Chapter 2
Investigating

Unit **2B**

Figure 2.1 Investigating involves observation and performing experiments, such as preparing a DNA profile for examination

Unit content

Approaches to investigating and communicating human biology

- plan and conduct a safe investigation on a question of choice, developed from a given contextual problem
- trial a range of techniques to collect data
- analyse data using rates, percentages and frequencies
- present information using appropriate symbols, terminology and conventions
- consider experimental errors and the ramification of results that support or disprove hypotheses
- discuss different perspectives of a problem.

As explained in Chapter 1, there are two aspects to science. Firstly, science is a process of investigation, and secondly, science is the knowledge that has been obtained by investigation. Because science is a process of investigation, scientific knowledge is not fixed and unchanging. Knowledge increases as new discoveries are made, and existing knowledge may have to be modified, or even rejected, as new evidence accumulates.

In this chapter we look more closely at some of the ways that scientists investigate and the ways in which they report their findings.

What do scientists do when they investigate? What does it mean to work scientifically?

- Do you put on a white coat and work in a laboratory surrounded by intricate glassware and strange chemicals?
- Do you visit remote areas observing and collecting unusual plants and animals?
- Do you spend hours in libraries or on the Internet finding out about the work of others?
- Or, do you attend conferences and give reports using a lot of mysterious words?

To work scientifically may involve all of these things, but it may also involve none of them. Working scientifically describes a *method* of working that can be applied to many areas of study, not just science. When you work scientifically, you:

- are objective
- are systematic
- are thorough
- ask questions
- make careful observations, often involving measurements
- look for trends and relationships in observations
- may use scientific equipment to make and measure observations
- make hypotheses to explain observations
- make predictions based on hypotheses
- test hypotheses using experiments
- communicate your findings.

Scientific method

How are discoveries made? What procedures does a scientist use to gather new information?

There are no hard and fast rules, and no particular sequence of steps that must be followed, but scientific investigation usually follows a pattern that is known as the **scientific method**. The precise method will be unique to the particular circumstances, but the underlying pattern of logical thought is similar in all cases (Fig. 2.2).

Scientific investigation begins with a problem. Curiosity—about why and how things happen—is a characteristic of human nature. Curiosity raises all sorts of questions to be answered and problems to be solved. Sometimes it is difficult to know the right question to ask, but until someone asks the question, research into the answer cannot begin. For example, Louis Pasteur (1822–95) was curious about the cause of infectious disease and of fermentation. In investigating these problems he found that micro-organisms are responsible for many diseases and for fermentation. Knowing what questions to ask is one of the characteristics of a good scientist.

Having defined the problem, the scientist then begins to collect information about the problem. This may involve direct observation (for Pasteur this was looking at samples of fermenting liquid to see if they contained micro-organisms). It will almost certainly involve a review of books, scientific journals and the Internet to see what

