

Skills Build-up

The following are essential skills needed in science:

- Using apparatus and materials appropriately and safely
- Following instructions in an organised and safe manner
- Making and recording observations in a suitable format
- Taking precise measurements
- Analysing results and coming to an appropriate conclusion
- Planning an experiment
- Evaluating the procedure stated in the plan

The next few pages list essential guidelines for you to follow when carrying out science practicals.

Basic Safety Procedures

Safety is the most important aspect of any practical work. Some general rules for laboratory safety are:

- Walk slowly in a laboratory. Do not rush or run in the laboratory.
- Use the safety equipment provided, for example, wear goggles, especially when using the Bunsen burner, and dealing with corrosive chemicals.



▲ Figure 1 A pair of safety goggles

- When handling any inflammable materials or chemicals such as ethanol, turn off all Bunsen burners. Keep these materials away from flames. Flammable materials can be identified by the presence of the symbol shown below:



▲ Figure 2 Flammable symbol

- Tie back long hair. If possible, tie the hair into a bun to prevent the hair from hitting any glassware, chemicals or coming near the Bunsen burner flame.

- Read the labels on any chemical bottle before taking the chemicals. Take note of any safety precautions that need to be taken when handling the chemicals. Toxic chemicals can be identified by the presence of the symbol shown below:



▲ **Figure 3** Toxic symbol

- Always put on gloves when handling biological specimens / biohazard materials. Biohazard materials can be identified by the presence of the symbol shown below:



▲ **Figure 4** Biohazard symbol

- Clean up any spillage immediately or ask the teacher for help.
- Handle sharp objects with care, for example, avoid pointing sharp edges at anyone.
- Always dispose biological materials / waste into the biohazard bin.
- Be aware of the location of the first aid kit (Figure 5) in your laboratory.



▲ **Figure 5** A first aid kit

- Do not eat or drink in the laboratory.
- If you are not sure of how to do something, ask the teacher for help.
- When heating a substance in a test tube, make sure that the mouth of the test tube is not pointed at you or others.

Good Laboratory Practices

Before beginning any experiment:

- Take some time to carefully read through the aims, instructions and procedures of any practical, even those that you think you might have conducted before. Avoid rushing to start the experiment, as you might miss some crucial steps, or forget to record essential data, such as the time at which you start your experiment.
- While reading the instructions, create a mental picture of how the steps will follow one after another, and the types of data that you need to record.
- After reading through the instructions, aim and procedure, organise your apparatus on the workbench properly.
 - Put away apparatus or chemicals that will not be used.
 - Label all test tubes so as to avoid confusion during the course of the experiment.
 - In Biology experiments, one important precaution to take note of in enzyme-related experiments, is to put the enzyme solution far away from any heat source, for example, the Bunsen burner.

It is important to develop good habits for practical skills.

- Read the entire procedure before attempting to carry out the experiment. While reading, highlight important points. Construct a mental picture of the experimental procedure.
- Plan and construct all tables for recording results before starting the experiment.
- Do not dismantle the experimental set-up(s) or throw away any samples before completing your experimental report. This will allow you to repeat the experiment if you find some discrepant result(s) and have time to redo some parts of the experiment.

I will give you 5-10 min to READ THROUGH practical WS every lesson.

