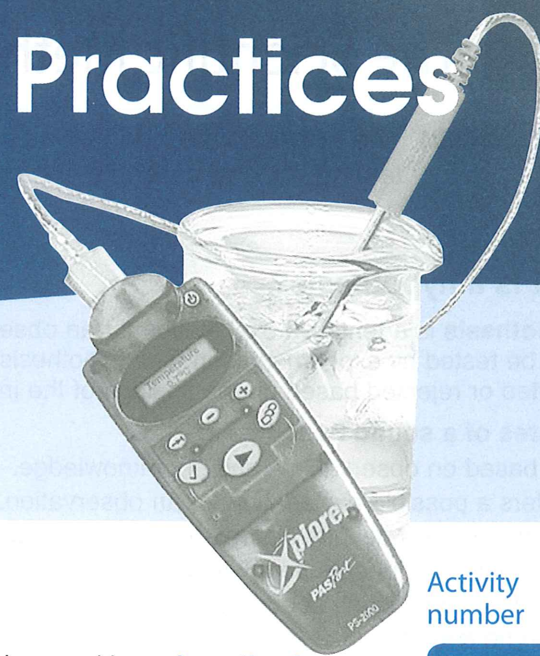
Science Practices



Key terms

- accuracy
- biological drawing
- control
- controlled variable
- data
- descriptive statistics
- dependent variable
- graph
- hypothesis
- independent variable
- mean
- median
- mode
- model
- observation
- precision
- qualitative data
- quantitative data
- raw data
- scientific method
- table
- variable

Science practices

	Activity number
The scientific method	
☐ 1. The **scientific method** involves making a **hypothesis** based on **observations**, and then testing it using controlled experimental conditions.	1
☐ 2. **Observation** is the basis for forming hypotheses and making predictions.	3
☐ 3. **Models** can be used to study biological systems and determine how they work.	2
Collecting data	
☐ 4. **Accurate** and **precise** measurements of any variable provide confidence that the data collected correctly represent the value of that variable in the wider population.	4
☐ 5. **Data** may be **quantitative**, **qualitative**, or ranked. Quantitative data can be **continuous** or **discontinuous**.	5
☐ 6. **Variables** are factors which can be changed in an experiment to see what effect they have. Variables are classified as **independent**, **dependent**, and **controlled**.	6
☐ 7. Experimental **controls** help to insure that the experiment is working properly and the results obtained are due to the variable being tested.	6
☐ 8. **Tables** provide a way to accurately record results and summarize data.	8 11
Transforming and graphing data	
☐ 9. **Raw data** can be transformed (changed) to identify important features. Common transformations include tallies, percentages, and rates.	9 10
☐ 10. **Graphs** provide a way to visualize data and see the trends more easily. The type of graph used depends on the type of data you have collected.	12 13 14 15
☐ 11. **Descriptive statistics** (e.g. **mean**, **median**, and **mode**) are used to summarize a data set and describe its basic features. The type of statistic calculated depends on the type of data and its distribution.	16
Biological drawings	
☐ 12. **Biological drawings** record what a specimen looks like, and provides an opportunity to record its important features. A good biological drawing records what you have actually seen, and includes only as much detail as needed to distinguish different structures or tissues.	17 18

1 The Scientific Method

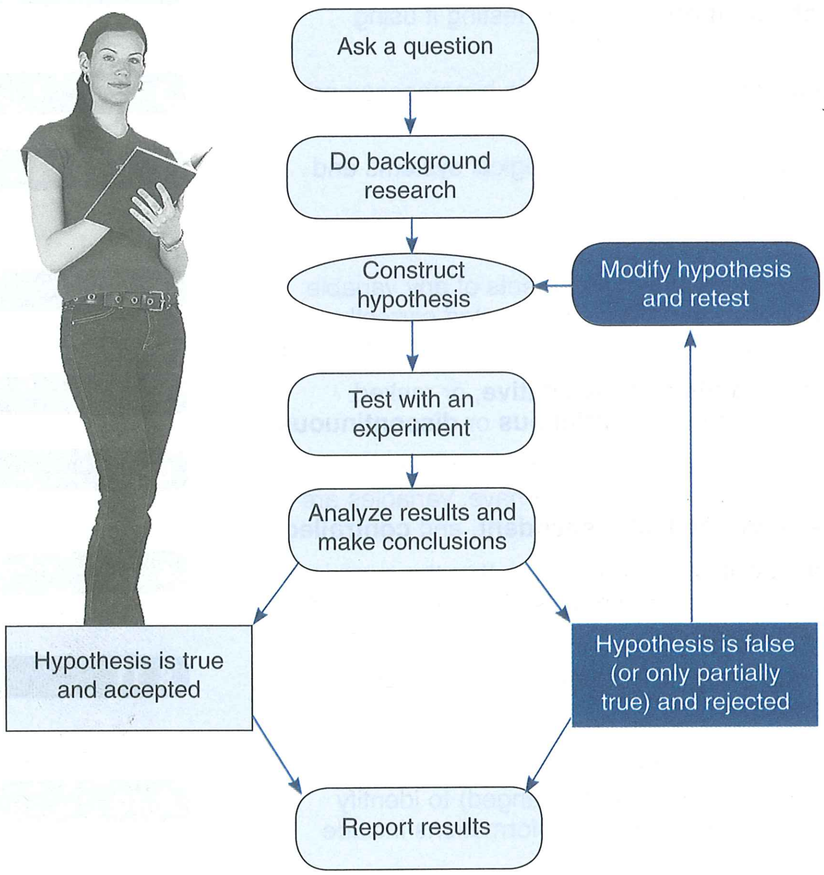
Key Idea: The scientific method involves making a hypothesis based on observation, and testing it using carefully controlled experiments.

What is a hypothesis?

A **hypothesis** is a tentative explanation for an observation. It can be tested by experimentation. The hypothesis can be accepted or rejected based on the findings of the investigation.

Features of a sound hypothesis:

- It is based on observations and prior knowledge.
- It offers a possible explanation for an observation.
- It is written as a definite statement, not as a question.
- It has only one independent variable.
- It leads to predictions about a system.
- It can be tested.



Testing a hypothesis

A hypothesis needs to be tested using sound methodology. Features of a sound method include:

- It is repeatable. Another person should be able to carry out the method and achieve the same results as the initial investigation.
- It tests the validity of the hypothesis.
- It includes a control which does not receive the treatment.
- All variables are controlled where possible.
- The method includes a dependent and independent variable.
- Only the independent variable is changed (manipulated) between treatment groups.
- A hypothesis may be rejected or modified at a later date as new information from later investigations is revealed.

The null hypothesis

Every hypothesis has a corresponding null hypothesis, which is a hypothesis of no difference or no effect.

- A null hypothesis enables a hypothesis to be tested using statistical tests.
- If the results of an experiment are statistically significant, the null hypothesis can be rejected.
- If a hypothesis is accepted, anyone should be able to test the predictions with the same methods and get a similar result each time.

1. What is a hypothesis? ______________________________

____

2. Why can an accepted hypothesis be rejected at a later date? ______________________________

____

3. Why is it important that a method being used to test a hypothesis is repeatable? ______________________________

____

____

2 Systems and System Models

Key Idea: Scientists use models to learn about biological systems. Models usually study one small part of a system, so that the system can be more easily understood.

A **system** is a set of interrelated components that work together. Energy flow in ecosystems (such as the one on the right), gene regulation, interactions between organ systems, and feedback mechanisms are all examples of systems studied in biology.

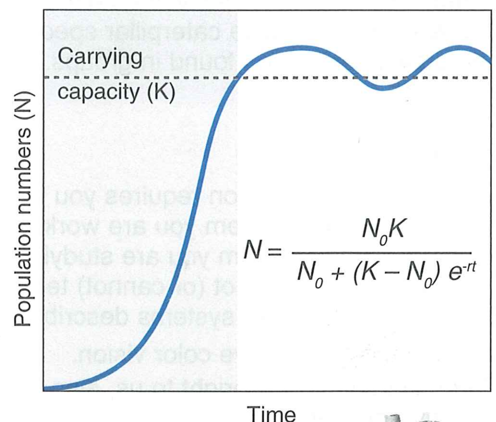
Scientists often used models to learn about biological systems. A **model** is a representation of a system, and is useful for breaking a complex system down into smaller parts that can be studied more easily. Often only part of a system is modelled. As scientists gather more information about a system, more data can be put into the model so that eventually it represents the real system more closely.

Modeling data

There are many different ways to model data. Often seeing data presented in different ways can help to understand it better. Some common examples of models are shown here.