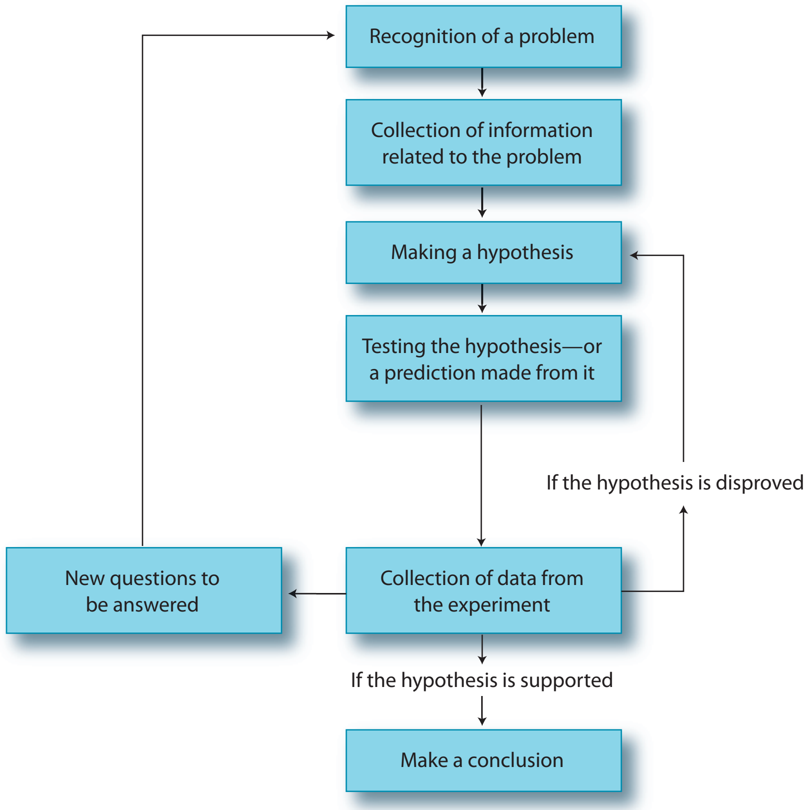


Figure 2.2 The scientific method

information relating to the problem has been collected by others. In this way, science builds on past discoveries and the scientist does not duplicate work already done by other scientists.

After collecting information related to the problem, the scientist can then make a hypothesis. A **hypothesis** is a suggested explanation for the observations that gave rise to the problem. For example, Louis Pasteur observed that certain diseases seemed to be passed on from one person to another. This gave rise to the problem of what caused these diseases. One of Pasteur's hypotheses was that micro-organisms in the air were the cause.

Having made a hypothesis, the scientist often makes a **prediction** based on the hypothesis. The scientist can reason: '*If* my hypothesis is true, *then* such and such should happen.' This is called 'if—then' reasoning. Louis Pasteur was able to say '*If* micro-organisms in the air cause disease, *then* those micro-organisms will be present in the air in hospital wards containing sick people'.

The steps in the scientific method are described in more detail at http://www.sciencebuddies.org/mentoring/project_scientific_method.shtml

The next step is to **test** the hypothesis, or a prediction made from the hypothesis, by using a suitable experiment.

During the experiment, the scientist observes and **records** all of the information from the experiment. This information is called the **data**. Whenever possible, observations are made by measurement rather than by simply recording such things as the appearance of an organism or the smell of a solution. Measurements are more likely to be free of any bias the observer may have and should not be open to interpretation. For example, if a person is described as tall, this observation will mean different things to different people. If the person is said to have a height of 185 cm, there can be no misunderstanding.

After all the data are collected the scientist can make an **interpretation** of the results. Data from a well-designed experiment will either support or disprove the hypothesis. If the hypothesis is disproved, the scientist must make a new hypothesis or modify the original hypothesis. If the scientist concludes that the hypothesis is supported, the **conclusion** is communicated to others in a report with details of the experiments and the data collected. It is important to note that the results of an experiment cannot prove a hypothesis: a hypothesis can only be *supported* or *disproved* (see Fig. 2.2).

Not all science involves experimentation. Some scientists are theorists; they propose hypotheses that may in time be tested by others. Albert Einstein worked in this way. Other scientists, such as astronomers or archaeologists, are observers because experimentation in some fields is difficult or impossible. Still others, such as taxonomists, are involved in identification and classification. However, experimentation is a very important part of science, and the majority of scientists carry out experiments at some time.

Hypotheses

A hypothesis is a tentative proposal made to explain certain observations. Any hypothesis requires investigation to collect evidence that will support the hypothesis.

A good hypothesis:

1. is usually a definite statement—not a question
2. is short—it is much easier to test a simple hypothesis than a complex one
3. has a single idea that can be tested
4. usually links two variables—for example, Pasteur's hypothesis that micro-organisms (one variable) cause disease (second variable).

Note that a hypothesis must be able to be tested. The belief that individual species were created by God, or that hip hop music is better than classical music, are not hypotheses because they cannot be tested. Science cannot test matters of religious faith or personal taste in music.

