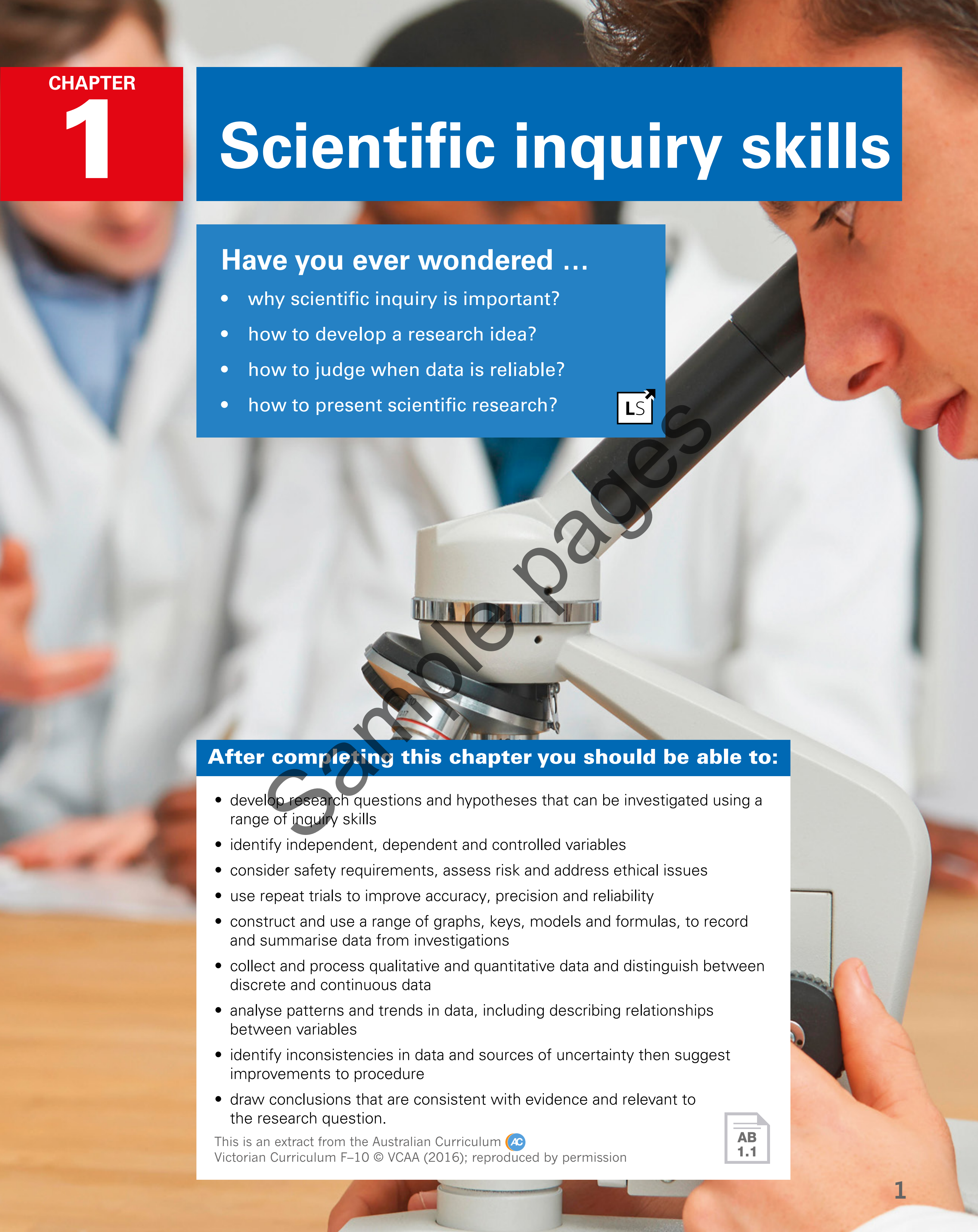


CHAPTER 1

Scientific inquiry skills

Have you ever wondered …

- why scientific inquiry is important?
- how to develop a research idea?
- how to judge when data is reliable?
- how to present scientific research?

LS

After completing this chapter you should be able to:

- develop research questions and hypotheses that can be investigated using a range of inquiry skills
- identify independent, dependent and controlled variables
- consider safety requirements, assess risk and address ethical issues
- use repeat trials to improve accuracy, precision and reliability
- construct and use a range of graphs, keys, models and formulas, to record and summarise data from investigations
- collect and process qualitative and quantitative data and distinguish between discrete and continuous data
- analyse patterns and trends in data, including describing relationships between variables
- identify inconsistencies in data and sources of uncertainty then suggest improvements to procedure
- draw conclusions that are consistent with evidence and relevant to the research question.

AB 1.1

MODULE 1.1

Planning investigations

When you wonder why something happens, you are beginning to think like a scientist. Turning ideas and thoughts into knowledge involves a process called the scientific method.

science 4 fun

Making little things bigger

What happens to gummy bears when left in water?

Collect this ...

- glass or jar about 250 mL in size
- water for the jar
- Haribo® gummy bear

Do this ...

1. Add water to the jar until it is approximately ¾ full.
2. Place one Haribo® gummy bear in the water.
3. Leave overnight.

Record this ...

1. Describe what happened.
2. Explain why you think this happened.

Scientific investigation can take different forms. Scientists may conduct experiments or fieldwork where they test a hypothesis, collect and analyse first-hand data and reach a conclusion. Scientists also carry out investigations through research of scientific information in books, journals and other sources. An investigation may also involve a combination of both experiments and research.

In this chapter, you will focus on doing scientific investigation through experiments. When you wonder why something happens, you are beginning to think like a scientist. Turning ideas and thoughts into knowledge involves a process called the scientific method.

The scientific method

The scientific method, shown in Figure 1.1.1, is a practical way of asking and answering scientific questions. It is a process that uses observation and experimentation to make new discoveries, find out how the world works and to build up scientific knowledge. The scientist in Figure 1.1.2 is using a variety of approaches in her investigation.

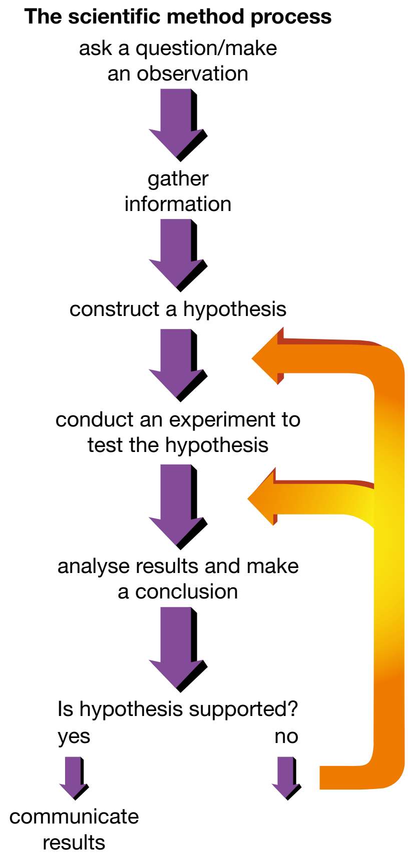


FIGURE 1.1.1 The scientific method includes a number of steps that help scientists follow a process to research and answer questions.

FIGURE 1.1.2 Careful observation in the field and analysis of DNA extracted from feathers helped scientists at the Museum of Western Australia confirm that the night parrot (*Pezoporus occidentalis*) is not extinct, as previously thought.