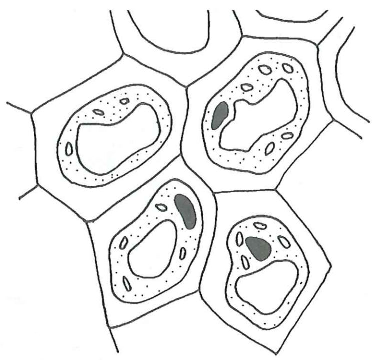
Mathematical models

Displaying data in a graph or as a mathematical equation, as shown below for logistic growth, often helps us to see relationships between different parts of a system.

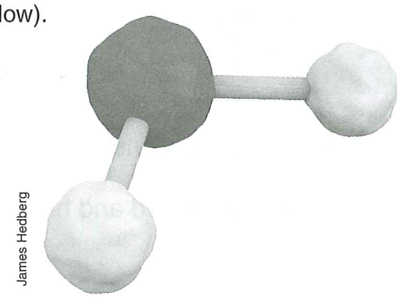


Visual models

Visual models can include drawings, such as these plant cells on the right.

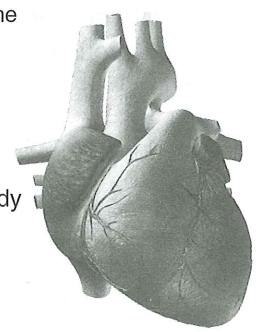


Three dimensional models can be made out of materials such as modeling clay and ice-cream sticks, like this model of a water molecule (below).



Analogy

An analogy is a comparison between two things. Sometimes comparing a biological system to an everyday object can help us to understand it better. For example, the heart pumps blood around the body in blood vessels in much the same way a fire truck pumps water from a fire hydrant through a hose.



1. What is a system? ____________________

2. (a) What is a model? ____________________

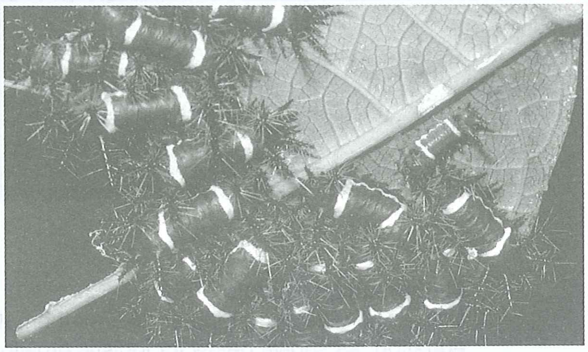
   (b) Why do scientists often study one part of a system rather than the whole system? ____________________

3 Observations and Assumptions

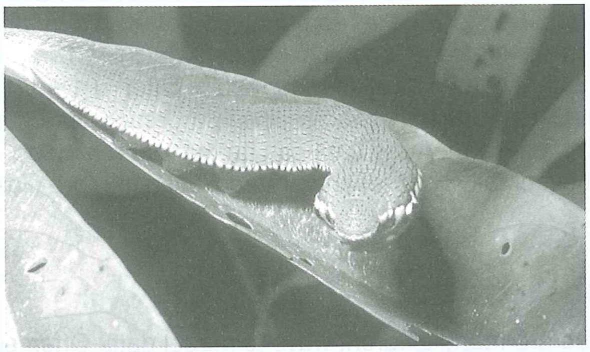
Key Idea: Observations are the basis for forming hypotheses and making predictions about systems. An assumption is something that is accepted as true.

Observations

An observation is watching or noticing what is happening. Observation is the basis for forming hypotheses and making predictions. An observation may generate a number of hypotheses, and each hypothesis will lead to one or more predictions, which can be tested by further investigation.



Observation 1: Some caterpillar species are brightly colored and appear to be highly visible to predators such as insectivorous birds. Predators appear to avoid these caterpillar species. These caterpillars are often found in groups.



Observation 2: Some caterpillar species have excellent camouflage. When alerted to danger they are difficult to see because they blend into the background. These caterpillars are usually found alone.

Assumptions

Any biological investigation requires you to make **assumptions** about the biological system you are working with. Assumptions are features of the system you are studying that you assume to be true but that you do not (or cannot) test. Some assumptions about the two caterpillar systems described above include:

- Insect eating birds have color vision.
- Caterpillars that look bright to us, also appear bright to insectivorous birds.
- Insectivorous birds can learn about the tastiness of prey by eating them.

1. Read the two observations about the caterpillars above and then answer the following questions:

   (a) Generate a hypothesis to explain the observation that some caterpillars are brightly colored and highly visible while others are camouflaged and blend into their surroundings:

   Hypothesis: ______________________________

   ____

   ____

   (b) Describe one of the **assumptions** being made in your hypothesis: ______________________________

   ____

   (c) Generate a **prediction** about the behavior of insect eating birds towards caterpillars: ______________________________

   ____

   ____

4 Accuracy and Precision

Key Idea: Accuracy refers to the correctness of a measurement (how true it is to the real value). Precision refers to how close the measurements are to each other.

The terms accuracy and precision are two terms that are often used when talking about scientific measurements.

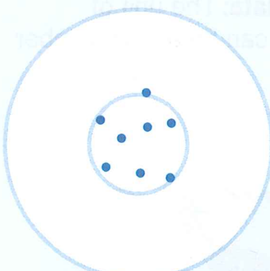
Accuracy refers to how close a measured value is to its true value. Simply put, it is the correctness of the measurement.

Precision refers to the closeness of repeated measurements to each other, i.e. the ability to be exact.

For example, a digital device, such as a pH meter, will give very precise measurements, but its accuracy depends on correct calibration.

Using the analogy of a target, repeated measurements are compared to arrows being shot at a target. This analogy can be useful when thinking about the difference between accuracy and precision.

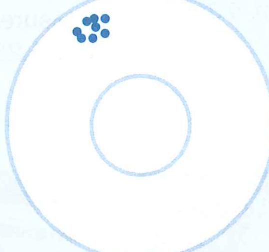
Accurate but imprecise



The measurements are all close to the true value but quite spread apart.

Analogy: The arrows are all close to the bullseye.

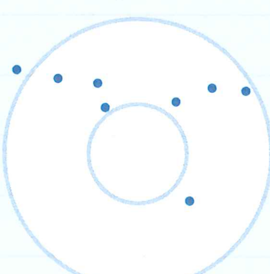
Precise but inaccurate



The measurements are all clustered close together but not close to the true value.

Analogy: The arrows are all clustered close together but not near the bullseye.

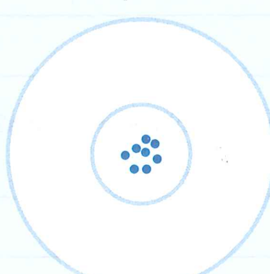
Inaccurate and imprecise



The measurements are all far apart and not close to the true value.

Analogy: The arrows are spread around the target.

Accurate and precise



The measurements are all close to the true value and also clustered close together.

Analogy: The arrows are clustered close together near the bullseye.

When measuring scientific data, it is important to take measurements that are both accurate and precise. Taking care with your measurements and observations will help to insure that the sample data you collect will be close to the true value of that measured variable in the wider population.

1. What is accuracy?

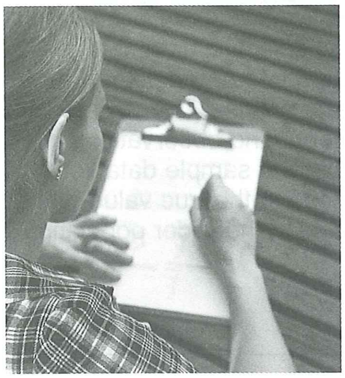
2. What is precision?

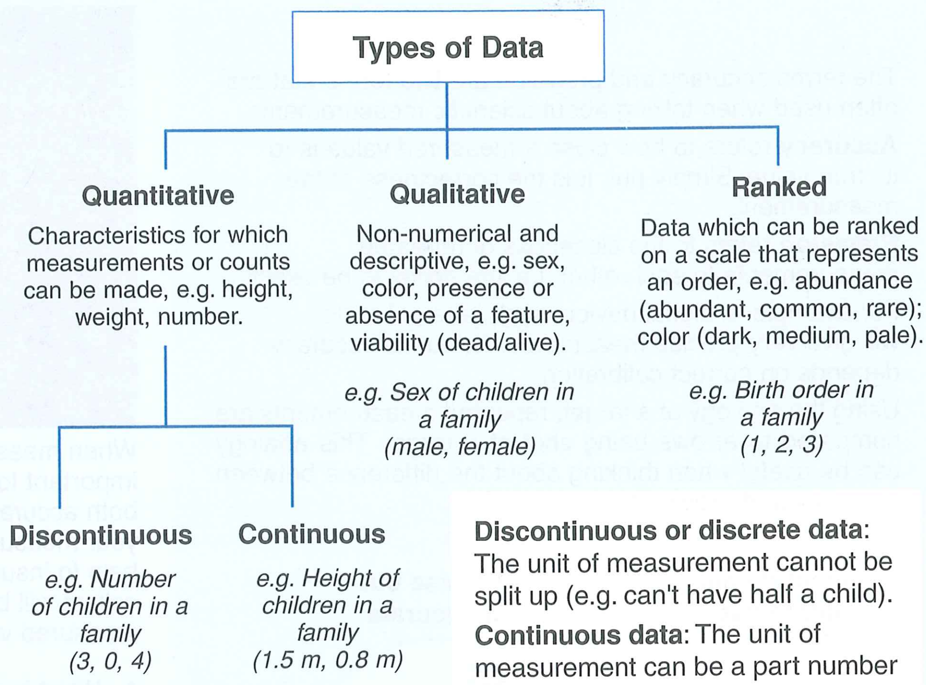
3. Why are precise but inaccurate measurements not helpful in a biological investigation?