If you are proposing a hypothesis it should state what you think is the relationship between two variables. For example a student was interested in a possible link between sweating and urine production. Three hypotheses are possible:

1. 'sweating causes a decrease in urine production'
2. 'sweating increases urine production'
3. 'sweating has no effect on urine production'.

These are all valid hypotheses because they state the relationship between the two variables—sweating and urine production. 'Sweating affects urine production' would not be a good hypothesis because it does not specify the relationship between the two variables.

Eventually, if enough supporting evidence is collected and there is no evidence against the hypothesis, then the hypothesis will become a **theory**. Examples of scientific theories that have been widely accepted because they have a huge amount of evidence to support them are the atomic theory, Einstein's theory of relativity and Charles Darwin's theory of evolution through natural selection. The use of the word theory in science is different from the everyday use of the word. A scientific theory has been established and verified through investigation. It has been accepted as valid because it has been repeatedly tested.

Designing experiments

An experiment must be designed so that the results clearly support or disprove the hypothesis being tested. Suppose Louis Pasteur tested the air in hospital wards containing sick people and found that a certain micro-organism was always present.

Would this support the hypothesis that the disease was caused by that micro-organism? Clearly it would not because the same micro-organism might occur in air from any source.

To ensure that the results of an experiment will either support or disprove the hypothesis, only one factor, or variable, is tested at a time. A **control**, or comparison, experiment is done in which the only difference is in the one variable being tested. If a scientist were testing the hypothesis that vitamin A is essential for the normal development of young rats, two groups of young rats would be needed: an **experimental group** and a **control group**. The experimental group would be given a diet deficient in vitamin A, while the control group's diet would contain normal amounts of vitamin A. All other variables, such as the age and sex of the rats, the type and quantity of the food, the length of time for which the rats were observed and the temperature under which the rats were kept, would have to be the same for both groups. These are known as **controlled variables**. If, at the end of the experiment, the experimental rats were small and underweight for their age whereas the control rats were of normal size and weight, one could confidently say that the difference between the two sets of rats was due to the presence or absence of vitamin A in the diet. This interpretation could only be made if just *one* variable were allowed to differ between the two groups of rats.

Variables

A **variable** is any factor that may change during an experiment.

The **independent variable** is the factor that is being investigated—the factor that is deliberately changed to determine its effect. It is deliberately different between the control and the experimental groups in an experiment. The independent variable may also be called the experimental variable or the manipulated variable.

The **dependent variable** is the factor that changes in response to the changes made to the independent variable. It is sometimes called the responding variable.

Controlled variables are the factors that are kept the same for both the control and experimental groups in an experiment.

Uncontrolled variables are variables that were not kept the same for the control and experimental groups in an experiment. They may have been overlooked by the experimenter or they may have been impossible to control.

As mentioned before, whenever possible the results of an experiment should involve measurement as well as direct observation. A scientist would record the appearance of the rats in this imaginary experiment, but more importantly would *measure* such things as the weight of the rats, and perhaps the length of the body or body parts. Measurement is precise and is easier to compare than descriptions of observations.

Scientific experiments always involve **repetition**. This may mean doing the same experiment many times, or it may mean performing the experiment on a large number of subjects at the same time. In the rat experiment, one experimental rat and one control rat would not be sufficient, as there is natural variation within any species. One of the rats may be slightly unusual or abnormal in some way (this would be an uncontrolled variable). If this were so, the result could lead the scientist to the wrong interpretation. If 10 experimental and 10 control rats were used, the *average* change in weight over the period of the experiment could be calculated. Any chance differences between individual rats would then be unlikely to affect the result.

Experimental error

Results of experiments always contain errors. This is one of the reasons that scientists rarely make definite statements about their results. Rather than make an exact statement they are likely to say 'it is probable that …' or 'it is likely that …'. Experimental error is also one of the reasons that favourable experimental results cannot prove a hypothesis. They can only provide support for it.

In designing experiments it is important to be aware of possible sources of error and to minimise them as far as possible.