Observations and questions

All scientific inquiry is based on an idea or a question that needs to be answered. This question is often based on an **observation**, such as noticing that ice melts quicker in a hot drink than in a cold drink.

Observation is an important part of the scientific process. It includes using your senses and a wide variety of instrument and laboratory techniques that allow closer and more accurate observation. Observation allows scientists to collect and record data which provides the basis to construct a hypothesis to be tested.

Developing a question

One way of answering a question is through conducting an **experiment**. When choosing a topic of investigation for an experiment:

- choose a question you find interesting
- start with a topic which you know something about, or where you have some clues about how to perform the experiment
- make sure your school laboratory has the resources for your experiment
- choose a topic that can provide data that is clear and able to be measured.

The question should be one sentence that clearly describes the purpose of the experiment. An experimental hypothesis must be able to be tested.

The question, aim/purpose and hypothesis are interlinked. It is important to note that each of these can be refined as the planning of the investigation continues. For example, if you are investigating the drying time for clothes on a line like the one in Figure 1.1.3, then this may be phrased as a question or as an aim as shown in Table 1.1.1 on page 4.

FIGURE 1.1.3 Clothes drying on a line

TABLE 1.1.1 Relationship between question, aim and hypothesis

Question / Aim / Hypothesis	Examples
Question: this is a sentence that needs an answer and must end with a question mark ('?').	What is the effect of wind speed on the time taken to dry clothes in the shade when the temperature is 20°C?
Aim/Purpose: a sentence summarising what will be investigated. It states the purpose of the experiment starting with a 'to' verb. Be very specific about its purpose (aim).	To determine the effect of wind speed on the clothes drying time when the temperature is 20°C.
Hypothesis: a possible outcome of the experiment. It is an educated guess based on previous knowledge on which you can make a prediction for the results of the experiment. The form of a hypothesis is 'if X happens, then Y will happen'. Formulate a question first and it will lead you to a hypothesis when you: • are able to reduce the question to measurable variables. • can suggest a possible outcome of the experiment.	If the wind speed increases (X), the time taken for the clothes to dry will decrease (Y).

Experimental variables

A **variable** is a factor that can change (or 'vary') and may affect the result of the experiment. A good experiment has carefully **controlled variables** and tests only one variable at a time. This is called a **fair test**. Table 1.1.2 describes independent, dependent and controlled variables in an experiment to melt ice cubes (Figure 1.1.4).

SciFile

A hypothesis or a theory?

A hypothesis is really just an educated guess of the outcome of an experiment. 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**. A theory is a model that fits the available evidence and predicts the outcome of an experiment. One theory you may have heard of is the theory of evolution.

TABLE 1.1.2 Variables in an experiment to test how quickly an ice cube melts in hot water

Type of variable	Description	Example
independent variable	• is changed in a systematic way • what you change (the cause of the change) • observe effect on dependent variable as this variable is changed.	Temperature of the water could be the variable being changed. The experiment would be repeated with the water heated to different temperatures: 20°C, 30°C, 40°C, 50°C and so on.
dependent variable	• the variable being observed and measured • what you observe (the effect of the change) • the variable that changes when the independent variable is changed • provides the data for experiment.	The time taken for the ice to melt is the dependent variable.
controlled variables	• all other variables in the experiment besides the dependent and independent variables • what you keep the same (the things that do not change) • kept the same in all tests that are part of the experiment.	Other possible variables in this experiment include the amount of water used, the size and shape of the container and the size of the ice cube.

FIGURE 1.1.4 Ice cubes will melt when placed in water.

Constructing a hypothesis

A **hypothesis** is an educated guess based on evidence and prior knowledge to answer the question. The hypothesis must be worded so that you can test it. To do this, you will need to identify the **dependent variables** and **independent variables**.

Testing a hypothesis

A good hypothesis should be a testable. This means that the independent variable can be changed and the resulting change in the dependent variable can be measured. It may be written like this:

If X happens, then Y will happen.

A testable hypothesis may look like the three examples below:

If the water temperature increases, then a block of ice placed in the water will melt faster.

If the amount water decreases, then the ice cubes will melt more slowly.

If the size of ice cubes placed in water decreases, then the ice will melt more quickly.

Not all hypotheses are written in exactly the same way, but they should all clearly identify the change in the independent variable and the expected change in the dependent variable.

A correctly written hypothesis will clearly state exactly what you expect will happen in the experiment.

Hypothesis checklist

If you have written a good hypothesis, then you should be able to answer *yes* to the following questions:

- Is the hypothesis based on information contained in the question?
- Does the hypothesis include the independent and dependent variables?
- Can the independent variable be changed?
- Can changes in the dependent variable be measured?

To be a fair test, an experiment should only test one hypothesis at a time.

AB 1.2 AB 1.3

Writing a hypothesis from an inference

Another way to write a hypothesis is to make an **inference** and then convert that inference into a hypothesis. An inference is a logical idea that comes from an **observation**. For example, many parts of Australia have a dry season during which grass changes from being green to being brown or yellow. One observation is that the grass does not turn brown as quickly near the edges of a road, but remains green for much longer (Figure 1.1.5).

FIGURE 1.1.5 Grass growing on the side of the road remains green.

An inference can be made based on this observation and using what information is known about how grass grows. Some inferences that may explain why grass growing near the edge of the road remains green in summer are:

- The road insulates the grass roots from the heat and cold.
- The grass near the road receives runoff when it rains.
- People do not walk on grass near the road.
- The soil under the road remains moist while the other soil dries out.
- More earthworms live under the road than under the open grass.

For the first inference in the list above, the hypothesis might be:

If the temperature of the grass roots were measured, then the temperature of the grass roots under the road would be cooler than the grass roots beside the path.

All of the hypotheses from these inferences can be tested, either by more observations or by taking measurements in multiple experiments, to find out which hypothesis is supported.

Prac 1 p. 8

MODULE 1.1

Review questions

Remembering

1 Define the terms:

a observation

b dependent variable

c independent variable

d research question.

2 What term best describes each of the following?

a an inference that can be tested by an experiment

b test to determine whether or not a hypothesis is supported

c the variables that are kept consistent during an experiment.

Understanding

3 Write a hypothesis for each of these to test whether:

a carrot seeds or tomato seeds germinate quicker

b sourdough, multigrain or white bread goes mouldy the quickest

c dogs like dry food or fresh food better.

4 Read the hypothesis then answer the following questions.

If the water temperature increases, then an ice block placed in the water will melt quicker.

a What is the independent variable for the experiment?

b What is the dependent variable for the experiment?

c List three other variables that would need to be controlled.

Applying

5 An experiment to determine the effect of sunlight on plant height was carried out. The plant and experimental variables are shown in Figure 1.1.6. Copy Table 1.1.3 and identify each variable by placing a tick in the correct column. The first has been done for you.