5 Types of Data

Key Idea: Data is information collected during an investigation. Data may be quantitative, qualitative, or ranked.

Data is information collected during an investigation. Data may be quantitative, qualitative, or ranked. When planning a biological investigation, it is important to consider the type of data that will be collected. It is best to collect quantitative or numerical data, because it is easier to analyze it objectively (without bias).



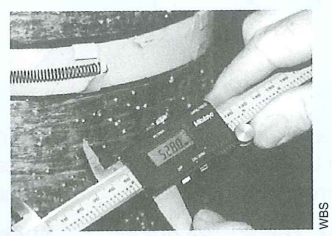


Discontinuous or discrete data: The unit of measurement cannot be split up (e.g. can't have half a child).

Continuous data: The unit of measurement can be a part number (e.g. 5.25 kg).


A: Skin color


B: Eggs per nest



C: Tree trunk diameter

1. For each of the photographic examples A-C above, classify the data as quantitative, ranked, or qualitative:

   (a) Skin color: ______________________________

   (b) Number of eggs per nest: ______________________________

   (c) Tree trunk diameter: ______________________________

2. Why is it best to collect quantitative data where possible in biological studies? ______________________________

   ____

   ____

   ____

3. Give an example of data that could not be collected quantitatively and explain your answer:

   ____

   ____

   ____

6 Variables and Controls

Key Idea: Variables may be dependent, independent, or controlled. Controls make sure an experiment is running properly.

Types of Variables

A **variable** is a factor that can be changed during an experiment (e.g. temperature). Investigations often look at how changing one variable affects another.

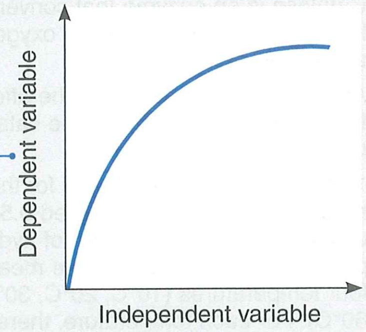
There are several types of variables:

- Independent
- Dependent
- Controlled

Only one variable should be changed at a time. Any changes seen are a result of the changed variable.

Remember! The dependent variable is 'dependent' on the independent variable.

Example: *When heating water, the temperature of the water depends on the time it is heated for. Temperature (dependent variable) depends on time (independent variable).*



Dependent variable

- Measured during the investigation.
- Recorded on the y axis of the graph.

Independent variable

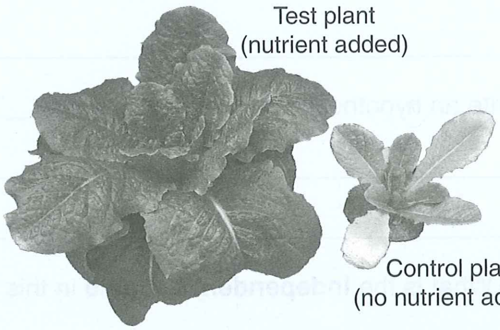
- Set by the experimenter, it is the variable that is changed.
- Recorded on the graph's x axis.

Controlled variable

- Factors that are kept the same.

Experimental Controls

- A **control** is the standard or reference treatment in an experiment. Controls make sure that the results of an experiment are due to the variable being tested (e.g. nutrient level) and not due to another factor (e.g. equipment not working correctly).
- A control is identical to the original experiment except it lacks the altered variable. The control undergoes the same preparation, experimental conditions, observations, measurements, and analysis as the test group.
- If the control works as expected, it means the experiment has run correctly, and the results are due to the effect of the variable being tested.



An experiment was designed to test the effect of a nutrient on plant growth. The control plant had no nutrient added to it. Its growth sets the baseline for the experiment. Any growth in the test plant above that seen in the control plant is due to the presence of the nutrient.

1. What is the difference between a dependent variable and an independent variable? ______________________

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2. Why should experiments include a control? ______________________

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7 A Case Study: Catalase Activity

Key Idea: A simple experiment to test a hypothesis involves manipulating one variable (the independent variable) and recording the response.

Investigation: catalase activity

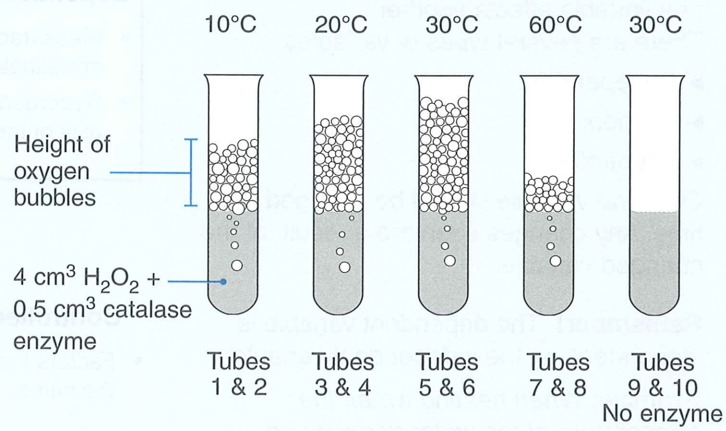
Catalase is an enzyme that converts hydrogen peroxide (H_2O_2) to oxygen and water.

An experiment investigated the effect of temperature on the rate of the catalase reaction.

10 cm^3 test tubes were used for the reactions, each tube contained 0.5 cm^3 of catalase enzyme and 4 cm^3 of hydrogen peroxide. Reaction rates were measured at four temperatures (10°C, 20°C, 30°C, and 60°C). For each temperature, there were two reaction tubes (e.g. tubes 1 and 2 were both kept at 10°C).

The height of oxygen bubbles present after one minute of reaction was used as a measure of the reaction rate; a faster reaction rate produced more bubbles than a slower reaction rate. The entire experiment, was repeated on two separate days.

$$H_2O_{2\,(l)} \xrightarrow{Catalase} H_2O_{(l)} + O_{2\,(g)}$$



1. Write a suitable aim for this experiment: ______________________________

____

____

2. Write an hypothesis for this experiment: ______________________________

____

____

3. (a) What is the **independent variable** in this experiment? ______________________________

(b) What is the range of values for the independent variable? ______________________________

(c) Name the unit for the independent variable: ______________________________

(d) List the equipment needed to set the independent variable, and describe how it was used:

____

____

4. (a) What is the **dependent variable** in this experiment? ______________________________

(b) Name the unit for the dependent variable: ______________________________

(c) List the equipment needed to measure the dependent variable, and describe how it was used:

____

____

5. Which tubes are the control for this experiment? ______________________________

8 Recording Results

Key Idea: Accurately recording results makes it easier to understand and analyze your data later. A table is a good way to record data.

Recording your results accurately is very important in an experiment. Analyzing and understanding your data is easier when you have recorded your results accurately, and in an organized way.

A table is often the best way to record and present your results. Tables can also be useful for showing calculated values (such as rates and means).

An example of a table for recording results is shown below. It relates to an investigation looking at the growth of plants at three pH levels, but it represents a relatively standardized layout which you can adapt for your own investigations.

Dependent variable and its units

Space for repeats of the experimental design (in this case, three trials).

The labels on the columns and rows are chosen to represent the design features of the investigation.