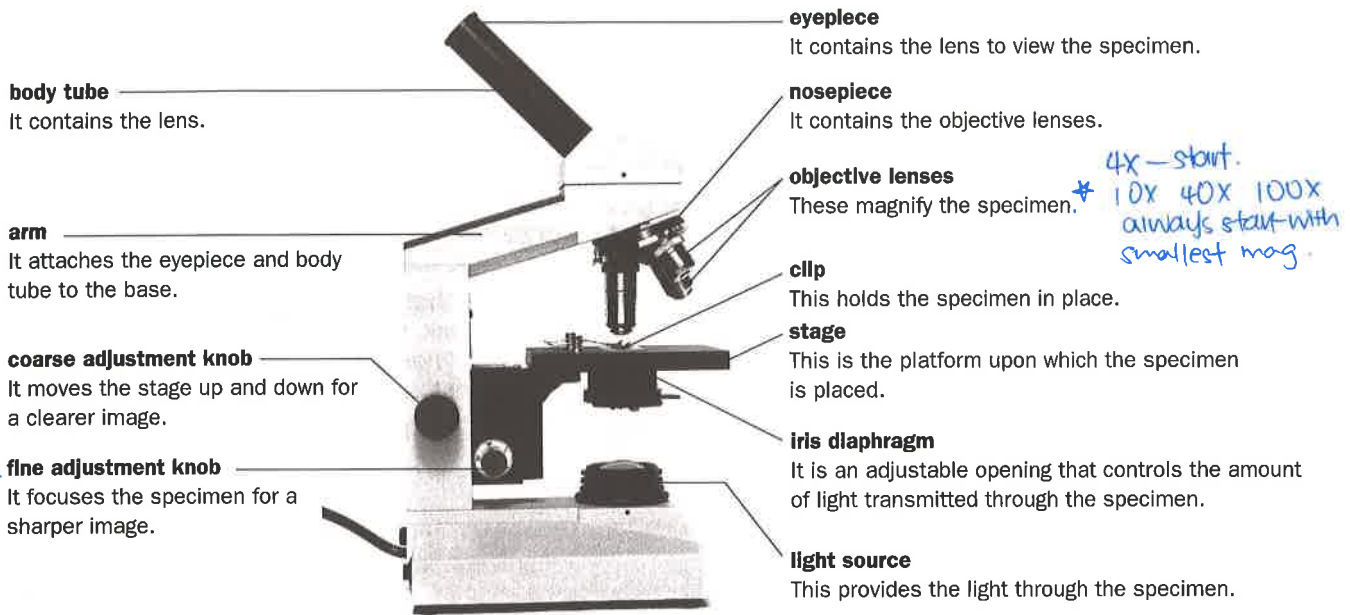
* Simulate exam conditions.

At the end of every practical session:

- Turn off the water and gas.
- Return all materials to their proper places.
- Clean your work area.
- Wash your hands thoroughly.

The Light Microscope

Some specimens, for example, cells, are too small to be seen clearly even with a magnifying glass. You may use a light microscope to view such specimens. The figure below explains the functions of the different parts of the light microscope.



▲ Figure 6 A light microscope

Handling a Light Microscope

- When lifting the microscope, hold it upright with both hands. Use one hand to hold the arm of the microscope and the other hand to support the base of the microscope.
- Ensure that the eyepiece and objective lenses are clean by wiping them gently with **special lens cleaning wipe**. **Do not use paper towels or cloth!**
- Before keeping the microscope in storage, rotate the nosepiece to position the objective lens of the lowest power in line with the eyepiece. Adjust the stage to the lowest position by using the coarse adjustment knob, before removing the microscope slide.

? means you do not ever clean the lens yourself!

Viewing a Specimen

- Remove the dust cover and plug in the microscope. Turn on the light source and place the microscope slide on the stage. Use the clips to secure the slide beneath the objective lens. Handle microscope slides with care as they are made of glass!
- The proper techniques for preparing fresh specimen are covered in Experiment 1.1.
- ① **Begin viewing the specimen with the objective lens of the lowest power.** In most light microscopes, this is the 4x objective lens.
- Look into the eyepiece. You may need to adjust the iris diaphragm to control the amount of light transmitted through the specimen. **Turn the coarse adjustment knob slowly** to elevate the stage until the specimen comes into focus. Be careful **not to crush** the microscope slide against the objective lens.
- Using your fingers, **adjust the slide on the stage** to bring the desired area of study into the centre of the field of view. ③ *adjust and focus.*
- To see the specimen in greater detail, rotate the nosepiece to view the specimen at a **higher power**. After the rotating the nosepiece, adjust the **fine adjustment knob** to see the specimen in sharp focus. ⑤
- Examine the specimen carefully. You may be required to **produce a labeled drawing** ⑥ **of the specimen.** Refer to the next section for tips on how to produce good biological drawings.

Making Observations

It is important that you make good observations in order to obtain quality results for your experiments. To make good observations, we must make use of our five senses – sight, smell, taste, touch, hear. A good observation is a detailed and accurately written or drawn description. Some possible information to take note of during an observation are colour changes, formation of precipitate, texture and other visible features of a specimen.