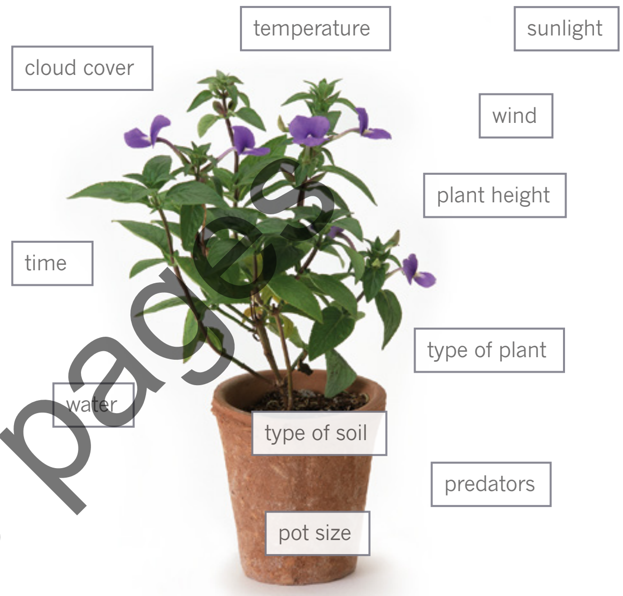


FIGURE 1.1.6

TABLE 1.1.3

	Independent variable	Dependent variable	Controlled variable
type of plant			✓
plant height			
type of soil			
pot size			
temperature			
sunlight			
wind			
cloud cover			
time			
water			
predators			

MODULE 1.1

Review questions

6 Identify the independent and dependent variables for each of the following hypotheses.
  a If a cup of hot chocolate has a lid on it, then it will stay hot longer.
  b Aquatic plants produce more oxygen in warmer water than in cold water.
  c Increasing the intensity of exercise will increase a person's breathing rate.

7 Isla wants to test how many drops of water can sit on top of a coin before the surface tension breaks and the water spills. Identify as many variables as you can for the:
  a independent variable
  b dependent variable
  c controlled variables.

8 A scientist observes that the human eye responds to sudden increases in light by decreasing the diameter of the pupil (Figure 1.1.7). He wonders if this response would change for light of different colours. He ran an experiment to investigate this.
  a What would the independent variable be and how could it be changed?
  b What would the dependent variable be? How could this data be collected?
  c Write a hypothesis for the experiment.
  d List three variables that need to be controlled and identify how these could be controlled. Describe the effect on the experiment of not controlling one of these variables.

FIGURE 1.1.7 The human eye responds to an increase in light intensity by decreasing the diameter of the pupil. Is the response different for light of different colours?

Analysing

9 Explain the difference between an inference and a hypothesis.

10 Read the following paragraph then write an appropriate question and hypothesis for the experiment.
When watching the tennis I have noticed that the tennis balls get changed regularly. I have also heard that Wilson supplies the Australian Open with 48 000 tennis balls each year! When players start a match in the Australian Open, they are supplied with six new balls, which are used for the five-minute warm-up and the first seven games of the match. I wonder if this is because the balls heat up over the duration of a game and this affects their bounce.

Evaluating

11 Three statements are given below. One is an observation, one is an inference and one is a hypothesis. Identify which is which and give a reason for your choice.
  a If there is more water in the soil, then the grass will be greener in these areas.
  b The grass growing next to the path is green.
  c The grass next to the path gets more water than the grass that is further from the path.

MODULE
1.1 Practical investigation

• STUDENT DESIGN •

1 • Melting ice

Questioning & Predicting | Evaluating

Purpose

To test whether adding substances to water will change how quickly ice melts.

Hypothesis

Once you have decided which investigation to perform, write a hypothesis in your workbook.

Timing 45 minutes

Materials

- ice
- water
- choose from: sugar, salt, sand, flour, pebbles, other substances

---

- beaker
- stopwatch

SAFETY

A risk assessment is required for this investigation.

Procedure

1 Design an experiment that will answer one of the following questions.
- Will dissolving a substance in water change the melting rate of ice more than adding an insoluble substance?
- Will adding the same amount of different soluble substances have the same effect on the melting rate of ice?
- Will adding different amounts of the same substance have different effects on the time it takes an ice block to melt?

2 Write your procedure in your workbook. Include a diagram of your design for your experiment.

3 Before you start any practical work, assess your procedure. List any risks that your procedure might involve and what you might do to minimise those risks. Show your teacher your procedure and risk assessment. If they approve, then collect all the required materials and start work.

See Activity Book Toolkit to assist with developing a risk assessment.

Use the STEM and SDI template in your eBook to help you plan and carry out your investigation.

Results

Record your results and observations in your workbook.

Review

1 Construct a conclusion for your investigation.

2 Assess whether your hypothesis was supported or not.

MODULE 1.4

Presenting and evaluating data

After an experiment, you will usually write a report about what you did and what you found out. In your report you will describe and analyse the collected data, evaluate the procedure, discuss any improvements that should be made and give a conclusion about the relationship between the independent and independent variables.

Presenting data

After you have completed your experiment, the data collected will need to be organised and presented appropriately. There are a number of ways to **process** and present data, including tables, graphs, flow charts, pictures or diagrams. The best way to visualise data depends on the type of data that has been collected.

Presenting data in tables

Tables provide an accurate record of the numerical values and allow you to organise your data. Tables usually present data in rows and columns, and can vary in complexity according to the nature of the data.

The simplest form of a table is a two-column chart. The first column should contain the independent variable (the one that is changed in a systematic way) and the second column should contain the dependent variable (the one that may change in response to the changes in the independent variable).

As you can see in Figure 1.4.1, tables should have the following features:

- descriptive title including the independent and dependent variable
- column headings (including the units)
- the independent variable placed in the left column
- the dependent variable placed in the right column/s.

Tables can be much simpler than the one shown in Table 1.4.1 on page 26, depending on the data being collected.

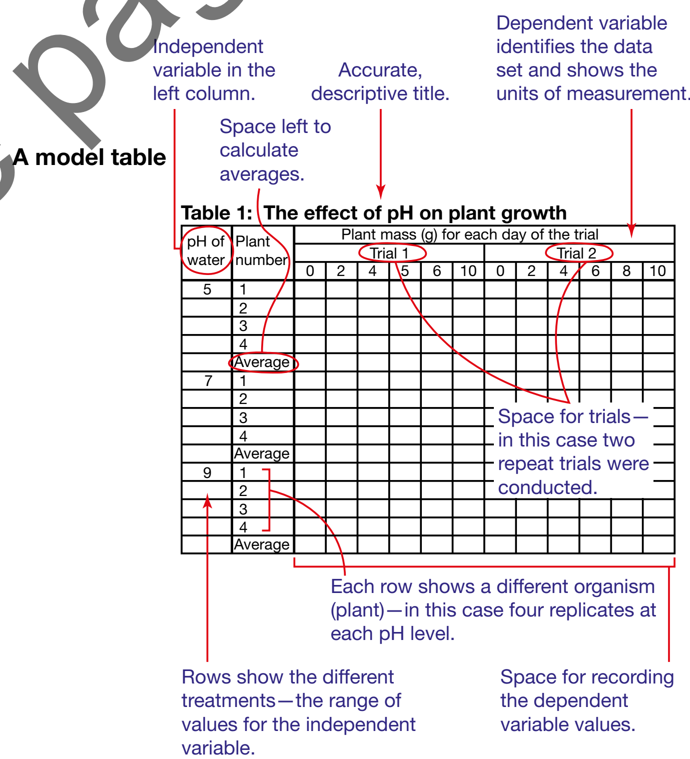


FIGURE 1.4.1 Features of a good table

The same rules always apply though. The independent variable (water temperature) is always shown in the first column and the dependent variable (time taken for sugar to dissolve) is shown in the second column. Units of measurement are included in the column headings only (Water temperature and Time taken for sugar to dissolve) and not with the data entered into the table.