Space for three plants at each pH

The range of values for the **independent variable** are in this column

Recordings of the dependent variable

Space for calculated means

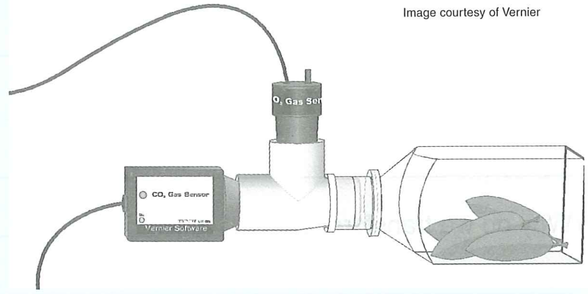
		Trial 1 (plant mass in grams)						Trial 2 (plant mass in grams)						Trial 3 (plant mass in grams)					
		Day No.						Day No.						Day No.					
		0	2	4	6	8	10	0	2	4	6	8	10	0	2	4	6	8	10
pH 3	1	0.5	1.1																
	2	0.6	1.2																
	3	0.7	1.3																
	Mean	0.6	1.2																
pH 5	1	0.6	1.4																
	2	0.8	1.7																
	3	0.5	1.9																
	Mean	0.6	1.7																
pH 7	1	0.7	1.3																
	2	0.8	1.3																
	3	0.4	1.7																
	Mean	0.6	1.4																

1. On a separate piece of paper page, design a table to record the data you would collect from the case study below. Include room for individual results and averages from the three set ups. Staple or paste it into your workbook once you have finished. You can use the table above as a guide to help you.

Case study:
Carbon dioxide levels in a respiration chamber

A datalogger was used to monitor the concentrations of carbon dioxide (CO_2) in respiration chambers containing five green leaves from one plant species. The entire study was performed in conditions of full light and involved three identical set-ups. The CO_2 concentrations were measured every minute, over a period of ten minutes, using a CO_2 sensor. A mean CO_2 concentration (for the three set-ups) was calculated. The study was carried out two more times, two days apart.

Image courtesy of Vernier



9 Transforming Raw Data

Key Idea: Unprocessed data is called raw data. Data often needs to be transformed to make it easier to understand and to identify important features.

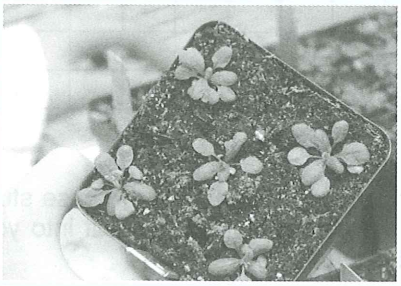
The data collected by measuring or counting in the field or laboratory are called **raw data.** They often need to be changed (**transformed**) into a form that makes it easier to identify important features of the data (e.g. trends). Basic calculations, such as totals (the sum of all data values for a variable), are commonly used to compare replicates or are performed before other data transformations can be carried out. Some common data transformations include tally charts, percentages, and rates. These are explained below.

Tally Chart

Records the number of times a value occurs in a data set

HEIGHT (cm)	TALLY	TOTAL
0-0.99	|||	3
1-1.99	~~||||~~ |	6
2-2.99	~~||||~~ ~~||||~~	10
3-3.99	~~||||~~ ~~||||~~ ||	12
4-4.99	|||	3
5-5.99	||	2

- A useful first step in analysis; a neatly constructed tally chart doubles as a simple histogram.
- Cross out each value on the list as you tally it to prevent double entries.



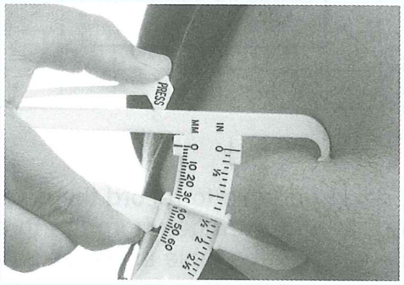
Example: Height of 6 day old seedlings

Percentages

Expressed as a fraction of 100

Men	Body mass (kg)	Lean body mass (kg)	% lean body mass
Athlete	70	60	85.7
Lean	68	56	82.3
Normal weight	83	65	78.3
Overweight	96	62	64.6
Obese	125	65	52.0

- Percentages provide a clear expression of what proportion of data fall into any particular category, e.g. for pie graphs.
- Allows meaningful comparison between different samples.
- Useful to monitor change (e.g. % increase from one year to the next).



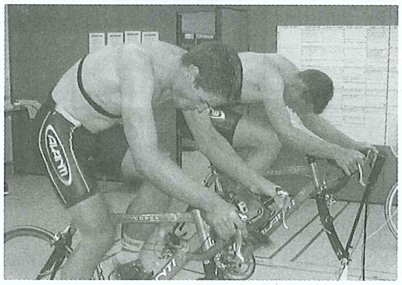
Example: Percentage of lean body mass in men

Rates

Expressed as a measure per unit time

Time (minutes)	Cumulative sweat loss (mL)	Rate of sweat loss (mL min^{-1})
0	0	0
10	50	5
20	130	8
30	220	9
60	560	11.3

- Rates show how a variable changes over a standard time period (e.g. one second, one minute, or one hour).
- Rates allow meaningful comparison of data that may have been recorded over different time periods.



Example: Rate of sweat loss during exercise in cyclists

1. What is raw data? ______________________________

____

2. (a) What is data transformation? ______________________________

____

(b) Why do we transform data? ______________________________

____

____

10 Practicing Data Transformation

Key Idea: Percentages, rates, and frequencies are commonly used data transformations.

1. Complete the transformations for each of the tables on the right. The first value, and their working, is provided for each example.

(a) TABLE: Incidence of red clover in different areas:

Working: $124 \div 159 = 0.78 = 78\%$

This is the number of red clover out of the total.

Incidence of red and white clover in different areas

Clover plant type	Frost free area		Frost prone area		Totals
	Number	%	Number	%	
Red	124	78	26		
White	35		115		
Total	159				

(b) TABLE: Plant water loss using a bubble potometer:

Working: $(9.0 - 8.0) \div 5 \text{ min} = 0.2$

This is the distance the bubble moved over the first 5 minutes. Note that there is no data entry possible for the first reading (0 min) because no difference can be calculated.

Plant water loss using a bubble potometer

Time (min)	Pipette arm reading (cm^3)	Plant water loss ($cm^3 \ min^{-1}$)
0	9.0	–
5	8.0	0.2
10	7.2	
15	6.2	
20	4.9	

(c) TABLE: Frequency of size classes in a sample of eels:

Working: $(7 \div 270) \times 100 = 2.6\ \%$

This is the number of individuals out of the total that appear in the size class 0-50 mm. The relative frequency is rounded to one decimal place.

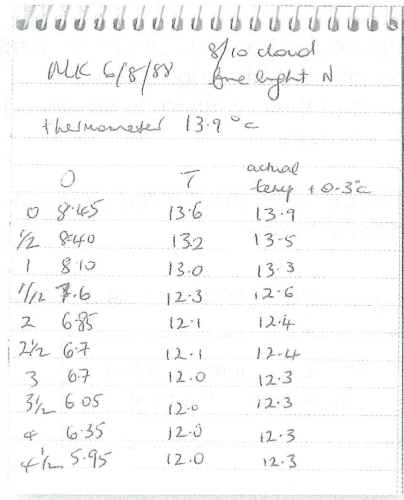
Frequency of size classes in a sample of eels

Size class (mm)	Frequency	Relative frequency (%)
0-50	7	2.6
50-99	23	
100-149	59	
150-199	98	
200-249	50	
250-299	30	
300-349	3	
Total	270	

11 Constructing Tables

Key Idea: Tables are used to record and summarize data. Tables allow relationships and trends in data to be more easily recognized.

- Tables are used to record data during an investigation. Your log book should present neatly tabulated data (right).
- Tables allow a large amount of information to be condensed, and can provide a summary of the results.
- Presenting data in tables allows you to organize your data in a way that allows you to more easily see the relationships and trends.
- Columns can be provided to display the results of any data transformations such as rates. Basic descriptive statistics (such as mean or standard deviation) may also be included.
- Complex data sets tend to be graphed rather than tabulated.



Features of tables

Tables should have an accurate, descriptive title. Number tables consecutively through a report.

Heading and subheadings identify each set of data and show units of measurement.

Independent variable in the left column.

Table 1: Length and growth of the third internode of bean plants receiving three different hormone treatments.

Treatment	Sample size	Mean rate of internode growth (mm day^{-1})	Mean internode length (mm)	Mean mass of tissue added (g day^{-1})
Control	50	0.60	32.3	0.36
Hormone 1	46	1.52	41.6	0.51
Hormone 2	98	0.82	38.4	0.56
Hormone 3	85	2.06	50.2	0.68

Control values should be placed at the beginning of the table.

Each row should show a different experimental treatment, organism, sampling site etc.

Columns for comparison should be placed alongside each other. Show values only to the level of significance allowable by your measuring technique.

Organize the columns so that each category of like numbers or attributes is listed vertically.

