presented with a light source, the algae will move toward the light.

5 **a** What do 'objective' and 'subjective' mean?

b Why must experiments be carried out objectively?

6 Write each of the five numbered inferences below as an 'if ... then ...' hypothesis that could be tested in an experiment.

a The grass receives the rain runoff from the path when it rains.

b The concrete path insulates the grass roots from the heat and cold.

c People do not walk on this part of the grass.

d The soil under the path remains moist while the other soil dries out.

e More earthworms live under the path than under the open grass.

7 Define 'independent', 'controlled' and 'dependent' variables.

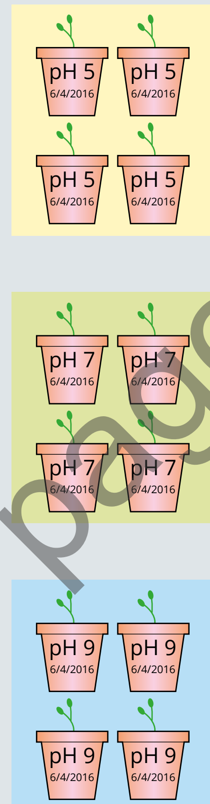
8 Design an experiment to test whether temperature is an important factor in the distribution of a mollusc species on a rocky coast. Clearly state the hypothesis that your experiment will test. Explain the procedures that you would use. Do not forget to include experimental controls.

9 Consider the seedling growth investigation below.

Purpose
To investigate the effect of pH on seedling growth.

Hypothesis
If there is a positive relationship between soil pH and seedling growth and the pH of the soil that seedlings are planted in is increased, then seedling growth will increase.

Procedure
1 Germinate 20 pea seeds on damp cotton wool and choose 12 seedlings with a height of about 12 mm.
2 Plant one seedling in each of 12 pots of the same size. For each pot, use 80 g of quality potting mix, and add 10 mL of tap water. Safety note: ensure that gloves and a mask are worn when handling potting mix, as it may contain harmful microbes.
3 Label each pot with the date and the pH treatment the soil will receive: four pots at pH 5, four pots at pH 7 and four pots at pH 9.
4 Weigh each pot to the nearest 0.1 g. Draw up a data table and record the results for each pot in a column with the heading 'Day 0'.
5 Reweigh the seedlings in their pots two days later. Record the results for each pot in the column for day 2.
6 Immediately after weighing, give each plant 10 mL of water at the appropriate pH according to the label on the pot.
7 Repeat steps 5 and 6 every two days for the next 10 days.
8 Keep plants in the same position where light is available to maintain light conditions.
9 Repeat steps 1–8 twice to reduce the chance of variability between trials.



a State the independent variable for the experiment.
b State the dependent variable for the experiment.
c List the controlled variables stated in the procedure.
d Explain the importance of controlling all variables except the dependent variable.

10 List three things that need to be considered when preparing a risk assessment.

11 List the components of the hierarchy of risk control in order from the least effective to the most effective.

12 Complete the following table to list and describe the three ways a laboratory chemical could enter the body, and how you might prevent this occurring.

Mode of entry	How the substance enters	Prevention

13 If you spilled a live bacterial culture on the lab bench, you would use paper towel to soak up the liquid.
a Who would you consult about proper clean-up procedures?
b What personal protective equipment (PPE) would you wear during this clean-up?
c What would you use to clean the bench top?

14 Suggest a procedure you could use for detecting photosynthesis in plants or algae.

15 You are learning about genetically inherited diseases and are searching for facts about cystic fibrosis. From the list below, which would be the best resource to use? Explain your answer.
A the book *Cystic Fibrosis*, published in 1997
B the article ‘Living with cystic fibrosis’ published in the *Daily Mail* on 23 February 2008
C the website www.cysticfibrosis.org.au, accessed on 30 October 2015

16 Identify which of the following pieces of information about a cup of coffee are qualitative, and which are quantitative. Place a tick in the appropriate column.

Information	Qualitative	Quantitative
cost $3.95		
robust aroma		
coffee temperature 82°C		
cup height 9 cm		
frothy appearance		
volume 180 mL		
strong taste		
white cup		

17 Using a Venn diagram, present the differences and similarities between discrete and continuous data.

18 Calculate the percentage change in mass for these plants exposed to light of different intensity.

Plant	Mass on Day 1 (g)	Mass on Day 2 (g)	% change
plant 1 (control)	13.4	13.7	
plant 2 (intense light)	14.8	15.3	
plant 3 (low light)	13.0	12.8	

19 Describe the advantages of calculating percentage change for the results of an experiment repeated by different groups of scientists.

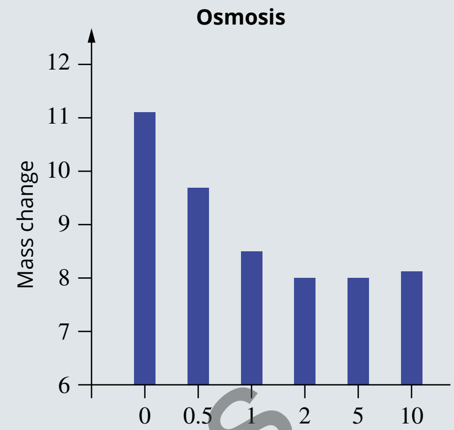
20 Immunologists have measured the levels of antibodies in blood serum to gather background data on population responses to infection. They collected the following data on the concentration of two different types of antibody, IgG and IgA, from subjects ranging in age from 6 months to 20 years (the antibody levels are listed in order of increasing age of subject).

- Age of subject: 6 months, 1, 2, 4, 10, 20 years
- Concentration of IgG (mg/100 mL): 300, 600, 800, 1000, 1500, 1500
- Concentration of IgA (mg/100 mL): 50, 100, 100, 150, 200, 400

a Prepare a data table.

b Prepare a graph of the data.

21 Describe at least four ways the graph below could be improved.



22 Explain why repeat trials and replication are necessary.

23 Consider the following experiment.

Hypothesis
If mineral water is better than tap water for the growth of plants, then seedlings watered with mineral water will grow more leaves than seedlings watered with tap water.

Experiment
Set up two identical trays of seedlings. They should have the same type of plant, age of plant, type of potting mix, drainage, and amount of sunlight and water. Everything should be the same except the type of water given to the plants.

Variables
Anything that could be different in the experiments must be kept the same. This includes everything listed above and even the height of the plants, the depth of potting mix and the intensity of the sunlight. These variables are kept the same—they are the controlled variables.

Only one variable is changed—the type of water. It is the effect of this variable that we are measuring. It is the independent variable. Its measurement should be objective (be able to be measured quantitatively).

The independent variable—the type of water—may change the number of leaves. The number of leaves is the dependent variable. The number of leaves depends on the type of water.

Results
Measure or count the number of leaves on each plant. This will give you objective results. Your friends could replicate the experiment at their houses. When you and your peers have repeated the experiment many times on different plants, the results can become a generalisation.

a In this experiment, what does the term 'sample size' refer to?

b Identify the controlled variables.

c Identify the independent and dependent variables.

d Will the results be objective or subjective? Explain.

e Will the results be valid for all plants? Explain.

24 Explain what the visual model below represents. Why is this a useful model in science classrooms?

25 Below is a molecular model of the enzyme catalase, which converts hydrogen peroxide to water and oxygen. Suggest reasons why scientists construct molecular models in addition to simple diagrams or a written description of its molecular composition.