TABLE 1.4.1 The effect of water temperature on the time taken for sugar to dissolve

Water temperature (°C)	Time taken for sugar to dissolve (seconds)			
	Trial 1	Trial 2	Trial 3	Average
20				
40				
60				

Presenting data as a graph

Graphs are a very useful way of presenting data visually to display any patterns or trends that may not be visible from a table. It is usually appropriate to include both a table and a graph in your report.

There are several types of graphs, including line graphs, bar or column graphs and pie charts. The best one to use will depend on the nature of the data. The general rules for drawing graphs are shown in Figure 1.4.4.

A **column graph** is the most appropriate type of graph for discrete (discontinuous) data. Consider the following example: a scientist records whether or not students eat breakfast before coming to school. This variable has two discrete categories and should therefore be graphed using a column graph. When drawing a column graph it should have bars of equal width, with a space between each bar as shown in Figure 1.4.2.

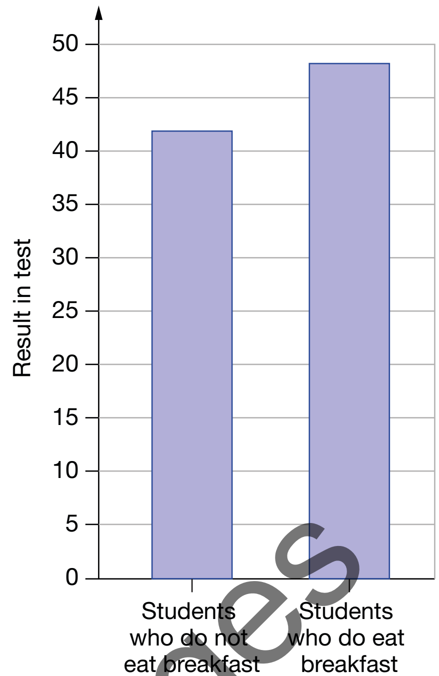


FIGURE 1.4.2 A column graph should be used to represent discontinuous data.

A **line graph** is a good way of representing continuous quantitative data. In a line graph, the values are plotted as a series of points on the graph. A line can then be drawn from each point to the next, as shown in Figure 1.4.3. In an experiment in which a scientist records the number of eagles observed each month for a year, then time is a continuous variable so it is appropriate to use a line graph.

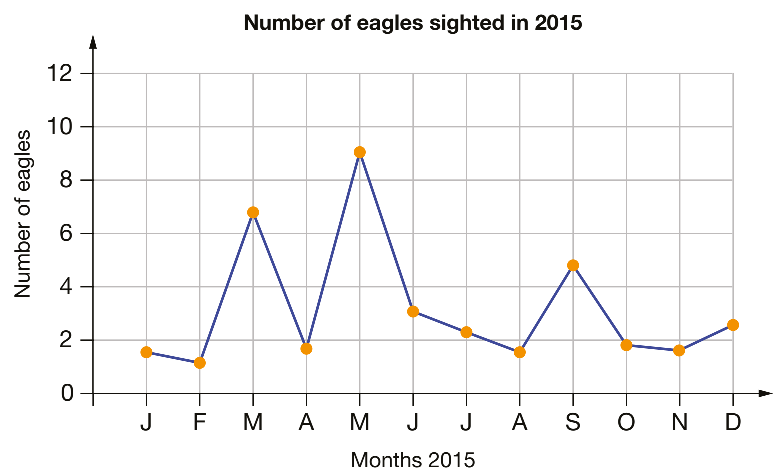


FIGURE 1.4.3 A line graph should be used to represent continuous data.

Drawing a graph correctly requires careful attention.
The following are general rules to follow when drawing a graph.
These points are summarised in Figure 1.4.4.

General rules for correctly drawing a graph

Scale:
- Evenly distribute scale on both axes—a scale is a number line so you must always write a sequence of numbers with equal intervals between them on each axis.
- Only use a scale break if it is necessary because it is not possible to draw a long enough *y*-axis on the page.

Axis:
- Represent the independent variable on the horizontal *x*-axis.
- Represent the dependent variable on the vertical *y*-axis.
- Match the length of the axes to the data.
- Clearly label each axis with both the variable it represents and the unit in which it is measured.

Legend:
- Include a key or legend to show what the colours and symbols on the graph represent.

Title:
- Use a descriptive title that includes both the independent and dependent variable.

Size:
- Use two-thirds to three-quarters of the space on graph paper.

Data:
- Only draw a line to zero if zero is actually part of the data collected.
- Use small symbols such as circles or squares for data points.

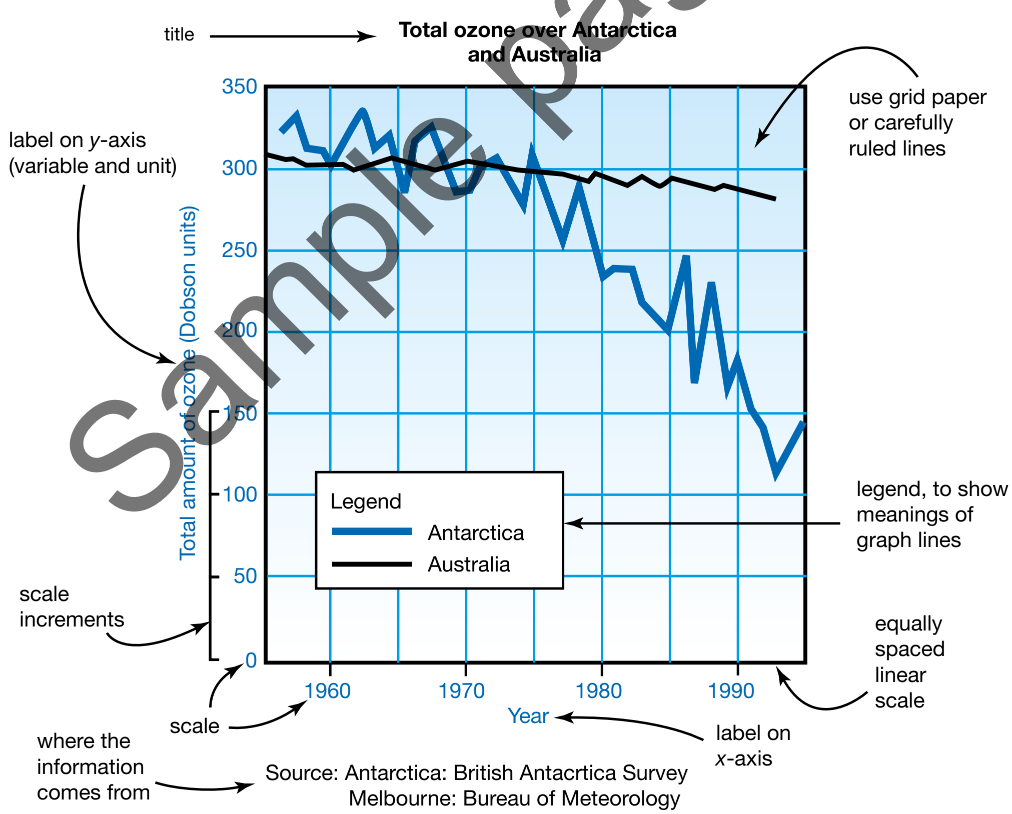


FIGURE 1.4.4 General rules to follow when drawing a graph

Interpreting data

After you have collected your data and represented it with a diagram, you will need to interpret your results. Clearly state whether a pattern, trend or relationship was observed between the independent and dependent variables. This is where your research on the topic becomes important—you should have an idea of what sort of relationship to expect. For example, you might expect that the experimental group of plants given fertiliser (independent variable) will grow larger than control group of plants given none (dependent variable). So your data would show a relationship between plant growth and fertilisation, and a relationship between plant growth without fertilisation. Relationships should be stated clearly and concisely.