1. What are two advantages of using a table format for data presentation?

(a) ____

____

(b) ____

____

2. Why might you tabulate data before you presented it in a graph? ______________________

____

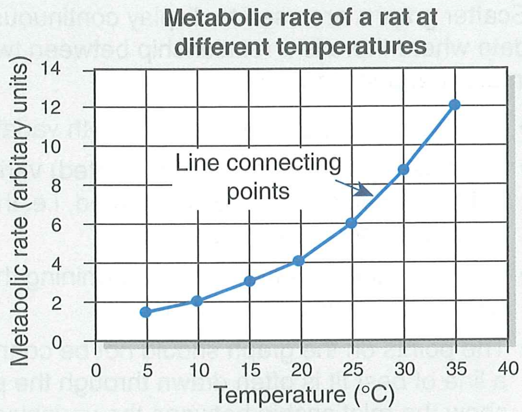
____

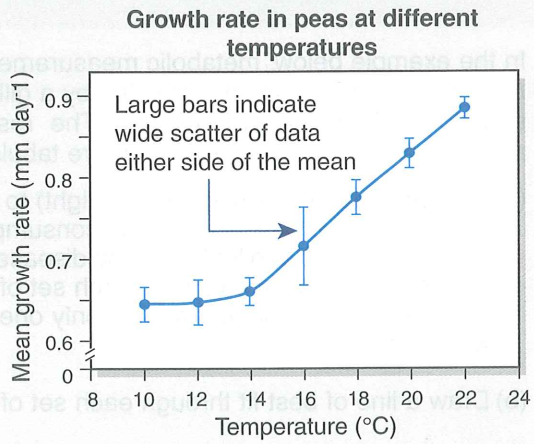
12 Drawing Line Graphs

Key Idea: Line graphs are used to plot continuous data when one variable (the independent variable) affects another, the dependent variable.

Graphs provide a way to visually see data trends. Line graphs are used when one variable (the independent variable) affects another, the dependent variable. Important features of line graphs are:

- The data must be continuous for both variables.
- The dependent variable is usually a biological response.
- The independent variable is often time or the experimental treatment.
- Where there is a trend, a line of best fit is usually plotted to show the relationship.
- If fluctuations in the data are likely to be important (e.g. environmental data) the data points are usually connected directly (point to point), as shown top right.
- Line graphs may be drawn with measure of error (bottom right). The data are presented as points (the calculated means), with bars above and below, indicating a measure of variability or spread in the data (e.g. standard error or standard deviation).
- Where no error value has been calculated, the scatter can be shown by plotting the individual data points vertically above and below the mean. Bars are not used to indicate the range of raw values in a data set.

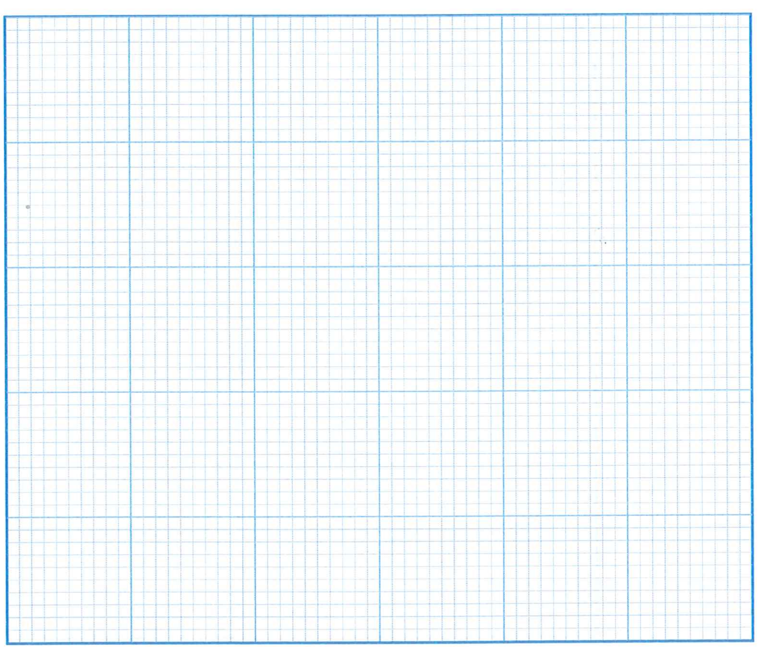




1. The results (shown right) were collected in a study investigating the effect of temperature on the activity of an enzyme.

(a) Using the results provided, plot a **line graph** on the grid below:

(b) Estimate the rate of reaction at 15°C: _______________



Lab Notebook

An enzyme's activity at different temperatures

Temperature (°C)	Rate of reaction (mg of product formed per minute)
10	1.0
20	2.1
30	3.2
35	3.7
40	4.1
45	3.7
50	2.7
60	0

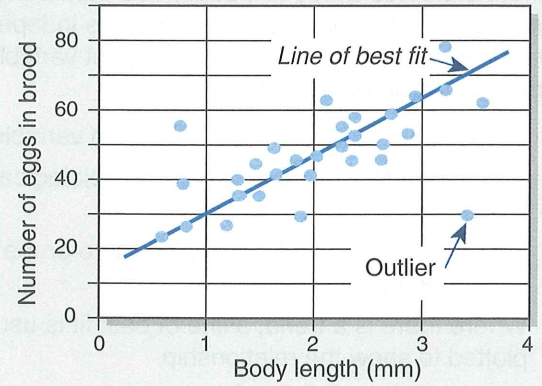
13 Drawing Scatter Graphs

Key Idea: Scatter graphs are used to plot continuous data where there is a relationship between two interdependent variables.

Scatter graphs are used to display continuous data where there is a relationship between two interdependent variables.

- The data must be continuous for both variables.
- There is no independent (manipulated) variable, but the variables are often correlated, i.e. they vary together in some predictable way.
- Scatter graphs are useful for determining the relationship between two variables.
- The points on the graph should not be connected, but a line of best fit is often drawn through the points to show the relationship between the variables.

Body length vs brood size in *Daphnia*



1. In the example below, metabolic measurements were taken from seven Antarctic fish *Pagothenia borchgrevinski.* The fish are affected by a gill disease, which increases the thickness of the gas exchange surfaces and affects oxygen uptake. The results of oxygen consumption of fish with varying amounts of affected gill (at rest and swimming) are tabulated below.

   (a) Plot the data on the grid (bottom right) to show the relationship between oxygen consumption and the amount of gill affected by disease. Use different symbols or colors for each set of data (at rest and swimming), and use only one scale for oxygen consumption.

   (b) Draw a line of best fit through each set of points.

2. Describe the relationship between the amount of gill affected and oxygen consumption in the fish:

   (a) For the **at rest** data set:

   ____

   ____

   ____

   ____

   ____

   ____

   (b) For the **swimming** data set:

   ____

   ____

   ____

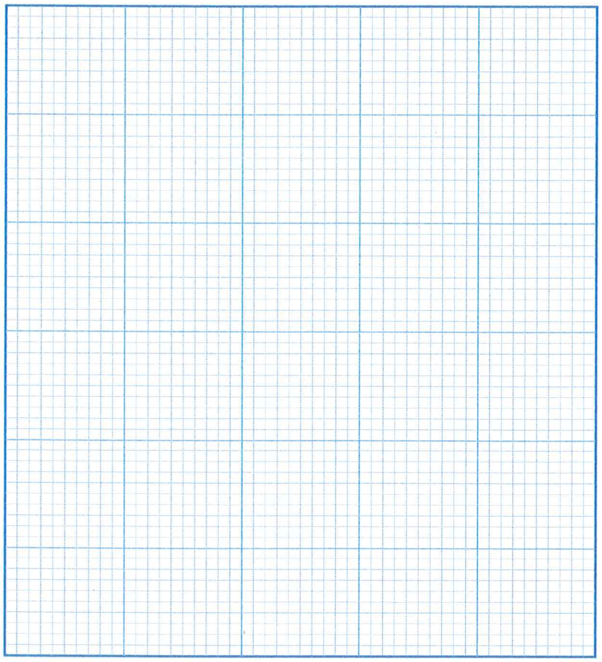
   ____

   ____

   ____

Oxygen consumption of fish with affected gills

Fish number	Percentage of gill affected	Oxygen consumption ($cm^3\ g^{-1}\ h^{-1}$)	
		At rest	Swimming
1	0	0.05	0.29
2	95	0.04	0.11
3	60	0.04	0.14
4	30	0.05	0.22
5	90	0.05	0.08
6	65	0.04	0.18
7	45	0.04	0.20

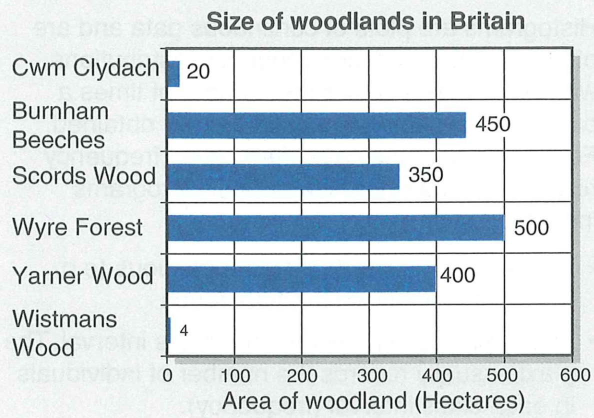


14 Drawing Bar Graphs

Key Idea: Bar graphs are used to plot data that is non-numerical or discrete for at least one variable.