There are three possible types of error that may occur in an experiment. **Human error** is simply a mistake; for example, incorrectly reading the scale on an instrument, spilling some liquid before measuring the volume or making a mistake in a calculation. Human errors are not part of the experimental error. They should be avoidable with sufficient care and checking.

Random errors are unpredictable and occur in all experiments. They occur because no measurement can be made with absolute precision. For example, if you are using a stopwatch to time how long it takes a person to carry out a particular task, sometimes you will stop the watch a little early, sometimes a little late. This is not human error, it is a limitation of the timing procedure. Because such an error is random it can be reduced by taking several measurements and averaging them.

Systematic errors occur because of the way in which the experiment was designed. In this case a measurement will *always* be too high or too low. Systematic errors cannot be reduced by averaging; the only solution is to change the experimental procedure.

Statistical tests are available to try to determine whether differences in measurements are random or systematic. Despite these tests the experimenter may never be aware that a systematic error is occurring.

When you design an experiment it is important that you critically examine your design in order to eliminate as many sources of error as possible. In reporting the results of your experiment possible sources of error should be acknowledged. Remember, even the most accomplished scientists are unable to eliminate error.

Investigating humans

Ethical problems

Ethics are a set of moral principles or values; **ethical behaviour** is behaviour that conforms to those principles or values. In scientific research, particularly research with human participants, many ethical issues arise.

Each Australian university or research institute is required to have an ethics committee. The committee members represent a wide variety of interests and there must be some members who have no links to the university or institution. Ethics committees examine proposals for research involving humans and, if the proposed investigation satisfies ethical standards, approval is given to go ahead.

Some of the principles that an investigation must satisfy if it is to be ethically sound are:

1. *voluntary participation*—people should not be pressured into taking part in the research
2. *informed consent*—the participants should be fully informed about the objectives of the research, the procedures to be followed, any possible risks

and the potential benefits; consent (in writing) should only be sought after all information has been given
3. *risk of harm*—for some research, such as testing new drugs, it is difficult to ensure that there is no risk that participants will be harmed, but the possibility of harm should be minimised and the relationship between the risk and the benefit should be carefully assessed
4. *confidentiality*—procedures need to be adopted to ensure that the identities of participants will not be revealed except to people directly involved in the study
5. *anonymity*—a stronger guarantee of privacy than confidentiality; the participants in the study remain anonymous, even to the researchers. Because of the nature of some research anonymity may not be possible; for example, where measurements must be made on participants over an extended period of time.

An ethical dilemma may arise when the effects of a trial on the experimental group of subjects is so advantageous that it seems unfair to withhold it from the control group. For example, if a new medical treatment for a disease was tested on an experimental group, which showed remarkable improvement compared to a control group, why should the control group be denied access to the treatment? Situations have actually occurred where the testing of a procedure has been so successful that the trial has been abandoned and the procedure made available to the control group as well as the experimental subjects. An example of this was a 2005 study of three thousand men living in a township in South Africa (*New Scientist*, 25 November, 2006, p. 8). Volunteers who were circumcised at the beginning of the study were found to be 60 per cent less likely to become infected with HIV than the control group of men who remained uncircumcised. The results were so dramatic that the trial was halted early so that the uncircumcised men could be circumcised.

Ethical problems may also arise when subjects are being adversely affected by the research. At what point should the trial be abandoned even if continued testing is desirable?

Investigations that you will carry out in your Human Biological Sciences course are unlikely to raise any serious ethical problems. However, when designing an investigation it is a good idea to keep in mind the five principles described above.

Placebos

Placebos are used in research into the effectiveness of medical treatments such as a new medicinal drug. In the case of a drug trial, a **placebo** is an inactive substance that looks like the real medication. One group of subjects, the experimental group, takes the drug that is being tested and the other group, the control, takes the placebo. The placebo should look exactly the same, and be given in the same way, as the drug being tested. Subjects do not know whether they are receiving the drug or the placebo. If there is a clear difference in results between the new drug and the placebo, then the researcher can say with confidence that the difference was due to the effectiveness of the drug.