- Refer to the measurements as **evidence**, and draw conclusions from the data. Be sure that conclusions are supported by the data from the experiment and not just based on what you expected to happen.
- Refer to the evidence you have collected using phrases such as 'the data shows that …', 'this is supported by …' and 'it can be inferred from the data that …'.

AB 1.5

Descriptive statistics

Data can be organised using **descriptive statistics**. Descriptive statistics are used to summarise, organise and describe data obtained from research. This allows data to be more easily interpreted. Descriptive statistics can be used to analyse both quantitative and qualitative data. Descriptive statistics include percentages, graphs and measures of central tendency. It is good practice to use a measure of central tendency to provide a clearer understanding of the data.

Measures of central tendency

Measures of **central tendency** (sometimes also called measures of central location) are single values that allow you to describe the central position in a set of data (Table 1.4.2). The mean, median and mode are all measures of central tendency.

TABLE 1.4.2 Measure of central tendency: mean, median and mode

Mean	Median	Mode
The **mean** (or average) is the sum of the values divided by the number of values.	The **median** is the 'middle' value in an ordered list of values.	The **mode** is the value that occurs most often in a list of values. This measure is particularly useful for describing qualitative or discrete data.
For example, the mean of 3, 7, 9, 10 and 11 is (3 + 7 + 9 + 10 + 11) ÷ 5, which is 8.	For example, the median of the seven values 5, 5, 8, 8, 9, 10, 20 is the fourth value, which is 8.	For example, the mode of the values 0.01, 0.01, 0.02, 0.02, 0.02, 0.03, 0.04 is 0.02.

Percentage change

Percentage change applies to increases and decreases relative to the control or the starting point of the measurement.

For example, data was collected in an experiment that investigated the osmotic strength of different solutions. Four sets of dialysis tubing (a semipermeable membrane), each containing a different solution, were suspended in a beaker of saline (sodium chloride) solution. The procedure for preparing the dialysis tubing is seen in Figure 1.4.5. The mass of the dialysis tubing was measured at the start and after 24 hours. The results are shown in Table 1.4.3.

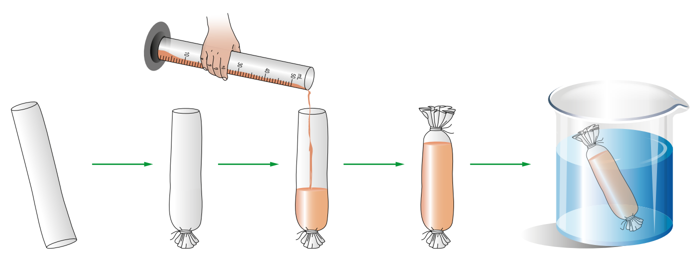


FIGURE 1.4.5 Procedure for preparing the dialysis tubing

TABLE 1.4.3 Table showing the % change in mass of dialysis tubing in 24 hours

Sample number	Original mass (g)	Mass after 24 h (g)	% mass change
1	20.55	20.89	1.65
2	20.01	21.94	9.65
3	21.25	22.09	3.95
4	20.55	20.32	–1.12

The percentage change in mass is calculated with the equation:

$$\% \text{ mass change} = \frac{\text{final mass} - \text{original mass}}{\text{original mass}} \times 100$$

Calculating percentage change accounts for natural variation and/or errors in the replicates within your experiment, or for the same experiment repeated by others. In Table 1.4.3, the starting mass is not identical in each sample, perhaps due to errors in measuring the volume put into the tubing as seen in step 3 of Figure 1.4.5. Although the final mass for sample 3 is the greatest, the percentage change is less than sample 2 because the original mass was higher.

Calculating percentage mass change shows that sample 2 has the greatest osmotic effect.

Percentage difference

The **percentage difference** (also often expressed as a fraction) is a measure of the precision of two measurements. It is calculated by working out the difference between the two measurements and dividing by the average of the two measurements:

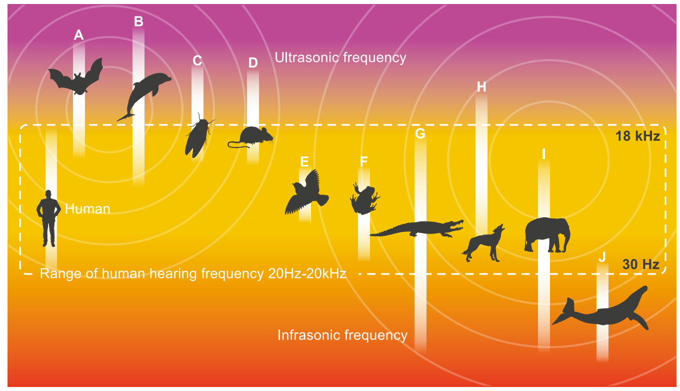
$$\text{percentage difference} = \frac{\text{measurement 1} - \text{measurement 2}}{\text{average of measurements}}$$

For example, if your two measurements were 25 cm and 24 cm, you would calculate percentage difference as follows:

$$\text{percentage difference} = \frac{(25 - 24)}{(25 + 24)/2}$$
$$= \frac{1}{24.5}$$
$$= 0.041 \times 100$$
$$= 4.1\%$$

Range

The **range** is simply the difference between the highest and lowest values in a data set. Figure 1.4.6 shows the range of hearing frequencies for different animals. From the diagram you can clearly see the range for human hearing and how this compares to different animals. This type of visual representation of the data clearly shows the differences in the sample set.



A. Bat	2kHz - 120kHz	F. Frog & Toad	50Hz - 4kHz
B. Dolphin	75Hz - 150kHz	G. Crocodile	16Hz - 18kHz
C. Insect	10kHz - 80kHz	H. Dog	64Hz - 44kHz
D. Rat	900Hz - 79kHz	I. Elephant	17Hz - 10.5kHz
E. Bird	1kHz - 4kHz	J. Blue whale	14Hz - 36Hz

FIGURE 1.4.6 Animal hearing frequency range. Hearing range describes the range of frequencies that can be heard by humans and other animals.

Table 1.4.4 shows the measurements taken for five different plants after treatment with a plant hormone. To determine the range for the values in Table 1.4.4, you would subtract the smallest value from the largest value. Notice how an abnormally large or small value in the data set makes the variability appear high. If one value appears way out of range, such as plant 1 in the hormone-treated group, it is considered an **outlier** and can be deleted from the calculations. The range for the hormone-treated plants would then be 378 – 320 = 58. This illustrates the importance of having a sample size that is large enough to limit the effect of anomalies in the data set.

TABLE 1.4.4 The range of measurements taken for five different plants after treatment with a plant hormone

Plant	1	2	3	4	5	Mean	Range
Hormone-treated plants (mm)	158	378	320	377	363	319.2	378 – 158 = 220
Untreated-control plants (mm)	140	135	170	171	193	161.8	193 – 135 = 58

Uncertainty in measurement

When averaging repeat measurements, the **uncertainty** should be reported alongside your average. Uncertainty results from errors and represents a realistic range within which the true value is likely to be. A simple way to calculate the uncertainty is the range divided by 2.