Bar graphs are appropriate for data that is non-numerical and discrete for at least one variable.

- There are no dependent or independent variables.
- Data is collected for discontinuous, non-numerical categories (e.g. place, color, and species), so the bars do not touch.
- Multiple sets of data can be displayed side by side for direct comparison.
- Axes may be reversed, i.e. the bars can be vertical or horizontal. When they are vertical, these graphs are called column graphs.



1. Counts of eight mollusk species were made from a series of quadrat samples at two sites on a rocky shore. The summary data are presented on the right.
   (a) Tabulate the mean (average) numbers per square meter at each site in the table (below).
   (b) Plot a **bar graph** of the tabulated data on the grid below. For each species, plot the data from both sites side by side using different colors to distinguish the two sites.

Field data notebook

Total counts at site 1 (11 quadrats) and site 2 (10 quadrats). Quadrats 1 sq m.

Species	Site 1 No (m^{-2}) Total	Site 1 Mean	Site 2 No (m^{-2}) Total	Site 2 Mean
Ornate limpet	232	21	299	30
Radiate limpet	68	6	344	34
Limpet sp. A	420	38	0	0
Cats-eye	68	6	16	2
Top shell	16	2	43	4
Limpet sp. B	628	57	389	39
Limpet sp. C	0	0	22	2
Chiton	12	1	30	3

Average abundance of 8 mollusk species from two sites along a rocky shore.

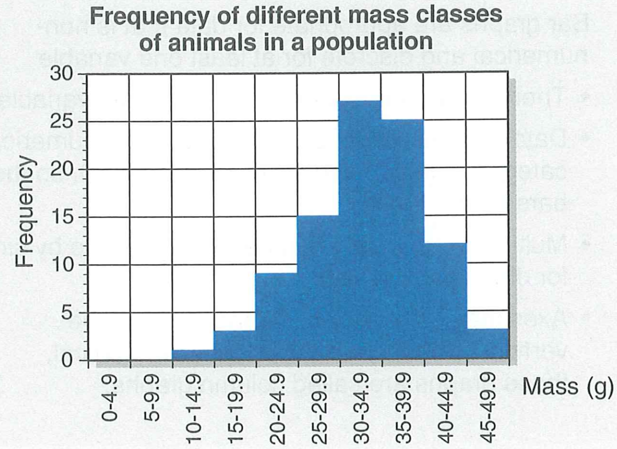
Species	Mean (no. m^{-2})	
	Site 1	Site 2

15 Drawing Histograms

Key Idea: Histograms graphically show the frequency distribution of continuous data.

Histograms are plots of continuous data and are often used to represent frequency distributions, where the y-axis shows the number of times a particular measurement or value was obtained. For this reason, they are often called frequency histograms. Important features of histograms include:

- The data are numerical and continuous (e.g. height or weight), so the bars touch.
- The x-axis usually records the class interval. The y-axis usually records the number of individuals in each class interval (frequency).



1. The weight data provided below were recorded from 95 individuals (male and female), older than 17 years.
   (a) Create a tally chart (frequency table) in the table provided (right). An example of the tally for the weight grouping 55-59.9 kg has been completed for you. Note that the raw data values, once they are recorded as counts on the tally chart, are crossed off the data set in the notebook. It is important to do this in order to prevent data entry errors.
   (b) Plot a **frequency histogram** of the tallied data on the grid below.

Weight (kg)	Tally	Total
45-49.9		
50-54.9		
55-59.9	𝍸 II	7
60-64.9		
70-74.9		
75-79.9		
80-84.9		
85-89.9		
90-94.9		
95-99.9		
100-104.9		
105-109.9		

Lab notebook

Weight (in kg) of 95 individuals

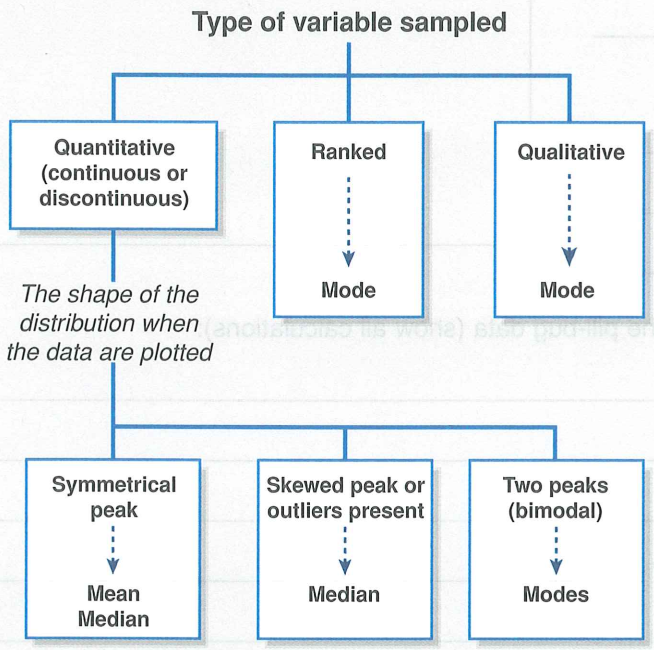
63.4	81.2	65
~~56.5~~	83.3	75.6
84	95	76.8
81.5	105.5	67.8
73.4	82	68.3
~~56~~	73.5	63.5
60.4	75.2	~~58~~
83.5	63	~~58.5~~
82	70.4	50
61	82.2	92
~~55.2~~	87.8	91.5
48	86.5	88.3
53.5	85.5	81
63.8	87	72
69	98	66.5
82.8	71	61.5
68.5	76	66
67.2	72.5	65.5
82.5	61	67.4
83	60.5	73
78.4	67	67
76.5	86	71
83.4	85	70.5
77.5	93.5	65.5
77	62	68
87	62.5	90
89	63	83.5
93.4	60	73
83	71.5	66
80	73.8	~~57.5~~
76	77.5	76
~~56~~	74	

16 Descriptive Statistics and the Spread of Data

Key Idea: Descriptive statistics are used to summarize a data set and describe its basic features. The type of statistic calculated depends on the type of data and its distribution.

Descriptive statistics

When we describe a set of data, it is usual to give a measure of **central tendency**. This is a single value identifying the central position within that set of data. **Descriptive statistics**, such as mean, median, and mode, are all valid measures of central tendency depending of the type of data and its distribution. They help to summarize features of the data, so are often called summary statistics. The appropriate statistic for different types of data variables and their distributions is described below.



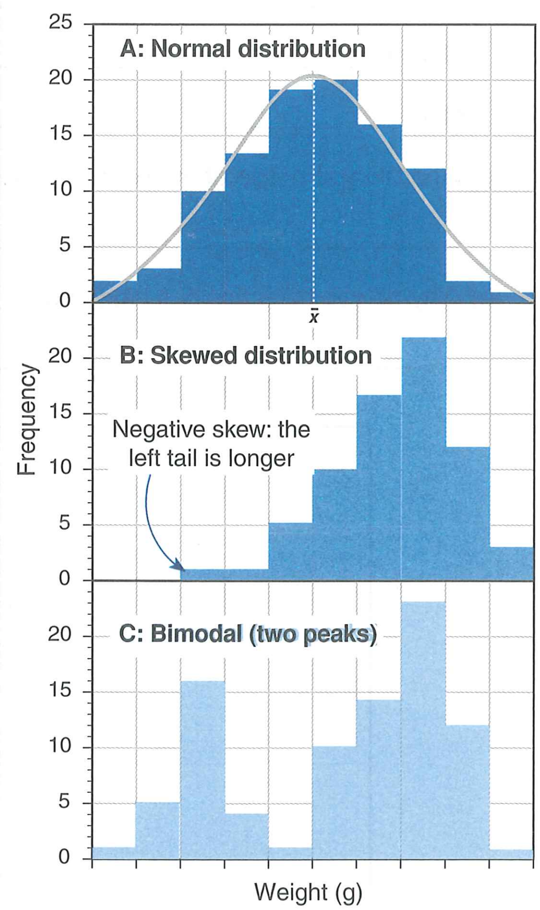
Statistic	Definition and when to use it	How to calculate it
Mean	• The average of all data entries. • Measure of central tendency for normally distributed data.	• Add up all the data entries. • Divide by the total number of data entries.
Median	• The middle value when data entries are placed in rank order. • A good measure of central tendency for skewed distributions.	• Arrange the data in increasing rank order. • Identify the middle value. • For an even number of entries, find the mid point of the two middle values.
Mode	• The most common data value. • Suitable for bimodal distributions and qualitative data.	• Identify the category with the highest number of data entries using a tally chart or a bar graph.