Not so good observation	Good observation
The solution turned orange-red.	The blue solution turned from green to orange to orange-red.
Some parts of the leaf turned blue-black	The parts of the leaf that were originally green turned blue-black, while the parts that were originally non-green turned brown after iodine test.

Recording Results

In Biology, the two formats frequently used for recording results are **biological drawings** and **tables**. In this section, we will see what makes a good biological drawing.

Biological Drawings

Drawing biological specimens is an important aspect of Biology practical skills. There are generally three types of biological drawings, as shown in the table below.

Type of biological drawing	Examples
Drawing a whole specimen	Drawing a leaf, fruit or a cross-section of a fruit
Drawing a low power plan of specimen seen under the microscope	Drawing a cross-section of a stem, root or leaf, often to show distribution of tissues
Drawing a high power plan of a few cells of microscopic specimen	Drawing onion epidermal cells, palisade mesophyll cells, blood cells or epithelial cells

Tips for producing a good biological drawing:

- Choose a **hard pencil**, and make sure that it is **sharpened**. *do not use blunt pencils!*
- Your drawing should **fill up at least two-thirds to half** of the space provided.
- Draw a **clean, clear and sharp outline**. Show all relevant features.
- ★ Add **straight labelling lines** using a ruler. Ideally, you should label on only one side of your drawing. It is also very important that label lines **do not cut across large sections of your drawing or criss-cross one another**. *(parallel lines)*
- Label all the features of your drawing, or as many as you can. The labels should be written **away** from the actual drawing so that they do not obscure any details. In some cases, annotations on the drawing are required. Annotations are short explanatory comments of biological significance.
- Add a **title** that describes the specimen drawn.
- Check that every part in the drawing **is in proportion** with one another. *eg. nucleus needs to be bigger than ribosomes.*
- Measure the size of the actual specimen and the size of drawing. Calculate

$$\text{magnification: } \left(\frac{\text{size of drawing}}{\text{size of actual specimen}} \right) \times$$

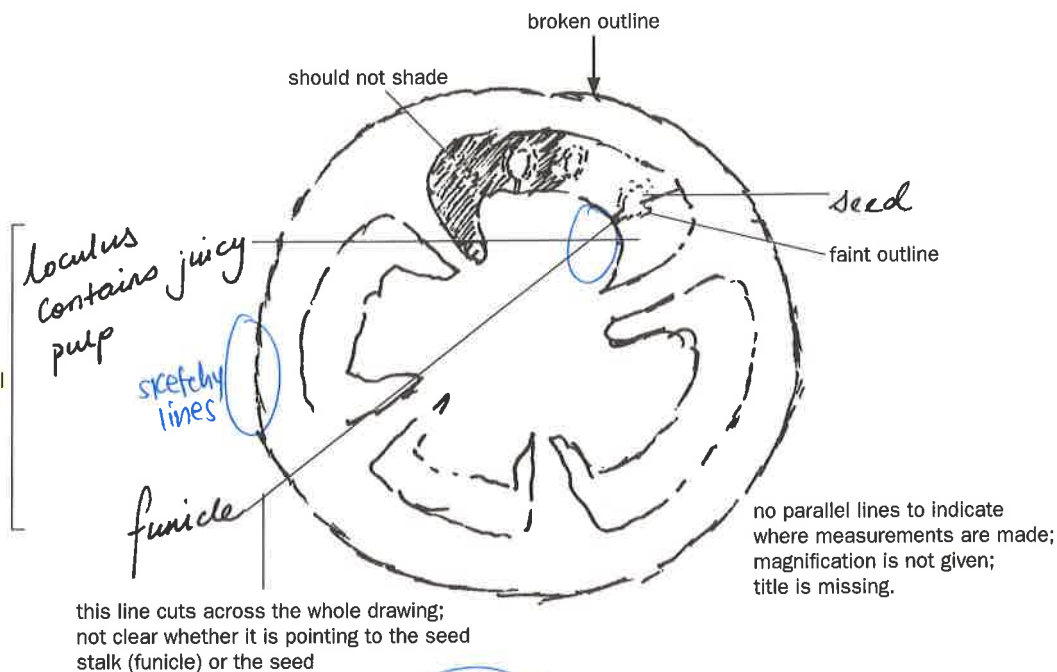
★ *will reinforce this later.*

- Express magnification to 1 decimal place.