For example, if an experiment were conducted to measure the length of time it takes to convert a substrate to a product in an enzymatic reaction, and three replications of the experiment produced the times 2.50, 3.47 and 2.81 seconds, the average time taken would be 2.93 seconds. The uncertainty would be calculated as follows.

The result showing the mean and uncertainty is expressed as:

- mean = 2.93 ± 0.49 seconds.

For the data set in Table 1.4.5, in which the range was calculated, the uncertainties are:

- control plants 161.8 ± 29.0 mm
- hormone-treated plants 359.5 ± 29.0 mm (with the outlier removed).

Presenting processed data in tables

Table 1.4.5 shows the relationship between temperature and mean transpiration rate. It displays transpiration data in a processed format, because several values have been averaged to calculate the mean.

TABLE 1.4.5 Relationship between temperature and mean transpiration rate

Temperature (°C)	Mean transpiration rate (mL/g/h)
15	0.038
25	0.043
35	0.059
45	0.074

Table 1.4.6 is an improved version of the data in Table 1.4.5, because it includes the uncertainty in the processed data.

TABLE 1.4.6 Relationship between temperature and mean transpiration rate (with uncertainty)

Temperature (°C)	Mean transpiration rate (mL/g/h)
15	0.038 ± 0.002
25	0.043 ± 0.001
35	0.059 ± 0.001
45	0.074 ± 0.0015

Evaluating the method

In your report you should acknowledge any possible sources of error that could not be eliminated. Even the most accomplished scientists are unable to eliminate error completely.

There are a number of different types of errors that can occur when you make measurements. Being aware of these errors is the first step to eliminating them and ensuring the validity of your results.

Systematic errors occur because of the way that an experiment has been designed. They will make the results consistently high or low. A systematic error can occur if the measuring instrument is not calibrated correctly or if you make the same mistake every time you take the measurement. This will mean that the measurements will be incorrect in the same way throughout the experiment.

A common form of systematic error is called 'zero error'. For example, if your bathroom scales read 5 kg when you are not standing on them, then it is likely that any measurement made with these scales will be 5 kg heavier than it should be (Figure 1.4.7). Systematic errors are easiest to spot when you have an idea of what the correct measurement should be.

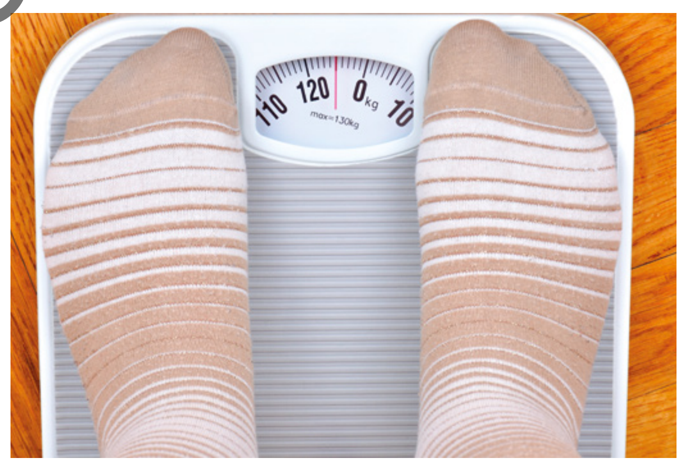


FIGURE 1.4.7 Before stepping onto bathroom scales they should read zero. A reading above or below zero will result in an incorrect reading called a systematic error.

Random errors are unpredictable errors that can occur in all experiments. They occur because no measurement can be absolutely exact. Random errors are due to unpredictable fluctuations in the equipment or inconsistencies in the way you have interpreted the readings.

Random errors can be detected when, for example, two readings for the same measurement appear as different numbers in the data. The effect of random errors can be reduced by repeating each measurement several times and taking an average of these results.

Systematic and random errors often occur if you have overlooked or were unable to control a variable that should have been controlled.

Mistakes are not errors. Whereas errors are unavoidable, mistakes can be avoided with care (Figure 1.4.8). Examples of a mistake are forgetting to press a button on a stopwatch, spilling some liquid when measuring volume or pressing the wrong calculator buttons.

FIGURE 1.4.8 It is important to work carefully to avoid making errors.

After you have identified any problems with the data you have collected, discuss how things could be done differently in the future to improve the method. Often this can be done by repeating measurements, collecting more data or controlling other variables.

Discussion of results

The discussion section of the report includes two important features. First, it explains the results of the investigation. Second, it explains the significance of the experiment and whether the data supports the hypothesis. In this section include:

- an explanation of what the results mean—the patterns, relationships that results show
- reference back to the question and check if it has been answered
- whether the results support a theory
- whether the results were what was expected
- any new questions that arise out of the results
- any qualifications or defects in the experiment design—possible sources of error, how the experiment could be improved.

Writing a conclusion

Your **conclusion** should be one or two paragraphs that link your evidence to your hypothesis. It should provide a carefully considered response to your research question based on your results and discussion. You should clearly state whether your hypothesis was supported or not. The conclusion briefly restates the main results and explains the significance of the findings.

Do not provide irrelevant information or introduce new information in your conclusion.

Prac 1 p. 33
AB 1.6

MODULE 1.4

Review questions

Remembering

1 Define the terms:
  a random error   b column graph.

2 What term best describes each of the following?
  a a summarising statement that links the evidence gathered to the hypothesis
  b raw data presented in rows and columns.

Understanding

3 A student measured the temperature outside every hour from 6 am to 6 pm. What would be the best graph for this type of data?

Applying

4 An experiment was conducted to find out whether salt dissolves more quickly in hot water than cold water.
  a Identify the independent variable.
  b Identify the dependent variable.
  c In a table representing the data from this experiment, which variable would go in the first column?

5 Two groups of students measured the time it took for ice cubes to melt on a sunny day. Their data is recorded in the Table 1.4.7.

TABLE 1.4.7 Raw data

Group	Time taken for ice cube to dissolve (min)					
	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6
A	11.4	10.9	11.8	10.6	1.5	11.1
B	25	27	22	26	28	23

  a Both sets of data below contain errors. Identify which set is more likely to contain systematic error and which is more likely to contain random error. Explain your answers.
  b Use the data set to draw an appropriate graph.

6 Identify whether the following are mistakes, systematic errors or random errors.
  a A student spills some solution during a **titration**.
  b The reported measurements are above and below the true value.
  c A weighing balance has not been calibrated.

Analysing

7 A student conducted an experiment to determine the effects of temperature on seed germination. She placed 50 seeds of wheat in a gauze cloth and heated them in water at various temperatures for two minutes. She then placed the seeds on moist cotton wool and kept them in the dark for seven days. She recorded the germination rate of the seeds in Table 1.4.8.

TABLE 1.4.8 Effect of temperature on seed germination

Temperature °C	Number of seeds germinating
10	0
20	30
25	42
35	40
40	27
50	10
60	2

  a What graph would be best to display this data?
  b Graph these results.
  c What can be concluded from these results?

Evaluating

8 A scientist conducted an experiment by asking 50 people to eat a piece of chocolate every day for two weeks. At the end of the experiment, all 50 people gained weight. The scientist concluded that eating chocolate causes weight gain.
  a Is this conclusion valid?
  b Justify your answer.

Creating

9 Create a checklist in your own words that will help you to remember all of the important points you need to include in a table and a graph. You can use words, diagrams or a flow chart. Once complete, get your checklist checked by your teacher then stick it into the front of your workbook.

MODULE 1.4 Practical investigation

• STUDENT DESIGN •

1 • Gas collection

Questioning & Predicting | Evaluating

When acid is added to calcium carbonate the gas carbon dioxide is produced (Figure 1.4.9).