A placebo does not have to be a tablet. It could be any 'dummy' treatment such as an injection, a skin patch, a nasal spray, a special diet, a physical therapy or even mock surgery. The important thing is that the subject believes that he or she is receiving exactly the same treatment as everyone else in the trial.

Patients who are given a placebo often show an improvement in their condition even though the placebo is inactive. This is called the **placebo effect**. It is thought to occur because of the patient's belief that the placebo is a real therapy that will bring about improvement. If, in a trial of a therapy, the test group show a better response than the control group, despite the placebo effect, the therapy can be assumed to have been effective.

Presentation of data

Tables

Results of investigations are often presented in the form of a **table**. A table is an organised and concise way of presenting data. Observations may be presented in a table; for example, Table 5.2 (on page 55) lists some of the changes that occur during the various stages of cell division. Tables are particularly useful for presenting numerical data; for example, Table 6.4 (on page 81) shows percentages of deaths in Australia from a number of different causes.

When you draw up a table to present the results of an experiment there are certain rules you should follow:

- The table must have a title. The title usually states the variables investigated in the experiment.
- Data are presented in columns. Usually the data for the independent variable are in the left-hand column and those for the dependent variable are in the right-hand column or columns. This is not a definite rule. The most important consideration is that the table is easy to understand.
- Each column has a heading that names the variable and the units in which it is measured.

For example, the results of the experiment on the effect of vitamin A on the growth of young rats (described on page 17) could have been presented in the way shown in Table 2.1. The independent variable, type of diet, is shown in the left-hand column, and the dependent variable, body weight, is shown in the right-hand columns.

Table 2.1 The effect of vitamin A deficiency on the body weights of rats

Type of diet	**Body weight of each rat at the end of the experiment (g)**										
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**Average weight**
Normal diet											
Vitamin A deficient diet											

Graphs

A useful way to present data so that they can be understood easily is to draw a graph. A **graph** shows how changes in one variable affect a second variable. For example, if the weight of a baby is measured every month for 2 years, the data can be plotted on a graph. Time (in months) is one variable; it affects the other variable, weight. In this case, time is called the **independent variable**. Weight is the **dependent variable**, because the weight of the baby *depends* on the month when it was measured (the month does not depend on the weight of the baby). The independent variable is normally plotted on the horizontal axis of a graph and the dependent variable on the vertical axis. Such a graph would look like that shown in Figure 2.3.

When drawing a graph it is important to remember to:

- label the axes with the names of the variables
- indicate the units in which each variable is measured
- give the graph a title that summarises the relationship illustrated by the graph
- use equal intervals of units on each axis.

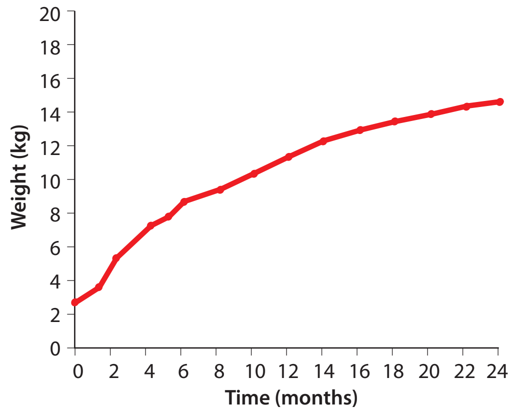


Figure 2.3 Hypothetical graph: weight of a baby over 2 years

Figure 2.3 is a **line graph**, the most commonly used type of graph in science. Other types of graph that you will come across, and may be required to draw, are bar or column graphs, and histograms.

Bar or **column graphs** represent data by rectangles of equal width with spaces between the rectangles. The length of each rectangle indicates the quantity and so the various quantities can be compared easily. Rectangles are drawn horizontally for a bar graph and vertically for a column graph. Figure 2.4 shows a column graph and a bar graph of the amount of calcium in soy milk and different types of milk.

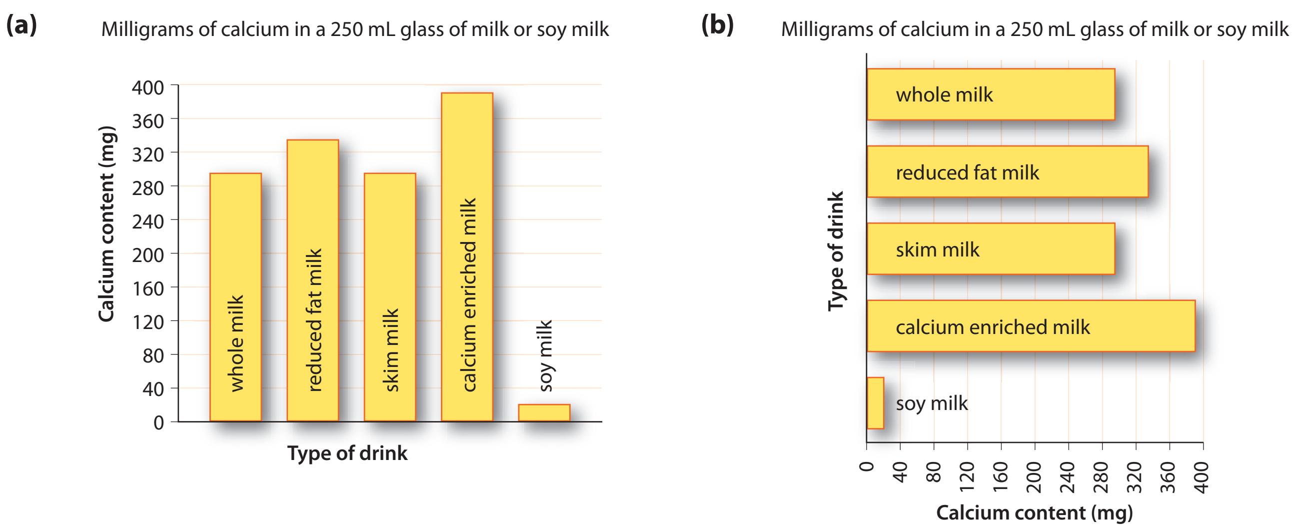
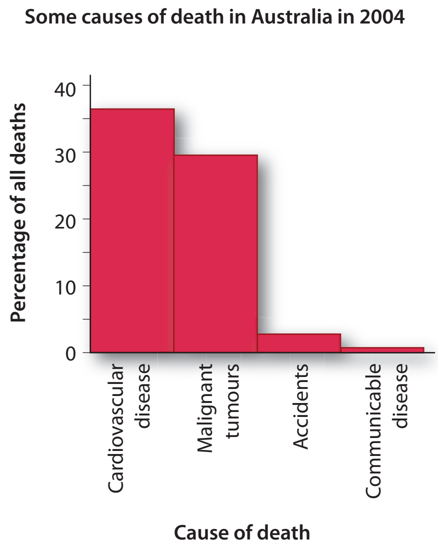


Figure 2.4 **(a)** A column graph; **(b)** a bar graph

Sometimes data are better represented by a **histogram**. Histograms are often used to show frequencies—how often a particular value or characteristic occurs. They have columns to represent the frequency and the columns are of equal width but there is no space between them. Histograms are particularly used where the data have been grouped into categories to make them more manageable. For example, if one were graphing the percentage of Australian males with heights in the categories 1.20 m to 1.29 m, 1.30 m to 1.39 m and so on, a histogram would be used. The data in Table 6.4, which gives the proportion of deaths in Australia in 2004 from a number of different causes, is shown in the histogram below (Fig. 2.5). It is not possible to use a line graph for such data.

Figure 2.5 A histogram



Scientific models

A scientific model is not like a model car or a model railway, which are scaled-down representations of real objects. A scientific **model** is a simplified representation of an idea or process. Figure 2.2 is a model of the scientific method. Once a model has been developed it can be applied to a number of situations. The model for scientific method can be applied to most scientific investigations. It can also be applied to other situations; for example, a mechanic trying to find a fault in a car engine.

Figure 3.10 (on page 35), which is a diagrammatic representation of the structure of a cell, is a model. The lock and key model is used in Chapter 4 (see Fig. 4.2) to describe why an enzyme will work with only one chemical reaction. Models may be diagrams, flowcharts or physical models, such as a model of the atoms in a protein. Scientific models often have to be modified as new data are collected.

Working scientifically

Activity 2.1 Hypothesising

In 1876 Robert Koch, a German doctor, was the first person to demonstrate that a particular type of bacterium caused a specific disease. He showed that a rod-shaped bacterium, later called *Bacillus anthracis*, caused anthrax, a disease that occurs in sheep, cattle, horses and sometimes humans.

Refer to the characteristics of a good hypothesis that are listed on page 16.

Which of the following could have been suitable hypotheses for Robert Koch to investigate in his search for the cause of anthrax? For each of the items below give reasons why it would, or would not, be a suitable hypothesis.

1. *Bacillus anthracis* causes anthrax.
2. Can anthrax be passed from sheep to cattle?
3. If a sheep is injected with *Bacillus anthracis* it will get anthrax.
4. To look for *Bacillus anthracis* in the blood of animals with anthrax.
5. Why does *Bacillus anthracis* cause anthrax?

6. If a cow is injected with *Bacillus anthracis* and is then kept out of the weather it will not get anthrax.
7. Injecting blood from a sheep suffering from anthrax into a healthy sheep will transmit the disease.
8. Any animal suffering from anthrax will have *Bacillus anthracis* in its blood and will pass the infection on to other animals.

Activity 2.2 Controlled experiments

One of the first controlled experiments in science was performed in 1668 by an Italian doctor, Francesco Redi. In Redi's time it was believed that living organisms arose from non-living matter, an idea known as spontaneous generation.

Redi put meat into a number of flasks. He sealed half of the flasks and left the other half open. He then repeated his experiment but instead of sealing half the flasks he covered them with gauze so that air could enter, but not flies. Redi found that maggots developed in the open flasks but not in the flasks that were sealed or covered with gauze.

1. Suggest the hypothesis that Redi was testing.
2. List the variables that Redi controlled in his experiments.
3. What other variables do you think Redi should have controlled?
4. What conclusion could Redi draw from his experiment?
5. Make a list of further questions to be answered that arise as a result of Redi's experiments.

The idea of spontaneous generation lingered in the belief that micro-organisms arose spontaneously in the medium in which they were found. It was not until the 1860s that Louis Pasteur finally quashed the idea of spontaneous generation. Pasteur's experiments showed that bacteria did not develop in a flask of nutrient solution if it was sterilised by boiling and if air entering the flask was filtered to remove bacteria.

6. What was Pasteur's independent (experimental) variable?
7. What was Pasteur's dependent variable?
8. List the variables that Pasteur would have controlled so he could make a valid conclusion from his experiment.

Activity 2.3 Tabulation of data

In this activity you will practise drawing up a table to organise data.

Some students were investigating the effect of temperature on the activity of a digestive juice. They added 20 mL of the digestive juice to 50 mL of an emulsion containing standard quantities of oil and protein. The time taken for all of the oil and all of the protein to be digested was measured. This same procedure was repeated at a number of different temperatures. The results of the students' experiment are shown pictorially in Figure 2.6.

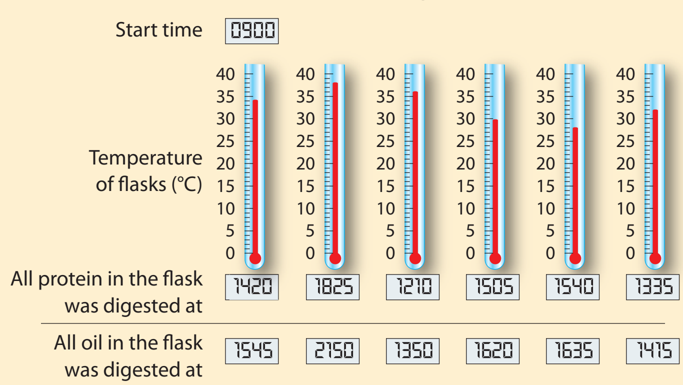


Figure 2.6 Results of digestion experiment showing times and temperatures

1. What were the independent and dependent variables in the students' experiment?
2. Draw up a table to show the data they collected (refer to page 20 for the rules for drawing up a table of scientific data).

Activity 2.4 Graphing

A. Table 2.2 shows data on the weights of five babies.

1. Which is the dependent variable and which is the independent variable?
2. Plot the data as a graph in the most appropriate manner.

Table 2.2 Weights (kg) of babies from birth to 1 year

	Birth	13 weeks	26 weeks	39 weeks	52 weeks
Bonnie	2.1	5.9	8.5	9.6	10.7
Hamish	3.3	6.6	8.2	9.5	11.1
Max	3.4	6.3	7.9	9.3	11.2
Chloe	2.9	6.0	7.5	8.9	9.9
Imogen	3.2	6.7	8.4	9.8	11.6

B. The Australian Bureau of Statistics conducts regular surveys of alcohol consumption. The results for the consumption of wine over a number of years are shown in Table 2.3.

3. Identify the dependent and independent variables in these data.
4. Plot the data as a graph in the most appropriate manner.

Table 2.3 Annual Australian per capita consumption of wine (L)

Year	1978	1981	1983	1986	1989	1993	1996	1999	2002	2004
Litres	14.2	18.2	19.7	21.3	19.1	18.3	18.3	19.7	20.5	21.8

Source: Australian Bureau of Statistics. *Australian Wine and Grape Industry*. Canberra: ABS, 2005. Catalogue number 1329.0.

REVIEW QUESTIONS

1. What is meant by a model in science?
2. Describe a model for the scientific method that is followed by many scientists.
3. **(a)** What is a hypothesis?
   (b) What are the characteristics of a good hypothesis?
4. Explain the difference between a hypothesis and a scientific theory.
5. **(a)** Explain the difference between the experimental group and the control group in an experiment.
   (b) What is the purpose of the control group?
6. **(a)** Explain the difference between the independent and dependent variables in an experiment.
   (b) What are controlled variables in an experiment?

7. Why is repetition important in experiments?
8. **(a)** What are the two types of experimental error?
   (b) How can the effects of each type be minimised?
9. List some of the ethical principles that must be satisfied in any research project.
10. What is a placebo? Why are placebos used in research?

APPLY YOUR KNOWLEDGE

1. Table 6.3 (on page 79) shows the blood flow through body organs at rest and during exercise. Using the appropriate format plot a graph showing the energy allowances for adult Australian men and women.
2. An American doctor, Dr William Bean, studied the growth of his fingernails for 35 years. He filed a horizontal line on his thumbnail just above the cuticle (the strip of skin at the base of the nail). By recording how long it took the mark to reach the tip of the thumbnail he was able to calculate the growth rate. He was eventually able to conclude:

> A 35-year observation of the growth of my nails indicates the slowing of growth with increasing age. The average daily growth of the left thumbnail, for instance, has varied from 0.123 mm a day during the first part of the study when I was 32 years of age to 0.095 mm a day at the age of 67.

Source: Bean, W. 'Nail growth: thirty-five years of observation'.
Quoted in *The Guardian*, 24 February 2004.

(a) Suggest a hypothesis that Dr Bean was testing.
(b) Which was the independent variable and which the dependent variable in this investigation?
(c) List some of the variables that should have been controlled in Dr Bean's study.
(d) Describe one source of random error in the investigation.
(e) Measure the length of your thumbnail. Assume that your thumbnail grows at the same rate as that of the 32-year-old Dr Bean. How long did it take the tip of your thumbnail to grow from the cuticle to its present position?
(f) Do you think your fingernails and toenails grow at the same rate? Propose a hypothesis and outline an investigation that you could do to test your hypothesis.