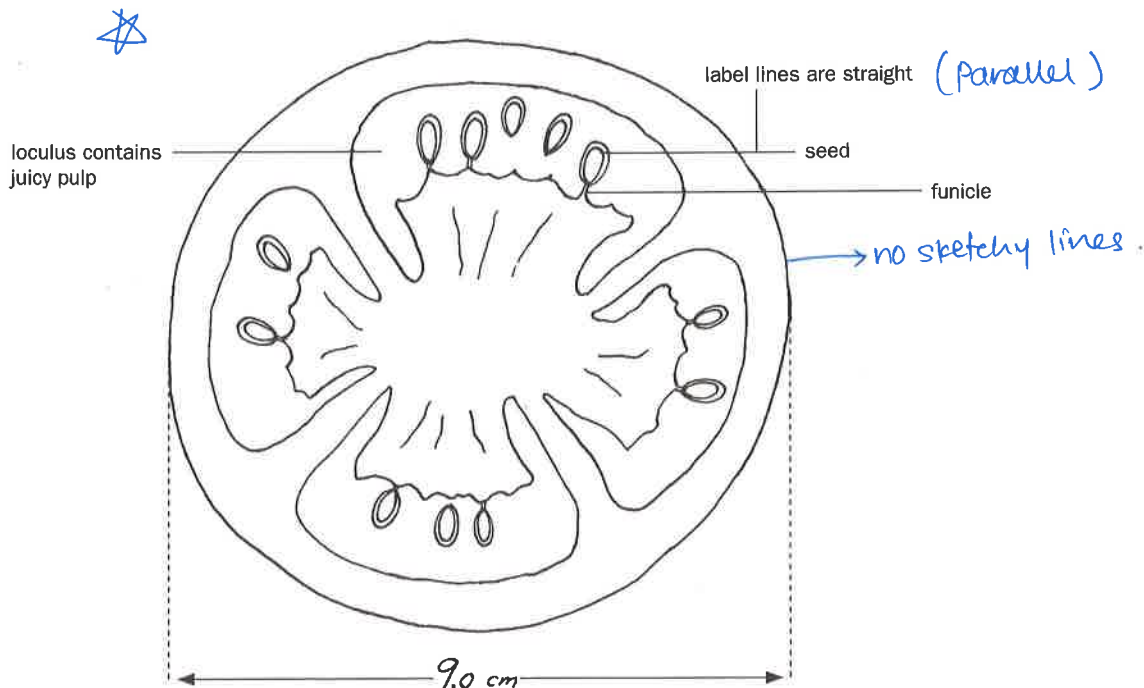
★ **Marks** are generally allocated for the following:

- Drawing — sharp, clear lines
- Accuracy — showing all details
- Proportion
- Size — at least two-thirds of the space provided
- Title of drawing
- Magnification

poor labelling —
words not horizontal



▲ Figure 7 A poorly-drawn diagram



T.S. OF FRUIT, TOMATO ← title

Actual size of tomato = 4.5 cm

$$\begin{aligned} \text{Magnification} &= \frac{\text{size of drawing (cm)}}{\text{size of actual specimen (cm)}} \times \\ &= \frac{9.0}{4.5} \times \\ &= 2.0 \times (\text{to 1 d.p.}) \end{aligned}$$