Purpose

To design an investigation that will change the rate at which carbon dioxide gas is produced.

Hypothesis

Once you have decided which investigation to perform, write a hypothesis in your workbook.

Timing
45 minutes

SAFETY

A risk assessment is required for this investigation.

Materials

- Choose from:
- calcium carbonate powder and chips
- hydrochloric acid 0.1 M, 0.5 M, 1 M

- test-tubes
- conical flasks
- rubber stopper with a side arm attached
- rubber tubing that will fit onto the side arm
- 250 mL beakers
- water bath

Procedure

1 Design an experiment that will answer one of the following questions.
   - Will changing the size of the particles of the calcium carbonate change the rate at which carbon dioxide is produced?
   - Will changing the concentration of the acid change the rate at which carbon dioxide is produced?
   - Will adding different amounts of the same substance have different effects on the rate at which carbon dioxide is produced?
   - Do small temperature changes have an effect on the rate that carbon dioxide is produced?

2 Write your procedure in your workbook. Include a diagram of your design for your experiment.

FIGURE 1.4.9 Carbon dioxide gas is produced during an acid–carbonate reaction.

3 Before you start any practical work, assess your procedure. List any risks that your procedure might involve and what you might do to minimise those risks. Show your teacher your procedure and risk assessment. If they approve, then collect all the required materials and start work.

See the Activity Book Toolkit to assist with developing a risk assessment.

Use the STEM and SDI template in your eBook to help you plan and carry out your investigation.

Results

Record your results and observations in your workbook.

Review

1 Construct a conclusion for your investigation.

2 Assess whether your hypothesis was supported or not.

CHAPTER 1 Chapter review

Remembering

1 Define the terms:
- a variable
- b quantitative data
- c reliability.

2 What term best describes each of the following?
- a a statement outlining what is being investigated
- b a prediction of the outcome of the experiment based on prior knowledge or research
- c all of the variables that must be kept constant during the investigation.

3 Copy and complete the following sentences.
- a A ________ __________ is used when comparing data in an investigation to represent discrete data.
- b A _______ __________ is used with continuous __________ data.

4 Appropriate protective equipment should be used when conducting laboratory experiments. List the protective equipment that is available in your school laboratory.

5 What factors are likely to cause errors in an experiment?

Understanding

6 What is the most suitable type of graph for the following data?
- a body temperature measured every two hours
- b the populations of different types of lizard found in an area of bushland.

7 Explain what is meant by the term *controlled variable*.

Applying

8 Use an example to distinguish between the terms *independent variable* and *dependent variable*.

9 For each of the following hypotheses, select the dependent variable.
- a The concentration of lead in water will be higher in storm water close to an industrial site than in drinking water.
- b The pH of commercially available sparkling mineral water will be lower than commercially available non-sparkling mineral water.

10 Identify the independent variable, the dependent variables and three variables that would be needed to be controlled to investigate each of the following hypotheses.
- a If an elastic band is wet, then it will not stretch as far as a dry elastic band.
- b If a cup of hot chocolate has a lid on it, then its temperature will decrease more slowly than when it is uncovered.

Analysing

11 If you spilled on yourself a chemical substance with the label in Figure 1.5.1 on it, what would be the appropriate thing to do?

FIGURE 1.5.1

Evaluating

12 Select the best hypothesis, and explain why the other options are not good hypotheses.
- A If light and temperature increase, the rate of photosynthesis increases.
- B The transpiration rate of a plant is affected by temperature.
- C If rock salt is broken into smaller pieces, it will dissolve more quickly.

CHAPTER 1

Chapter review

13 Everyone uses paper towel at some stage to clean up mess. But have you ever considered when using paper towel is it better to use it folded or flat? Your task is to design an investigation to find the answer.

- **a** Identify the following variables.
  - **i** independent variable
  - **ii** dependent variable
  - **iii** controlled variables.
- **b** Write a hypothesis for your experiment.
- **c** Draw a simple diagram for your experiment.
- **d** Use numbered steps to describe your procedure.

14 Have you ever noticed that you need to walk faster to keep up with some people whereas you have to decrease your pace to walk with others? This may be due to the leg length of the person you are walking with. A pedometer is an instrument that is often used by joggers or walkers to tell them the distance they have gone. On some pedometers you need to enter your height to get an accurate reading. Design an investigation to test just how much faster or slower different people walk, and see if you can use the relationship between a person's walking pace and their height to estimate your own height.

15 What conclusion do you think could be drawn from the graph in Figure 1.5.2?

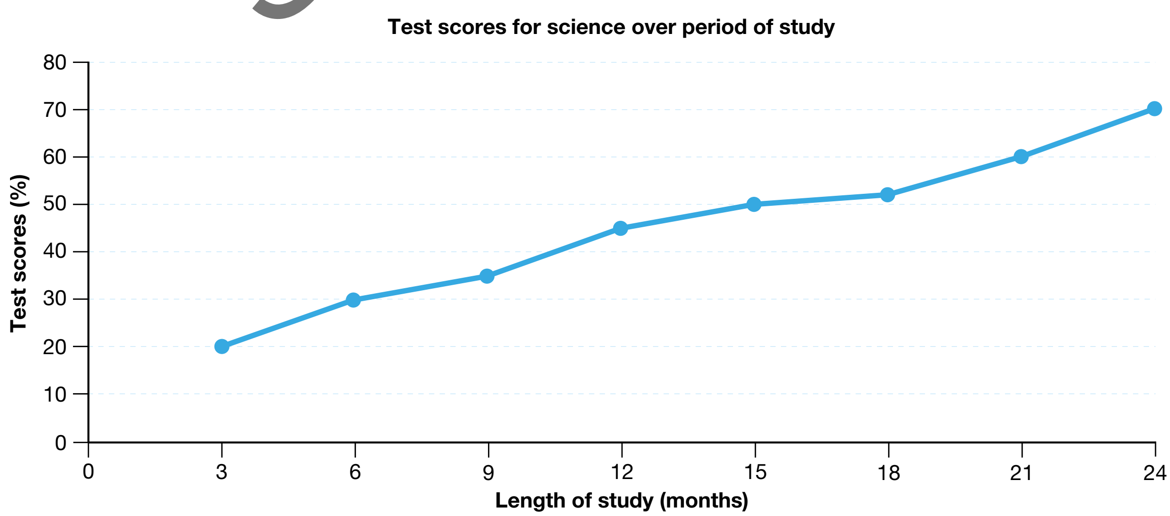
16 Scientist Dr Julie Jones noticed that on the hills where there were plants growing there was less erosion than on the hills with no plants. Dr Jones suggested that growing plants on an incline would help to slow soil erosion. Your task is to design an investigation to find the answer.

- **a** Identify the following variables.
  - **i** independent variable
  - **ii** dependent variable
  - **iii** controlled variables.
- **b** Write a hypothesis for your experiment.
- **c** Draw a simple diagram for your experiment.
- **d** Use numbered steps to describe your procedure.

Creating

17 Design an investigation to determine how temperature will affect the elasticity of a rubber band. As part of your design, complete the following.

- **a** At what temperature do you think elastic bands will have the greatest stretch? Write a hypothesis for your experiment.
- **b** Draw a diagram to show how you intend to carry out your experiment.
- **c** Describe the procedure you intend to use.
- **d** Identify the independent, dependent and controlled variables.
- **e** How will you make the test fair?