Distribution of data

Variability in continuous data is often displayed as a frequency distribution. There are several types of distribution.

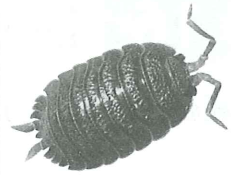
- Normal distribution (A): Data has a symmetrical spread about the mean. It has a classical bell shape when plotted.
- Skewed data (B): Data is not centered around the middle but has a "tail" to the left or right.
- Bimodal data (C): Data which has two peaks.

The shape of the distribution will determine which statistic (mean, median, or mode) should be used to describe the central tendency of the sample data.



1. The mass of 15 pill-bugs is shown in the table right.

Pill-bug mass (mg)					
10.1	8.2	8.5	8.0	8.8	8.8
7.8	6.7	7.7	8.8	9.8	8.5
8.8	8.9	6.2	8.8	8.4	8.9



(a) Draw up a tally chart in the space provided on the right for the pill-bug masses.

(b) On the graph paper at the bottom of the page, draw a frequency histogram for the pill-bug data.

(c) What type of distribution does the data have?

(d) What would be the best measure of central tendency in the pill-bug data set (mean, median, or mode)?

(e) Explain why you chose your answer in (d).

(f) Calculate the mean, median, and mode for the pill-bug data (show all calculations):

Mean:

Median:

Mode:

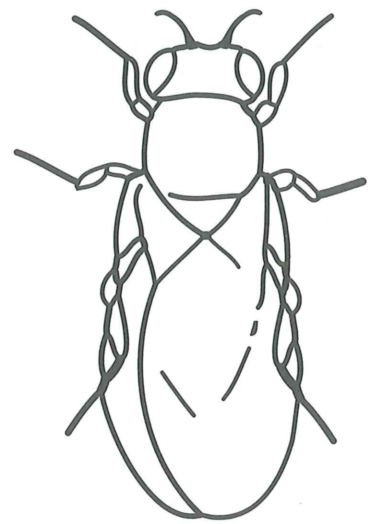
(g) What do you notice about your results in (f)?

(h) Why do you think this has happened?

17 Biological Drawings

Key Idea: Good biological drawings provide an accurate record of the specimen you are studying, and enable you to make a record of its important features.

- Drawing is a very important skill to have in biology. Drawings record what a specimen looks like, and gives you an opportunity to record its important features. Often drawing something will help you remember its features at a later date (e.g. in a test).
- Biological drawings require you to pay attention to detail. It is very important that you draw what you actually see, and not what you think you should see.
- Biological drawings should include as much detail as you need to distinguish different structures and types of tissue, but avoid unnecessary detail which can make your drawing confusing.
- Attention should be given to the symmetry and proportions of your specimen. Accurate labeling, a statement of magnification or scale, the view (section type), and type of stain used (if applicable) should all be noted on your drawing.
- Some key points for making good biological drawing are described on the example below.



All drawings must include a title. Underline the title if it is a scientific name.

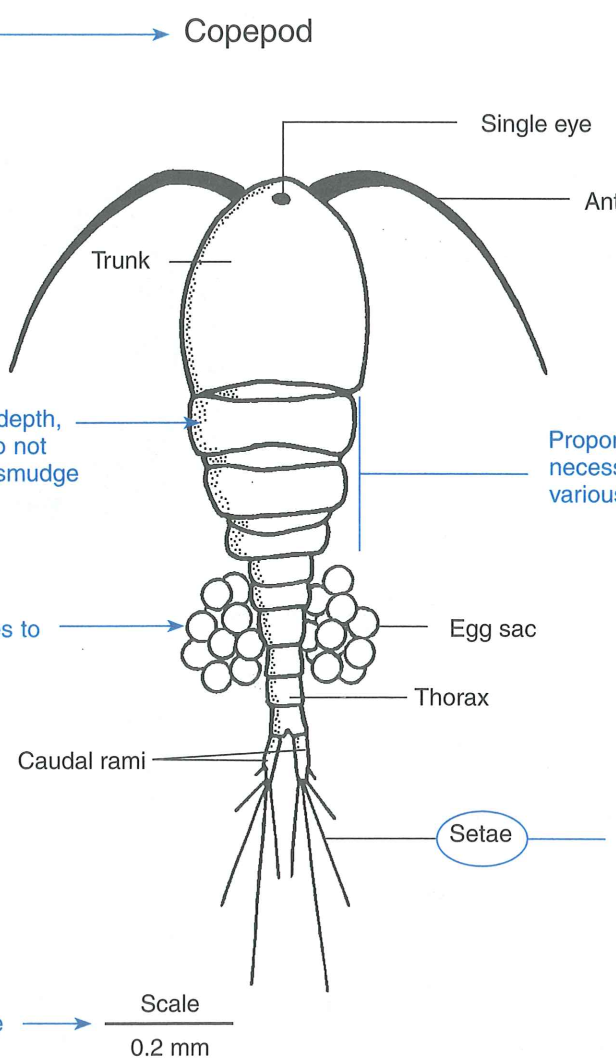
Center your drawing on the page, not in a corner. This will leave room to place labels around the drawing.

If you need to represent depth, use stippling (dotting). Do not use shading as this can smudge and obscure detail.

Use simple, narrow lines to make your drawings.

Use a sharp pencil to draw with. Make your drawing on plain white paper.

Your drawing must include a scale or magnification to indicate the size of your subject.



Proportions should be accurate. If necessary, measure the lengths of various parts with a ruler.

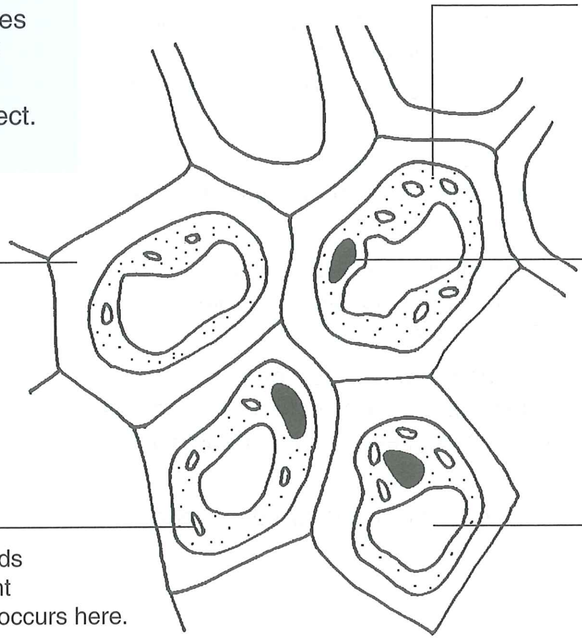
All parts of your drawing must be labelled accurately.

Labeling lines should be drawn with a ruler and should not cross over other label lines. Try to use only vertical or horizontal lines.

Annotated diagrams

Collenchyma transverse section of <u>*Helianthus*</u> stem
Magnification x 450

An annotated diagram is a diagram that includes a series of explanatory notes. These provide important or useful information about your subject.

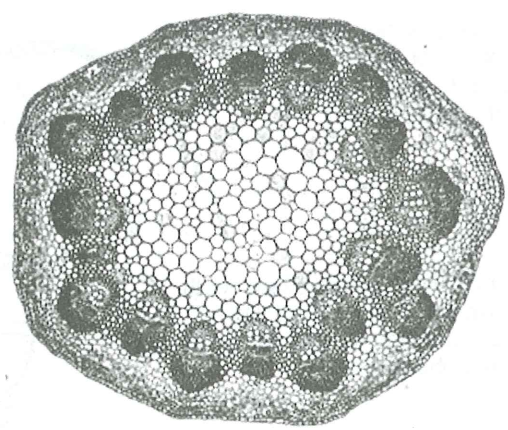


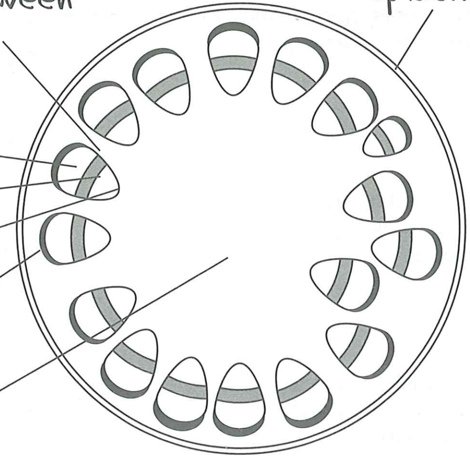
Plan diagrams

Plan diagrams are drawings made of samples viewed under a microscope at low or medium power. They are used to show the distribution of the different tissue types in a sample without any cellular detail. The tissues are identified, but no detail about the cells within them is included.