▲ Figure 8 An acceptable biological drawing

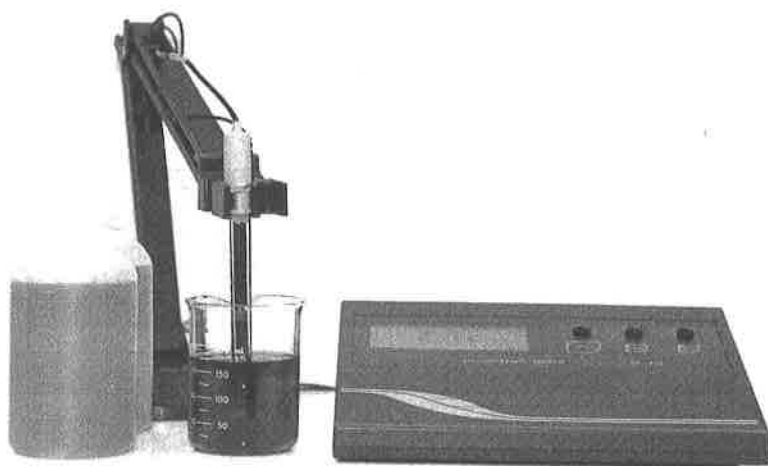
Data Handling

All biological experiments generate data (results) that should be recorded as the experiment is taking place and then presented in a suitable format. Even in theory assessments, questions are often asked based on data obtained from some experiments. It is thus important for you to be able to understand and interpret experimental data.

Types of Data

Experimental data can be **qualitative** or **quantitative**.

- Qualitative data is presented in a descriptive format, for example, a description of:
 - behaviour such as the bending of a plant towards a light source;
 - change in colour such as the colour change in Benedict's test;
 - change in texture such as a potato strip placed in distilled water feeling rough and hard after a period of time.
- Quantitative data is presented in a numerical format, for example:
 - size (length, breadth, area, volume);
 - pH values;
 - concentrations of solution.



▲ **Figure 9** pH of solutions are commonly measured using a laboratory pH meter

Both qualitative and quantitative data can be presented in tables. Quantitative data can often also be used to plot graphs.

In Science experiments, there are two key types of variables – independent and dependent variables.

- An **independent variable** is a factor/quantity that the experimenter changes or manipulates during the experiment.
- The **dependent variable** is a factor/quantity that the experimenter measures or observes in an experiment.

For example, we change the different concentrations of a solution to find out the effect it has on the length of potato strips. In this particular experiment, the concentration of the solution is the independent variable, while the length of the potato strips is the dependent variable.

Recording Data in Tables

When conducting investigations, you will have to take down raw data, both qualitative observations and quantitative measurements. It is, therefore, important that you present your data in a clear and logical format. One way would be to record data in a table.

- It is important that you spend time to think and work out how you are going to organise your data in a table.
- The table must be easy to read and simple to follow.
- The independent variable is usually placed on the extreme left column of the table. The subsequent columns record the values of the dependent variables or qualitative observations.
- All columns in the table must have a heading stating the variable that is being measured (with S.I. units) or the quality being observed.
- If there is a need to repeat the experiments, then it is important to group the measurements together so that an average or mean of the measurement can be calculated (see Sample table 1 below). Record the units of the quantity only in the headings (see Sample table 1).

Sample table 1 shows the change in length of potato strips in different salt concentrations. Three readings are taken for each salt concentration.

The independent variable is always recorded in the first column of the table.

The dependent variables will be recorded in subsequent columns.

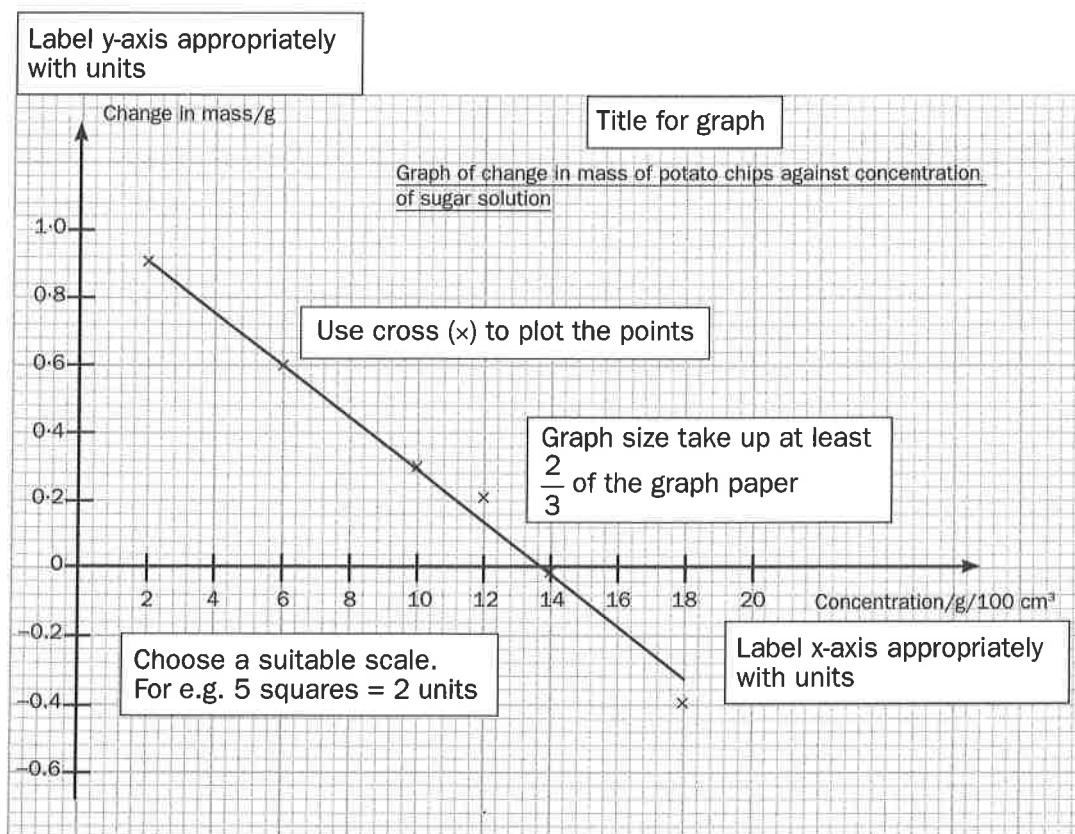
Units are put only in the header row. Do not put the units in the body of the table, i.e. do not put units for every value that you record.

Concentration of salt solution/ mol/dm ³	Potato strip in dish	Initial length of potato strip/cm	Final length of potato strip/cm	Change in length of potato strip/cm	Average change in length/cm
0.2	1				
	2				
	3				
0.4	1				
	2				
	3				
0.6	1				
	2				
	3				

▲ Sample Table 1

Plotting Graphs

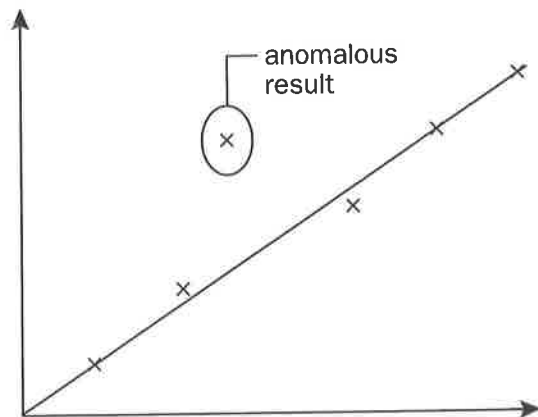
- When plotting a graph, both axes must be clearly labelled. The unit of the quantity being measured must be included in the label.
- The **independent variable** is plotted on the x-axis (horizontal axis) while the **dependent variable** is plotted on the y-axis (vertical axis).
- Choose a suitable scale such as 1 : 2. Avoid odd scales such as 1:3 or 1:6 on both axes.
- The graph should be large enough, i.e. it should take up at least two-thirds of the graph paper.
- The graph should have a title, for example, *The effect of temperature on rate of reaction* or *Graph of rate of reaction (y-axis) against time (x-axis)*, to describe the contents of the graph.
- Points should be plotted clearly on the graph, using either crosses (×) or circled dots (·). If more than one set of data is being plotted on the same axes:
 - Use different symbols to plot the points for each set of data.
 - Provide a key so that it is easy to identify which point belongs to which set of data.
 - Label each line or curve clearly.
- After plotting the points, draw a best-fit line/curve or simply join up the points. Generally, we draw a best-fit line/curve when we want to use it to determine the trend or to make predictions.
- To draw a best-fit line/curve, use the following guidelines:
 - There should be approximately the same number of data points on each side of the line.
 - The data points should be evenly distributed above and below your best-fit line/curve.
 - Your line/curve should have the smallest average distance from each of the data points.
 - Note that in some cases, best-fit lines/curves do not pass through any of the data points.



▲ Figure 10 Plotting a graph

Dealing with Anomalous Results

Anomalous results are dealt with during the data handling stage. An anomalous result is a result that deviates from the general trend of the data. Usually, anomalous results appear in graphs or in results tables. When an anomalous result appears, repeat the experiment for that variable. If the data remains different from the rest, then this is a case of true anomaly, for example, the sample used may not be a good representative.



If you have a large set of data and only one or two values are very different from the other values, then you may ignore the anomalous values and not use them in calculations.

Calculation of Mean

In many biological experiments, measurements need to be repeated and then presented by taking an average (see Sample table 1, page xiv). This helps to reduce errors and give a more accurate result. In most cases, average refers to the **mean**.

To find the mean, we sum up the data and then divide by the number of measurements taken (see the formula below).

$$\text{mean} = \left(\frac{\text{sum of all observations}}{\text{number of observations}} \right)$$

Planning and Evaluating Investigations

Planning an investigation involves:

- Stating the problem that can be investigated.
- Identifying the key variables to carry out the investigation.
- Producing a valid procedure to carry out the investigation.

To plan an investigation, you first need to understand the definitions of **hypothesis**, **variables**, **control**, **reliability**, **precision** and **accuracy**. In this section, you will also learn about **experimental errors** and how to deal with **anomalous results**.

Hypothesis

A hypothesis is a tentative, testable, falsifiable explanation for an observed phenomenon. Ideally, the hypothesis should be accompanied by some background information that supports the hypothesis. For example, a leaf will lose more water on a dry, windy day than on a wet, humid day. An investigation can be designed to test this hypothesis. If the results support the hypothesis, then it is **accepted**. If there is no difference in the amount of water loss on both types of condition, then the hypothesis is **rejected**.

Control

A control is a group that serves as a standard of comparison. It is exposed to the same experimental conditions as the experimental group, except for the variable being tested. For example, in typical experiment investigating the effect of an enzyme on a certain substrate, a control would be a treatment in which the enzyme is not added. Instead, distilled water is used in place of the enzyme. Looking at the results from the control group, we can attribute the experimental result to the enzyme and not to other factors.

Reliability, Precision and Accuracy

Reliability of an experimental result requires us to look at two aspects of the result – precision and accuracy. Generally, we are not able to confirm reliability of the results unless there is another independent way of obtaining the results, and both the results gave the same values or observations. Hence, in order to improve the reliability of the experimental results, we try to improve the accuracy and precision through selecting appropriate apparatus to measure variables and having good laboratory techniques.

Precision is a measure of confidence that can be placed on a set of data or observations. In simpler terms, it means that the data or observations taken from an experiment must be repeatable. Another experimenter who conducted the same experiment and followed the exact procedures should be able to obtain similar data or observations.

Precision of data and observations can be improved by repeating the experiment, replicating the observations and measurements. However, the average of the data, may or may not be near or the actual true value. In other words, we can have good precision but inaccurate results.

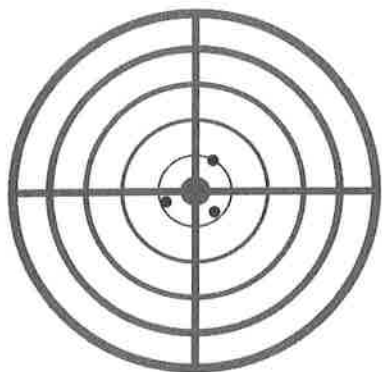


▲ **Figure 11** Precision — In this figure, the points are precise because they are clustered at the same place, but far from the actual value (indicated by the dot ●).

In the laboratory, one way to improve precision is the choice of apparatus used for the experiments. There are many types of apparatus that can be used to measure variables such as volume and length. To measure a specific volume of liquid, you can choose to use beaker, measuring cylinder, graduated syringe, burette or pipette. To measure a length, you can choose to use a metre ruler, a measuring tape or a vernier caliper. You must make the right choice of apparatus to measure the intended variable.

Accuracy is a measure of how close the data or observation is to the true value. In simpler terms, it means the quality of the results. The accuracy of the data or observation depends on the experimental techniques and the number of errors. It can be improved by eliminating or minimising errors.

Refer to the section on **Experimental Errors** to see how you can minimise errors. Ideally, the results obtained in an experiment should be both **accurate** and **precise** (Figure 14).



▲ **Figure 12** Accuracy — In this figure, the points are close to the actual value, but not precise because they are not clustered together.



▲ **Figure 13** Accuracy and Precision — In this figure, the points are close together and near the actual value. Hence, they are precise and accurate.

Experimental Errors

Experimental errors are errors that are inherent in the process of taking experimental readings, and cannot be eliminated simply by repeating the experiment, no matter how carefully. There are generally two types of experimental errors – systematic error and random error.

Systematic errors occur due to equipment, apparatus or materials that give inaccurate or unreliable results. One characteristic of systematic error is that in the absence of other types of errors, repeated measurements yield results that differ from the true value by a fixed amount.

Common sources of systematic errors are:

- faulty calibration of measuring instruments
- poorly maintained instruments
- faulty reading of instruments by the user. One example of systematic error is “parallax error”. For a guide on how to avoid parallax error, refer to page 27.

Random errors are errors that affect the precision of a measurement. One characteristic of random errors is that in the absence of other types of errors, repeated measurements yield results that fluctuate above and below the true value.

Random errors occur due to random, unpredictable variations in the measurement process. Unlike systematic errors, random errors can be improved by repeating those measurements, and then taking the average or mean value (see page xvi for a guide on how to calculate the mean). Note, however, that random errors cannot be eliminated entirely.

Common sources of random errors are:

- problems estimating a quantity that lies between the graduations (the lines) on an instrument
- the inability to read an instrument, because the reading fluctuates during the measurement

Errors may occur when ...	Suggestion to avoid or minimise error
the sample size is small	Increase the sample size or use more samples for each experimental variable
wide range of temperature, pH or concentration is used in original experiment	Use a narrower range of temperature, pH or concentration, or test at more frequent intervals, so that the relationship between the variables can be observed more accurately
instrument or apparatus used to measure a certain quantity is not the most accurate, for example, using a measuring cylinder to measure a volume of liquid	Use a more accurate instrument or apparatus, for example, use a burette to measure a volume of liquid
difficulty in detecting colour changes at a particular wavelength	Use a colorimeter (if available)

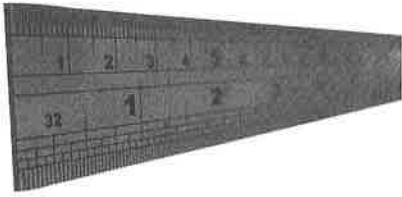
Common Units Used in Biology

The table below shows some commonly used quantities that you may encounter in learning biology.

Quantity	Symbol	SI Unit
Area	A	cm ² , m ²
Concentration	c	g/dm ³ , mol/dm ³
Energy	E	J
Length	l	mm, cm, m
Mass	m	mg, g, kg
pH	pH	—
Temperature	T	°C
Time	t	ms, s, min
Volume	V	cm ³ , dm ³ , m ³

Commonly Used Laboratory Measuring Tools

Note: The smallest division of each equipment/instrument is dependent on the instrument. The precision of the equipment/instrument refers to repeatable measurements, and can be obtained from the equipment/instrument when it is used to measure a fixed object or quantity.

Instrument		S.I. Unit	Smallest division	Equipment/Instrument precision
	Weighing balance / mass balance	mg, g	0.01 g	0.01 – 0.1 g
	Laboratory thermometer	°C	0.1°C or 0.5°C	0.1 – 0.5°C
	Metre rule	mm, cm, m	1 mm	0.5 – 1 mm
	Vernier calipers	mm	0.01 mm	0.01 mm

Instrument		S.I. Unit	Smallest division	Equipment/ Instrument precision
	Digital stopwatch	s, min	0.01 s	0.01 s
	10 ml measuring cylinder	ml	0.1 ml	0.05 – 0.1 ml
	25 ml measuring cylinder	ml	0.5 ml	0.5 ml
	Syringe	ml	0.1 ml	0.1 ml