AB 1.8

FIGURE 1.5.2

Inquiry skills

Research

1 Planning & Conducting | Processing & Analysing

Benjamin Franklin was one of the Founding Fathers of the United States of America. He was also a writer, oceanographer, inventor and scientist. One very famous experiment that it is said he performed is ‘the kite experiment’. It might have looked something like that shown in Figure 1.5.3.

- **a** **i** Investigate the kite experiment. Describe what it is and how it is proposed that it was performed.
  - **ii** What was the aim of the kite experiment?
  - **iii** What hypothesis was being tested?
  - **iv** What conclusion could be drawn from the results?
- **b** **i** It is said that Franklin only did the experiment once. How does that affect the validity of any conclusions to be drawn?
  - **ii** Consider the descriptions of the experiment and the conditions under which it was purportedly performed. Is it likely that the experiment was performed exactly as described? Explain your reasoning.

Present your findings in digital form.

2 Planning & Conducting | Communicating

Find out about a current topic of scientific research at CSIRO.

- **a** Where is the research being performed?
- **b** Who are the scientists performing the research?
- **c** What is the aim of the research?
- **d** What practical benefits could be derived from this research?

Present the information as a poster encouraging people to support the work of the CSIRO.

3 Planning & Conducting | Communicating

Research the Australian code for the care and use of animals for scientific purposes.

- **a** Identify the purpose of the code for the care and use of animals for scientific purposes.
- **b** What types of animals does this code include?
- **c** Who has to abide by this code?

Present your findings as a pamphlet.

4 Planning & Conducting | Communicating

Research the placebo effect.

- **a** Define the term *placebo*.
- **b** Identify how placebos are used in medical research.
- **c** How does the placebo effect work?

Present your findings as a pamphlet.

FIGURE 1.5.3 A painting of Benjamin Franklin conducting his kite experiment

CHAPTER 1

Inquiry skills

Thinking scientifically

1 Katy was investigating how changing the concentration of hydrochloric affects the rate at which marble chips dissolve. Identify the potential hazards in her experiment. More than one answer may be correct.

A hydrochloric acid, as it is an irritant
B hydrochloric acid, as it is corrosive
C marble chips, as they are harmful
D marble chips, as they are corrosive.

2 As part of her experiment, Katy used the following equipment: a measuring cylinder, a glass beaker, 100 g of small marble chips, three different concentrations of hydrochloric acid, a weighing balance, a glass stirring rod and a stopwatch. Which pieces of equipment will help Katy collect and record data accurately? More than one answer may be correct.

A stopwatch
B concentrations of acid
C measuring cylinder
D weighing balance.

Katy's results are shown in Table 1.5.1 and Figure 1.5.4.

TABLE 1.5.1

Concentration of hydrochloric acid (M)	Mass of marble chips (g)	Time taken for marble chips to dissolve (s)
0.5	10	98
1	10	57
1.5	10	22

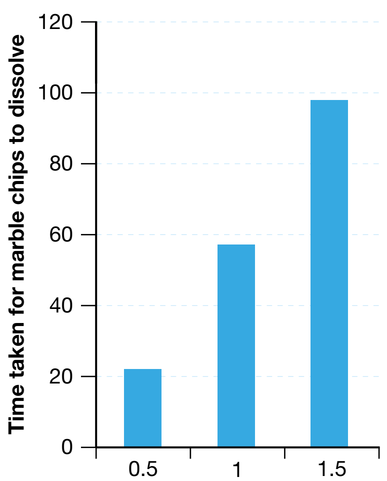


FIGURE 1.5.4

3 There are errors that may have occurred in this experiment—for example, the weighing balance giving a false reading. What type of error is this known as?

A systematic error
B zero error
C human error
D mistake.

4 What is missing from Katy's graph?

A title on y-axis and units on x-axis and a graph title
B title on x-axis, units on x-axis and y-axis, and a graph title
C labels on x-axis and a graph title
D labels on y-axis and a graph title.

5 Which of the following describes the trend in Katy's results bar chart?

A As the concentration of acid decreases, the rate at which marble chips dissolve decreases.
B As the concentration of acid decreases, the rate at which marble chips dissolve increases.
C As the concentration of acid increases, the rate at which marble chips dissolve decreases.
D As the concentration of acid increases, the rate at which marble chips dissolve increases.

6 How could Katy improve this investigation if she were to do it again?

A She could use a more precise weighing balance.
B She could repeat the experiment to get more reliable results.
C She could repeat the experiment to get more valid, accurate results.

7 Which of the following correctly describes the term *reliability*?

A how close a measurement is to the true value
B the closeness of two or more measurements to each other
C the ability to consistently reproduce results.

CHAPTER 1

Glossary

absorption: substances that pass through the skin

aim: a sentence summarising what will be investigated

central tendency: single values that allow you to describe the central position in a set of data

chemical code: warning symbol or HAZCHEM code on the label or container

column graph: a graph that shows the value of the dependent variable by the height of the column

continuous data: data measured within a range

control group: the experimental conditions of the control group are identical to the experimental group, except that the independent variable is also kept constant

controlled variable: the variable kept constant throughout an experiment

data: experimental results, often in the form of numbers or written observations

dependent variable: the variable you are measuring; it changes as the independent variable changes

descriptive statistics: used to summarise, organise and describe data obtained from research

discontinuous (discrete) data: data that can be counted

ethics: a set of principles by which your actions can be judged morally acceptable or unacceptable

evidence: results that can be used in support of statements being made

experiment: testing out a hypothesis under controlled conditions to examine its validity

experimental group: the experimental conditions of the experimental group are identical to the control group, except that the independent variable is changed

fair test: an experiment where one variable is changed; one variable is measured and all other variables are controlled

hypothesis: a statement about the relationship between two variables which can often be tested experimentally; an 'educated guess'

independent variable: a variable that is changed in a systematic way in an experiment

inference: a conclusion reached on the basis of evidence, an educated guess

ingestion: swallowed

inhalation: breathed in

line graph: a type of graph that is good for representing continuous quantitative data

objective: free of personal bias

observation: closely monitoring something or someone

outlier: abnormally big or small value in the data set

percentage change: applies to increases and decreases relative to the control or the starting point of the measurement

percentage difference: a measure of the precision of two measurements

personal protective equipment (PPE): clothing items that help to keep you safe when doing experiments

processed data: data that has been manipulated in some way, often mathematically

qualitative data: data recorded as words or descriptions

quantitative data: data recorded as numbers

random error: an error that affects experimental results in an unpredictable way

range: the difference between the highest and lowest values in a data set

reliability: the ability to consistently reproduce results

repeat trials: collecting multiple data sets by performing an experiment again after the initial test

replicates: duplicate experiments

replication: when duplicate sets of an experiment are run at the same time

research question: a statement describing in detail what will be investigated

risk: the chance of injury or loss

risk assessment: a systematic way of identifying potential risks

safety data sheet: an information sheet that contains important information about the hazards in using a substance and how it should be handled and stored

subjective: influenced by personal views

systematic error: error that affects all experimental results in the same way; occurs because of the way that the experiment has been designed

theory: a scientific explanation supported by all the experiment results obtained so far

titration: the process of adding one solution to another in a controlled environment to observe a reaction

uncertainty: a realistic range within which the true value is likely to be; calculated as the range/2

validity: how well an experiment and its results meet the requirements of a fair test

variable: a factor or condition that can change the result of an experiment

AB 1.7