The example here shows a plan diagram produced after viewing a light micrograph of a transverse section through a dicot stem.

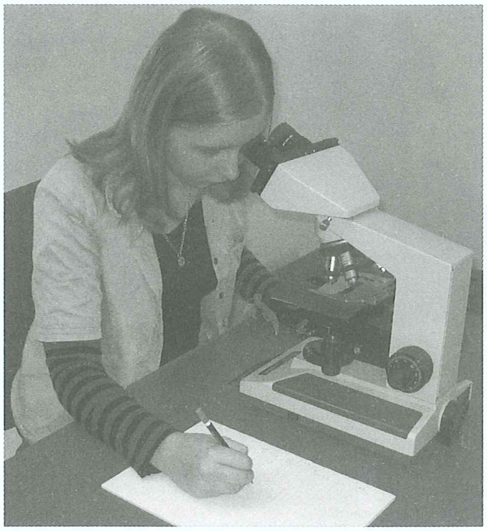
Light micrograph of a transverse section through a dicot stem.



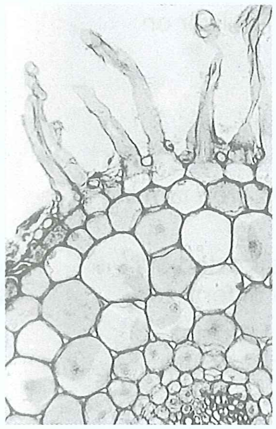


18 Practicing Biological Drawings

Key Idea: Attention to detail is vital when making accurate and useful biological drawings.

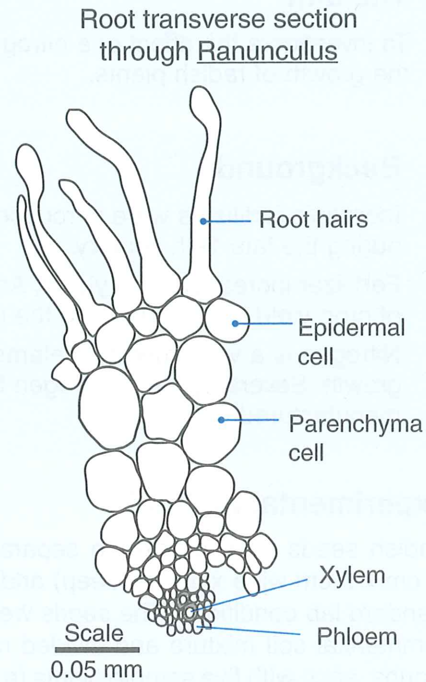


Above: Use relaxed viewing when drawing at the microscope. Use one eye (the left for right handers) to view and the right eye to look at your drawing.

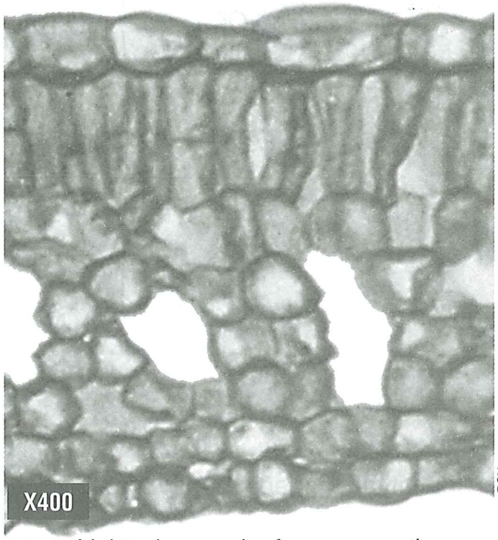


Above: Light micrograph Transveres section (TS) through a *Ranunculus* root.

Right: A biological drawing of the same section.



1. Complete the biological drawing of a cross section through a dicot leaf (below). Use the example above of the *Ranunculus* root as a guide to the detail required in your drawing



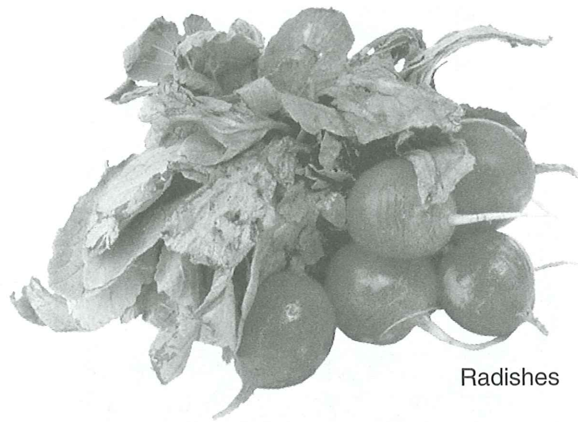
Light micrograph of a cross section through a leaf.

19 Test Your Understanding

This activity will test your understanding of science practices. Analyze the data below about the effect of fertilizer on the growth of radishes. Tabulate and graph the data, and draw conclusions about how nitrogen fertilizer effects radish growth.

The aim

To investigate the effect of a nitrogen fertilizer on the growth of radish plants.



Radishes

Background

Inorganic fertilizers were introduced to crop farming during the late 19th century.

Fertilizer increased crop yields. An estimated 50% of crop yield is attributable to the use of fertilizer.

Nitrogen is a very important element for plant growth. Several types of nitrogen fertilizers are manufactured (e.g. urea).

Experimental method

Radish seeds were planted in separate identical pots (5 cm x 5 cm wide x 10 cm deep) and kept together in standard lab conditions. The seeds were planted into a commercial soil mixture and divided randomly into six groups, each with five sample plants (a total of 30 plants in six treatments). The radishes were watered every day at 10 am and 3 pm with 500 mL per treatment per watering. Water soluble fertilizer was added to the 10 am watering on the 1st, 11th and 21st days. The fertilizer concentrations used were: 0.00, 0.06, 0.12, 0.18, 0.24, and 0.30 g L^{-1} and each treatment received a different concentration. The plants were grown for 30 days before being removed from the pots, washed, and the radish root weighed. The results are presented below.

Fertilizer concentration ($g L^{-1}$)	Sample 1	2	3	4	5
0	80.1	83.2	82.0	79.1	84.1
0.06	109.2	110.3	108.2	107.9	110.7
0.12	117.9	118.9	118.3	119.1	117.2
0.18	128.3	127.3	127.7	126.8	DNG*
0.24	23.6	140.3	139.6	137.9	141.1
0.30	122.3	121.1	122.6	121.3	123.1

*DNG = did not germinate

† Based on data from M S Jilani, *et al* Journal Agricultural Research

1. Identify the independent variable for the experiment and its range: ______________________________

____

2. Identify the dependent variable for the experiment: ______________________________

3. What is the sample size for each concentration of fertilizer? ______________________________

4. (a) One of the radishes recorded in the table on the previous page did not grow as expected and produced an extreme value. Record the **outlying value** here:

____

(b) Why should this value not be included in future calculations? ____________________

____

____

5. Use table 1 below to record the raw data from the experiment. You will need to include column and row headings and a title, and complete some simple calculations. Some headings have been entered for you.

Table 1: --

	Mass of radish root (g)						
						Total mass	Mean mass

6. The students decided to collect more data by counting the number of leaves on each radish plant at day 30. This data is presented in Table 2.
Use the space below to calculate the **mean**, **median** and **mode** for the leaf data. Add these data to table 2.

Table 2: Number of leaves on radish plant under six different fertilizer concentrations.

Fertilizer concentration (g L^{-1})	Number of leaves: Sample (n) 1	2	3	4	5	Mean	Median	Mode
0	9	9	10	8	7			
0.06	15	16	15	16	16			
0.12	16	17	17	17	16			
0.18	18	18	19	18	DNG*			
0.24	6	19	19	18	18			
0.30	18	17	18	19	19			

* DNG: Did not germinate

7. Use the grid below to draw a **line graph** of the experimental results. Plot your calculated mean mass data from Table 1, and remember to include a title and correctly labelled axes.

8. Which concentration of fertilizer appeared to produce the best growth results for radish mass?

9. Which concentration of fertilizer appeared to produce the best growth results for leaves?

10. Write a short conclusion for the entire experiment: