

CHAPTER 01

Scientific investigation

Learning outcomes

The development of a set of key science skills is a core component of the study of VCE Biology and applies across Units 1 to 4 in all areas of study. Chapter 1 scaffolds the development of these skills. It is important to develop, use and demonstrate these skills in a variety of contexts before undertaking investigations and when evaluating the research of others.

Although this chapter can be read as a whole, it is best to refer to it and use it when the need arises as you work through other chapters. For example, you may need a refresher on the process of the scientific method. This chapter also contains useful checklists to assist when drawing scientific diagrams, graphing results and completing aspects of your report. Similarly, when performing a practical investigation, refer to this chapter to make sure you collect data properly and that your data is of high quality.

Key science skills

Develop aims and questions, formulate hypotheses and make predictions

- identify, research and construct aims and questions for investigation **1.1, 1.2**
- identify independent, dependent and controlled variables in controlled experiments **1.1, 1.2**
- formulate hypotheses to focus investigation **1.1, 1.2**
- predict possible outcomes **1.1, 1.2**

Plan and conduct investigations

- determine appropriate investigation methodology; case study; classification and identification; controlled experiment; correlational study; fieldwork; literature review; modelling; product, process or system development; simulation **1.1, 1.2**
- design and conduct investigations; select and use methods appropriate to the investigation, including consideration of sampling technique and size, equipment and procedures, taking into account potential sources of error and uncertainty; determine the type and amount of qualitative and/or quantitative data to be generated or collated **1.1, 1.3**
- work independently and collaboratively as appropriate and within identified research constraints, adapting or extending processes as required and recording such modifications **1.1, 1.2**

Comply with safety and ethical guidelines

- demonstrate safe laboratory practices when planning and conducting investigations by using risk assessments that are informed by safety data sheets (SDS), and accounting for risks **1.2**
- apply relevant occupational health and safety guidelines while undertaking practical investigations **1.2**
- demonstrate ethical conduct when undertaking and reporting investigations **1.2**

Generate, collate and record data

- systematically generate and record primary data, and collate secondary data, appropriate to the investigation, including use of databases and reputable online data sources **1.3, 1.4**
- record and summarise both qualitative and quantitative data, including use of a logbook as an authentication of generated or collated data **1.4**
- organise and present data in useful and meaningful ways, including schematic diagrams, flow charts, tables, bar charts and line graphs **1.5, 1.6**
- plot graphs involving two variables that show linear and non-linear relationships **1.5, 1.6**

Analyse and evaluate data and investigation methods

- process quantitative data using appropriate mathematical relationships and units, including calculations of ratios, percentages, percentage change and mean **1.5**
- identify and analyse experimental data qualitatively, handling where appropriate concepts of: accuracy, precision, repeatability, reproducibility and validity of measurements; errors (random and systematic); and certainty in data, including effects of sample size in obtaining reliable data **1.4, 1.5**
- identify outliers, and contradictory or provisional data **1.4, 1.5**
- repeat experiments to ensure findings are robust **1.4**
- evaluate investigation methods and possible sources of personal errors/mistakes or bias, and suggest improvements to increase accuracy and precision, and to reduce the likelihood of errors **1.4, 1.6**

Construct evidence-based arguments and draw conclusions

- distinguish between opinion, anecdote and evidence, and scientific and non-scientific ideas **1.2**
- evaluate data to determine the degree to which the evidence supports the aim of the investigation, and make recommendations, as appropriate, for modifying or extending the investigation **1.4, 1.6**
- evaluate data to determine the degree to which the evidence supports or refutes the initial prediction or hypothesis **1.4, 1.6**
- use reasoning to construct scientific arguments, and to draw and justify conclusions consistent with the evidence and relevant to the question under investigation **1.6**
- identify, describe and explain the limitations of conclusions, including identification of further evidence required **1.6**
- discuss the implications of research findings and proposals **1.6**

Analyse, evaluate and communicate scientific ideas

- use appropriate biological terminology, representations and conventions, including standard abbreviations, graphing conventions and units of measurement **1.4, 1.5, 1.6**
- discuss relevant biological information, ideas, concepts, theories and models and the connections between them **1.1, 1.2, 1.6**
- analyse and explain how models and theories are used to organise and understand observed phenomena and concepts related to biology, identifying limitations of selected models/theories **1.1, 1.6**
- critically evaluate and interpret a range of scientific and media texts (including journal articles, mass media communications and opinions in the public domain), processes, claims and conclusions related to biology by considering the quality of available evidence **1.2, 1.4**
- analyse and evaluate bioethical issues using relevant approaches to bioethics and ethical concepts, including the influence of social, economic, legal and political factors relevant to the selected issue **1.2**
- use clear, coherent and concise expression to communicate to specific audiences for specific purposes in appropriate scientific genres, including scientific reports and posters **1.6**
- acknowledge sources of information and assistance, and use standard scientific referencing conventions **1.6**

1.1 The scientific method

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

OBSERVATION

Observation includes using all your senses and a wide variety of instruments and laboratory techniques to allow closer observation. Through careful inquiry and observation you can learn a lot about organisms, the ways they function, and their interactions with each other and the environment. For example, animals clearly function very differently from plants. Animals usually move around, take in nutrients and water, and often interact with each other in groups. Plants, however, are stationary, turn their leaves towards the light and grow. Many other distinguishing macroscopic structures and behaviours can be discerned from simple observation. Microscopic observation of cells reveals similarities and differences in the structure of plant and animal cells, as well as the specialisations in the cells of a particular organism.

Practical investigations

The idea for a practical investigation of a complex problem arises from prior learning and observations that raise further questions. For example, indoor plants do not grow well in the long term without artificial lighting, which suggests light is required for photosynthesis in plants (Figure 1.1.2). This aspect of photosynthesis can be researched and the new knowledge applied to other applications, such as methods for growing plants in the laboratory for genetic selection and modification for crop improvement.

Interpreting observations

How observations are interpreted depends on past experiences and knowledge, but to enquiring minds they will usually provoke further questions such as:

- How do organisms gain and expend energy?
- How do multicellular organisms develop specialised tissues?
- What are the molecular building blocks of cells?
- How do species change and evolve over time?
- How do cells communicate with each other?

Many of these questions cannot be answered by observation alone, but they can be answered through scientific investigations. Good scientists have acute powers of observation and enquiring minds, and they make the most of these chance opportunities, like Alexander Fleming did when he discovered penicillin.

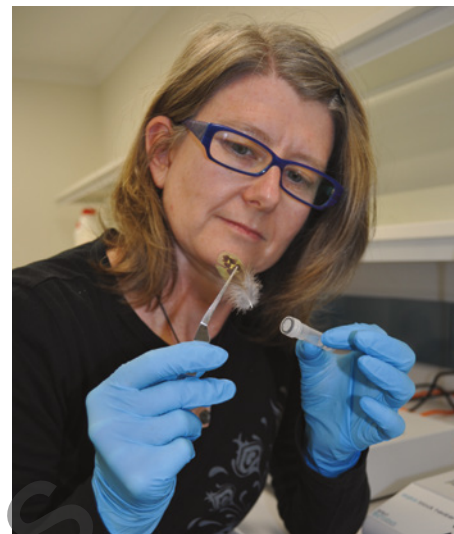


FIGURE 1.1.1 Biological research uses a variety of methodologies and methods. Analysis of DNA extracted from feathers by scientists at the Museum of Western Australia has confirmed that the night parrot (*Pezoporus occidentalis*) is not extinct, as previously thought.



FIGURE 1.1.2 Laboratory methods such as plant tissue culture rely on careful observations and data collection about the requirements for growth of plants in natural conditions. Laboratory investigations then provide new information that can be applied to plants growing in the field.

CASE STUDY

Australian discovery—peptic ulcers

In 2005, Australian scientists Professor Barry Marshall and J. Robin Warren (Figure 1.1.3) were awarded the Nobel Prize in Physiology or Medicine with their discovery of the role of the bacteria species *Helicobacter pylori* in gastritis and peptic ulcer disease.

Through careful observations and questioning, the two scientists showed that more than 90% of peptic ulcer cases that led to gastritis were not caused by stress, as previously thought, but were caused by infection with *H. pylori*. *H. pylori* is able to withstand the extreme acidic conditions of the stomach, pass through the protective mucous layer, and attach to and colonise the wall of the stomach. The bacteria release several compounds that lead to damage of the stomach lining (Figure 1.1.4).

The research of Marshall and Warren led to effective treatment of peptic ulcers with antibiotics. An unexpected outcome of their research was the discovery that gastritis is a precursor to stomach cancer. Marshall and Warren's research not only led to effective treatment for peptic ulcers but has also drastically reduced the rate of stomach cancer.



FIGURE 1.1.3 Australian scientists Professor Barry Marshall and Dr Robin Warren

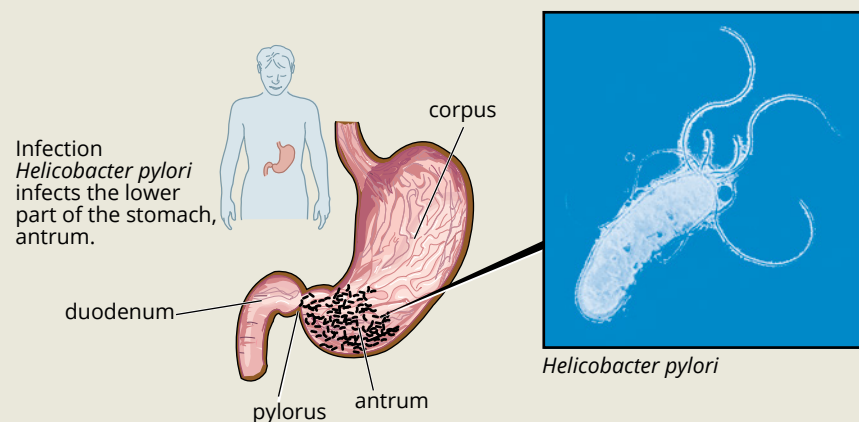


FIGURE 1.1.4 The majority of peptic ulcers are caused by the bacteria *Helicobacter pylori*.

● You will now be able to answer key question 1.

THE SCIENTIFIC PROCESS

Scientists observe, study what is already known, and then ask questions. Using their knowledge and experience, scientists suggest possible explanations for the things they observe. A **hypothesis** is a prediction based on scientific reasoning that can be tested experimentally. This is the basis of the **scientific method** (Figure 1.1.5).

i A hypothesis is a prediction based on scientific reasoning about what an investigator might expect to see in the results of their experiment.

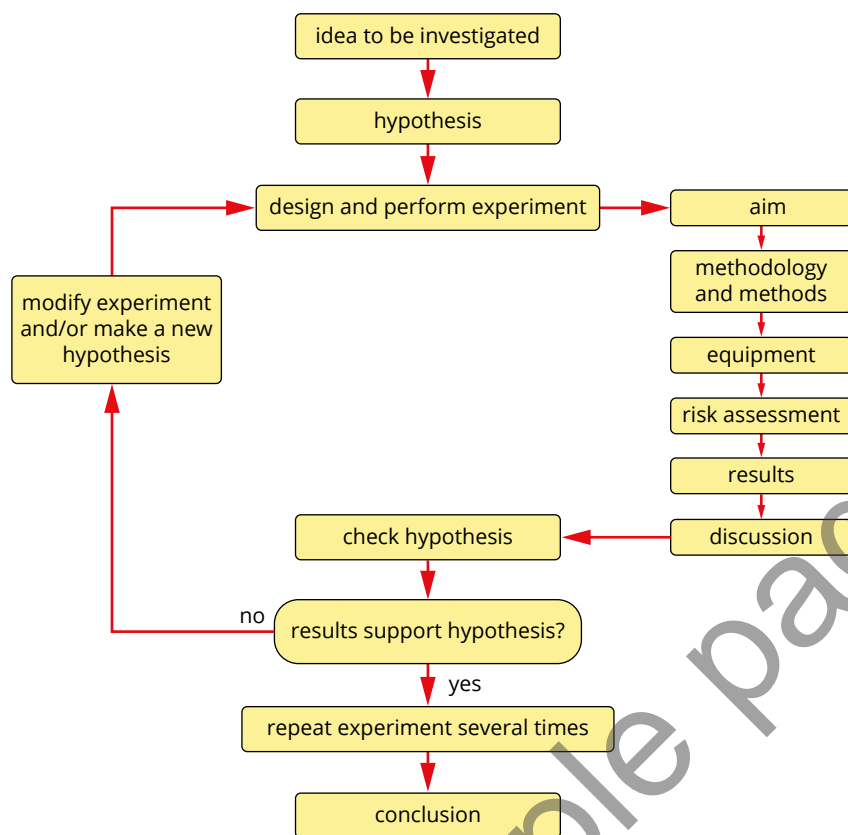


FIGURE 1.1.5 The scientific method

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

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

● You will now be able to answer key question 2.

Research questions

In science, there is little value in asking questions that cannot be answered. A hypothesis must be testable, but your inability to test a particular hypothesis does not mean that the hypothesis cannot be supported.

Your ability to test a hypothesis may be limited by the resources and equipment you have available. If you ask a research question, form and test your hypothesis, and find your hypothesis is supported, that does not mean it is true in all circumstances. Likewise, if your hypothesis is not supported, that does not mean it is never true.

For example, you might hypothesise 'If hydrogen peroxide is a toxic by-product of cellular respiration that is broken down by catalase, then all eukaryotes will contain catalase'. However, there may be a eukaryote that lacks catalase, but testing every eukaryotic organism would be impossible, and just because a eukaryote without catalase hasn't been identified does not mean none exist.

● You will now be able to answer key question 5.

Methodology and methods

The **methodology** is a brief description of the general approach taken to investigate the research question or hypothesis and the reasons why this approach is taken. The methodology can be described as the rationale behind your investigative methods. Examples of scientific investigation methodologies are controlled experiments, fieldwork, literature reviews, modelling and simulation. The **methods** (also known as procedures) are the specific steps that are taken to collect data during the investigation. The type of scientific investigation methodology and the methods selected will depend on the aim of the investigation and the research question.

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

Conducting an investigation once or using a small number of samples is not sufficient. You can have little confidence in a single result because you cannot be sure that the result was not due to some unusual circumstance that occurred at the time. The same experiment is usually repeated a number of times over a period of time and the combined results are then analysed statistically. If the statistics show that there is a low probability (usually less than 5%) that the results could have occurred as a result of chance, then the result is accepted as being significant.

● You will now be able to answer key question 3.

Experimental controls

It is difficult—sometimes impossible—to eliminate all **variables** that might affect the outcome of an investigation. In biology, time of day, temperature, amount of light, humidity, and unidentified infections in organisms are examples of such variables. A way to eliminate the possibility that random factors affect results is to set up a second group within the experiment (called a **control group**) that is identical in every way to the first group (the **experimental group**) except for the single experimental variable that is being tested. This is a controlled experiment, because it allows you to examine one variable at a time. Controlled experiments are an important way of testing your hypothesis.

i Scientific investigations must be able to be repeated by other scientists to be considered reliable.

i The experimental conditions of the control group are identical to those of the experimental group, except that the independent variable is also kept constant.

The variable that the experimenter is manipulating is the **independent variable**.

The **dependent variable** is what is measured when the independent variable changes. All of the other factors that could vary but must be kept the same in all experimental groups are called **controlled variables**.

When investigating antibacterial activity of compounds extracted from fungi or other sources, the variables to consider include the source, purity and concentration of the extract, the composition and consistency of the agar plates, the type of bacteria tested, the amount of substance on the test disc, the thickness of the discs and the incubation temperature. The independent variable would be the extract being tested. The dependent variable would be the presence and size of the zone of inhibition around the disc. The other variables listed above all need to be controlled. In Section 1.4 you will learn about setting up an investigation with controls.

i The independent variable is the only variable that the experimenter changes in a controlled experiment. The dependent variable is measured to determine the effect of changing the independent variable.

i In a controlled experiment, controlled (fixed) variables are kept constant.

Forming conclusions

Conclusions are evidence-based statements that are developed from the analysis of results. When drawing conclusions from the results of an investigation, the quality of the data needs to be considered—the data should be accurate, reliable and valid. A conclusion is valid if it provides a response to the research question that the investigation set out to answer. Conclusions should summarise and explain the results of the investigation, and identify the extent to which the investigation addressed the research question or hypothesis.

Speculation involves going beyond the results to make suggestions about what might be occurring. Conclusions are necessary, but speculation is interesting and thought-provoking. Both concluding and speculating are worthwhile, but you must be careful to keep them separate. It is also the usual practice of scientists to accept the simplest hypothesis that accounts for all the evidence available.

The conclusion made by Marshall and Warren, that *H. pylori* can cause gastritis and peptic ulcer disease (see the Case study on page 4), was evidence-based. Their study has been repeated many times, and has led to effective treatment for peptic ulcers.

LIMITATIONS OF THE SCIENTIFIC METHOD

The scientific method is not perfect; however, it remains the best way to understand your surroundings, and to constantly improve on that understanding. Even when the scientific method is strictly adhered to, there is still an element of chance in scientific discovery.

The scientific method can be applied only to hypotheses that can be tested, or to questions that can be answered. A hypothesis that is not testable can be neither supported nor disproved by the scientific method. Such hypotheses therefore remain as possible explanations. For example, Fleming's observation led to the hypothesis that certain fungi can produce chemicals that inhibit the growth of certain bacteria. This was testable for *Penicillium* and other fungi that can be grown on agar plates in the laboratory. If the hypothesis was broadened to 'All fungi produce antibiotics', this might not be testable, as testing it would depend on being able to grow all fungi and all potential bacterial targets in the laboratory.

It is also important to understand that although a hypothesis may be supported by experimental data, the same hypothesis may not be supported in all circumstances—it has only been found to be true under the conditions that have been tested.

The scientific method cannot be used to test morality or ethics. These judgements belong to the fields of philosophy, history, politics and law. Science can, however, provide valuable information that people can take into account when making these judgements. For example, science can be used to predict the environmental consequences of pollution and the medical consequences of chemical weapons, but it cannot itself make value or moral judgements about either.

i A hypothesis can never be proven by a scientific study; it can only be supported under the conditions that have been tested.

DETERMINING APPROPRIATE INVESTIGATION METHODOLOGY

When it comes to beginning your scientific investigation, you will need to think about the best way to address your research question. For some investigations, setting up a controlled experiment may require using equipment that is not readily available to you in the school setting. This may mean you need to look at a computer simulation to model the outcomes of the investigation. Other approaches could include a literature review of other studies focussed on a similar research question. The different approaches that you could use are outlined in Table 1.1.1.

TABLE 1.1.1 Scientific investigation methodologies

Type of methodology	Explanation	Example
case study	investigation of a real or hypothetical situation, such as an activity, event, problem or behaviour, often involving analysis of data within a real-world context	looking at the impact of an oil spill in one part of the world and using this analysis to prepare, hypothesise and plan for the impact of an oil spill of similar magnitude in another part of the world
classification and identification	arranging objects, events or organisms into manageable groups by identifying shared or similar features	using morphology (physical features) to group organisms into taxonomic groups based on shared characteristics
controlled experiment	experimental investigation that involves formulating a hypothesis and testing the effect of an independent variable on the dependent variable while controlling all other variables in the experiment	investigating the impact of a change in temperature on the activity of an enzyme
correlational study	making observations and recording events and behaviours to investigate the relationship or association between variables	investigating the correlation between body mass index and the incidence of coronary heart disease
fieldwork	observing and interacting with particular environments to determine if a relationship exists between organisms or environmental factors and organisms; often involves observations and sampling of organisms and environments	chi-square test to investigate whether a relationship exists between two different species of marine molluscs in an intertidal zone
literature review	critical analysis of what has already been investigated and published, using secondary data from other people's investigations to explain events or propose new ideas or relationships	analysis of data looking at the impact of smoking on lung cancer in a variety of research papers to support, refute or develop new hypotheses
modelling	using models as representations of objects, systems or processes to aid understanding or make predictions	model of the connections between neurons in the human brain constructed from brain-scanning technology
product, process or system development	using scientific understanding and advances in technology to design a new tool, method or process to meet the demands or needs of society	developing a new biodegradable packaging material
simulation	using mathematical models or simulations to test hypotheses, conduct virtual experiments or model the complexity of whole cells, systems, organs or organisms	computer simulation of immune cells attacking other cells

EXPERIMENTATION

Once you have a testable hypothesis, you are ready to conduct an experiment to test it. Every experiment has to be designed and planned carefully. You need to be sure that someone else can repeat your experiment exactly the way you did it and get similar results. In Section 1.2 you will learn how to formulate your hypothesis and design an experiment to test it.

- You will now be able to answer key questions 4 and 6–7.

MODELS

Scientific models are used to create and test theories and explain concepts. They may also be developed as prototypes for functional devices such as replacement organs. The introduction of computer technology, including two- and three-dimensional animations, has helped to create more detailed and realistic representations of biological processes. Different types of models can be used, but each model has limitations in the type of information it can provide.

Modelling concepts

Models are created to answer specific questions or demonstrate specific processes. How a model is designed will depend on its purpose. The two most familiar types of models are visual models and physical models, but mathematical models and computational models are also common and increasingly important in the biosciences. Models help to make sense of ideas by visualising:

- objects that are difficult to see because of their size (too big or too small) or position, such as ecosystems, organs such as the heart and pancreas, cells, molecules and atoms
- processes that cannot easily be seen directly, such as digestion, feedback loops, biochemical reactions, gene expression and protein folding
- abstract ideas, such as energy transfer and the particulate nature of matter
- complex processes, such as networks of biochemical reactions, genome organisation and regulation, evolution, and brain connectivity and function.

For example, models of all the connections between neurons in the human brain have been constructed from brain scanning technology. The models are used to predict and test signalling and communication between neurons (Figure 1.1.6).

A deeper understanding of concepts can be developed through models. However, you need to identify the benefits and limitations of using a particular model to represent a concept. Furthermore, the quality and validity of a model is limited by the depth and accuracy of the information used to construct the model.

Model organisms

Biologists use live bacteria, animals and plants as model organisms for the investigation of cells and systems in situ and in vivo. It is possible to test in animals hypotheses that cannot be tested in humans for ethical reasons. Most of the advances in understanding animal and plant biology, genetics, pathology and medicine result from the use of model organisms. These organisms include the bacterium *Escherichia coli*, the nematode *Caenorhabditis elegans* (Figure 1.1.7), rats and mice, the plant *Arabidopsis thaliana* and the fruit fly *Drosophila melanogaster*.

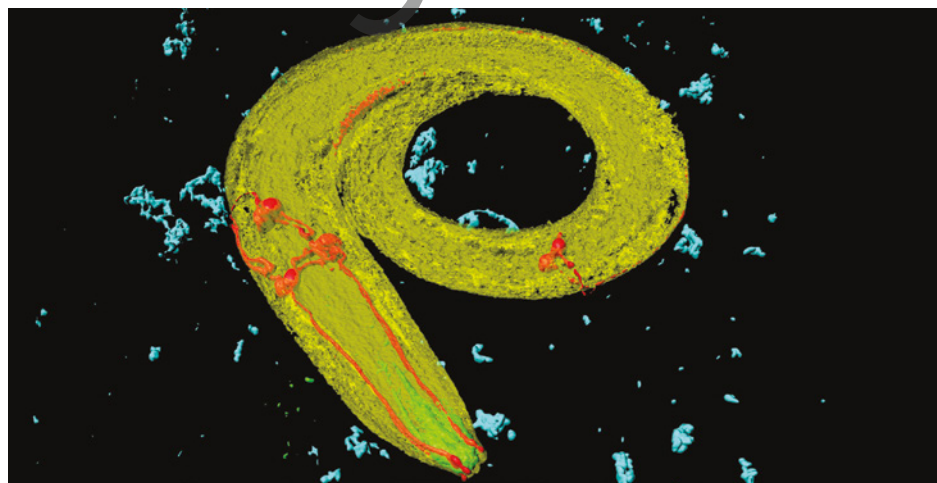


FIGURE 1.1.7 Model organism *Caenorhabditis elegans*, a nematode (roundworm). Confocal laser scanning micrograph of *C. elegans* with neurons stained green and the digestive tract stained red. *C. elegans* is a soil-dwelling nematode worm about 1 mm long and one of the most studied animals in biological and genetic research.



FIGURE 1.1.6 A model of the brain's wiring pattern explored in the Human Connectome Project

i Studies that are in situ are 'in position' or 'in place', such as when studying cells functioning within an intact organ, or molecules in their normal cellular location.

i Studies that are in vivo are 'within the living', such as when cells are studied in a living organism.

i Studies that are in vitro are 'in glass' or in a dish or test tube, such as when cells are removed from the organism and studied in a culture dish (it doesn't have to be glass).

i Studies that are *in silico* are 'in silicon', which refers to the silicon chips used in computers for computer simulations.

Efforts are being made to reduce the number of animals used in research, and strict ethical guidelines must be followed in their use. Studies performed *in vitro*, and advances in computer simulation and 'virtual' cells and organisms that have made *in silico* studies possible, allow for a reduced reliance on live animals. But keep in mind that the value and validity of a virtual model or simulation is only as good as the data and information used to construct the model. This ultimately comes from living cells and organisms.

● You will now be able to answer key questions 8–9.

1.1 Review



SUMMARY

- Well-designed experiments are based on a sound knowledge of what is already understood or known and careful observation.
- The scientific method is an accepted procedure for conducting investigations.
- A hypothesis is a possible explanation for a set of observations that can be used to make predictions, which can then be tested experimentally.
- Controlled experiments allow us to examine one factor at a time; they are a commonly used methodology for testing hypotheses.
- Scientific investigations are undertaken to test hypotheses. The results of an investigation may support or reject a hypothesis, but cannot show this to be true in all circumstances.
- Science cannot be used to evaluate hypotheses that are not testable, nor can it make value or moral judgements.
- Models are useful tools that can be created and used to assist in a deeper understanding of concepts.

KEY QUESTIONS

Knowledge and understanding

- 1 What is the scientific method based on?
A observation
B subjective decisions
C manipulation of results
D generalisations
- 2 Name the key components of the scientific method.
- 3 a What do 'objective' and 'subjective' mean?
b Why must experiments be conducted objectively?
- 4 Which of the following is an important part of conducting an experiment?
A disregarding results that do not fit the hypothesis
B making sure the experiment can be repeated by others
C producing results that are identical to each other
D changing the results to match the hypothesis
- 6 A scientist conducts a set of experiments, analyses the results and publishes them in a scientific journal. Other scientists in different laboratories repeat the experiment, but do not get the same results as the original scientist. Suggest several reasons that could explain this.
- 7 Design an experiment to test whether temperature is an important factor in the distribution of a mollusc species on a rocky coast. Clearly state the hypothesis that your experiment will test. Explain the methods that you would use. Do not forget to include experimental controls.
- 8 Explain the benefits of using a torso model to learn about the parts and relative positions of organs in the human body.
- 9 Explain two limitations of using models. Include an example.

Analysis

- 5 Write a hypothesis to test whether:
a carrot seeds or tomato seeds germinate quicker
b sourdough, multigrain or white bread goes mouldy the quickest
c Trigg the dog likes dry food or fresh food better.

1.2 Planning investigations

Practical investigations are those for which you gather the raw data yourself. These often take the form of experiments, activities, field trips or surveys (Figure 1.2.1). There are many elements to this type of practical investigation. A step-by-step approach will help you through the process and assist you in completing a solid and worthwhile investigation.

Taking the time to carefully plan and design an investigation before you begin will help you maintain a clear and concise focus throughout. Preparation is essential. In this section you will learn about some of the key steps to take when planning investigations:

- choosing a topic
- defining key terms
- sourcing information
- obtaining ethics approval
- ensuring occupational health and safety
- writing a protocol and schedule.

CHOOSING A TOPIC

Throughout this course you will conduct practical work (laboratory or fieldwork) on a range of topics. For Unit 1 Area of Study 3 you are required to adapt or design and then conduct a scientific investigation related to the function and/or regulation of cells or systems.

When you choose a topic, consider the following:

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

A number of topics that may be addressed in the course are suggested in Table 1.2.1 on page 12. You will learn more about useful research techniques for topics like these in Section 1.3.

Before you start

The topics in Table 1.2.1 on page 12 are only suggestions. Select your topic based on what resources are available to you. Before commencing your investigation, check that you have:

- the materials required to grow or culture an organism (e.g. plants, bacteria, yeast, protists or invertebrates)
- equipment such as microscopes, pH meters, spectrophotometers, centrifuges, and data loggers
- the materials needed to perform the experiments, such as biochemical test strips (for glucose, protein), enzymes and substrates, acids and bases.

Also ensure that you:

- can order any materials needed that are not on hand
- have a solid understanding of the theory behind your investigation
- are trained to use the required equipment
- have a detailed plan for the practical components of your investigation
- are able to access the school laboratory when you need to.



FIGURE 1.2.1 Scientists collecting grape vine samples for genetic research on the geographical origins of vines in the Mediterranean Basin

TABLE 1.2.1 Potential areas for investigation in Units 1 and 2

Laboratory experiments may be used to investigate cellular structure and function.	Possible topics for laboratory investigation include: <ul style="list-style-type: none">• surface area to volume ratio and its role in cellular functions• phagocytosis or endocytosis in living cells• variations in the cell cycle and mitosis in different cell types• the regulation of water balance in plants• modelling the effect of sweating on heat loss.
Fieldwork may be used to investigate cellular processes or the interactions, adaptations and distribution of species.	Possible topics for fieldwork investigation include: <ul style="list-style-type: none">• variations in photosynthetic pigments in leaves from different environments• the influence of the environment on phenotypes• variations in stomatal density in leaves along a transect• the biological advantages and disadvantages of different reproductive strategies• the ecological role of keystone species.
The use of data from online databases may facilitate, or be central to, your investigation.	Possible topics for investigation using online databases include: <ul style="list-style-type: none">• regulation of the eukaryotic cell cycle• the inheritance patterns of genes or traits• genetic diversity in different populations, using DNA sequence analysis• changes in the distribution and density of species over time.

DEFINING KEY TERMS

When you begin a scientific investigation, you first have to develop and evaluate a research question, determine the associated variables, formulate a hypothesis and define the aims. It is important to understand that each of these can be refined as the planning of your investigation continues.

- The **research question** defines what is being investigated. For example: Is the rate of photosynthesis in plants dependent on temperature?
- The variables are the factors that change during your experiment. For example: Temperature is a variable for the photosynthesis example given earlier.
- The hypothesis is a statement that can be tested and is based on previous knowledge, evidence or observations, and that attempts to answer the research question. For example: If the temperature increases from 20°C to 40°C, then the rate of photosynthesis will increase.
- The **aim** is a statement describing in detail what will be investigated. For example: To investigate the effect of temperature on the rate of photosynthesis in plants at 20°C, 30°C and 40°C.

Determining your research question

Before conducting an experimental investigation you need a research question to address. Once you have come up with a topic or idea of interest, the first thing you need to do is conduct a search of the relevant literature; that is, you must read scientific reports and other articles on the topic to find out what is already known, and what is not known or not yet agreed upon. The literature also gives you important information for the introduction to your report and ideas for experimental methods. Use this information to generate questions.

When you have defined the research question, you are able to formulate a hypothesis, identify the measurable variables, proceed with designing your investigation and suggest a possible outcome of the experiment.

Stop to evaluate the question before you progress; it may need further refinement or even further investigation before it is suitable as a basis for an achievable and worthwhile investigation. Consider the following checklist:

- ☐ relevance—Make sure your question is related to your chosen topic. For your investigation decide whether your question will relate to cellular structure or organisation, or to structural, physiological or behavioural adaptations of an organism to an environment.
- ☐ clarity and measurability—Make sure your question can be framed as a clear hypothesis. If the question cannot be stated as a specific hypothesis, then it is going to be very difficult to complete your research.
- ☐ time frame—Make sure your question can be answered within a reasonable period of time. Ensure your question isn't too broad.
- ☐ knowledge and skills—Make sure you have a level of knowledge and a level of laboratory skills that will allow you to explore the question. Keep the question simple and achievable.
- ☐ safety and ethics—Consider the safety and ethical issues associated with the question you will be investigating. If there are issues, determine if these need to be addressed.
- ☐ advice—Seek advice from your teacher on your question. Their input may prove very useful. Their experience may lead them to consider aspects of the question that you have not thought about.

i When writing a research question, it is advisable to include the independent and dependent variables. For example, what is the effect of [the independent variable] on [the dependent variable]?

Defining your variables

The factors that can change during your experiment or investigation are called the variables. An experiment or investigation determines the relationship between variables. There are three categories of variables:

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

You should have only one independent variable. Otherwise you could not be sure which independent variable was responsible for changes in the dependent variable.

Making predictions and constructing a hypothesis

The hypothesis is a prediction of what you think will happen during a scientific investigation. It is a statement that can be tested (based on evidence and prior knowledge) to answer your research question. It defines a proposed relationship between two variables. To do this, you will need to identify the dependent and independent variables.

A good hypothesis is written in terms of the dependent and independent variables, like this:

If x happens, then y will happen. The 'if' part of the hypothesis refers to the independent variable—the variable you alter in the experiment. The 'then' part relates to the dependent variable—the variable you measure or observe.

For example:

If yeast is grown in acidic conditions, **then** the rate of cellular respiration will decrease.

A hypothesis does not need to include ‘if’ and ‘then’ in its wording. For example, the previous hypothesis could also be stated the following way:

The rate of cellular respiration in yeast will decrease when yeast cells are grown in acidic conditions.

A good hypothesis can be tested to determine whether it is supported (verified), or not supported (falsified) by the investigation. To be testable, your hypothesis should include variables that are measurable.

When you evaluate your research question, consider the variables, and think about different potential hypotheses; it helps to create a table that outlines them. For example, Table 1.2.2 outlines a research question, the variables, and a potential hypothesis that relates to the effect of glucose on the rate of cellular respiration in yeast.

TABLE 1.2.2 Example of research question, variables and potential hypothesis

Research question	Will the rate of cellular respiration in yeast cells be faster if the cells are exposed to higher amounts of glucose?
Independent variable	glucose concentration
Dependent variable	rate of cellular respiration measured as change in CO ₂ released over time
Controlled variables	yeast culture volume, temperature, light conditions
Potential hypothesis	The rate of cellular respiration in yeast will increase as glucose concentration increases.

Determining your aim

The aim is the key step required to test your hypothesis. The aim should directly relate to the variables in the hypothesis, describing how each will be studied or measured. The aim does not need to include the details of the method.

For example:

- Hypothesis: If algae are exposed to low light levels, then the rate of photosynthesis will decrease.
- Aim: To compare the rates of photosynthesis in algae at different distances from a light source.
- Variables: distance from light source, i.e. light intensity (independent) and rate of photosynthesis (dependent).

● You will now be able to answer key questions 1–3 and 6–7.



SOURCING INFORMATION

When you are sourcing information during your search of the literature, researching experimental methods and investigating a broader issue, consider whether that information is from primary or secondary sources. You should also consider the advantages and disadvantages of using resources such as books or the internet.

Primary and secondary sources

Primary sources of information are created by a person directly involved in an investigation. Examples of primary sources are results from research and peer-reviewed scientific articles. **Secondary sources** of information are a synthesis, review or interpretation of primary sources. Examples of secondary sources are textbooks, newspaper articles and websites. For example, a scientist's journal article on a clinical trial of treatments for teenage obesity is a primary source, while a general magazine article about teenage obesity written by a journalist and referring to the scientific study is a secondary source. Table 1.2.3 compares primary and secondary sources.

Secondary sources of information may have a bias, so you need to determine if they are reliable sources of information. You will learn about assessing the accuracy, reliability and validity of data in Section 1.4.

TABLE 1.2.3 Summary of primary and secondary sources

	Primary sources	Secondary sources
Characteristics	<ul style="list-style-type: none">• first-hand records of events or experiences• written at the time the event happened• original documents	<ul style="list-style-type: none">• interpretations of primary sources• written by people who did not see or experience the event• use information from original documents but rework it
Examples	<ul style="list-style-type: none">• results of experiments• scientific journal/magazine articles• reports of scientific discoveries• photographs, specimens, maps and artefacts• interviews with experts• websites (if they meet the criteria above)	<ul style="list-style-type: none">• textbooks• biographies• newspaper articles• magazine articles• radio and television documentaries• websites that interpret the scientific work of others• podcasts

● You will now be able to answer key question 8.

Using books and the internet

Peer-reviewed scientific journals are the best sources of information, but you are unlikely to have access to many of them, and much of the information is difficult to interpret if you are not an expert in the field.

As books, magazines and internet searches will be your most commonly used resources for information, you should be aware of their limitations (Table 1.2.4 on page 16). Reputable science magazines you might find in your school library include *New Scientist*, *Cosmos*, *Scientific American* and *Double Helix* (Figure 1.2.2).



FIGURE 1.2.2 A reputable science magazine you might find in your school library

TABLE 1.2.4 Advantages and disadvantages of book and internet resources

	Book resources	Internet resources
Advantages	<ul style="list-style-type: none">• written by experts• authoritative information• reviewed to ensure information is accurate• logical, organised layout• content is relevant to the topic• contain a table of contents and index to help find relevant information	<ul style="list-style-type: none">• quick and easy to access• allow access to hard-to-find information• access to the whole world; millions of websites• up-to-date information• may be interactive and use animations to enhance understanding
Disadvantages	<ul style="list-style-type: none">• may not have been published recently• usable by only one person at a time	<ul style="list-style-type: none">• time-consuming looking for relevant information• a lot of 'junk' sites and biased material• search engines may not display the most useful sites• cannot always tell how up-to-date information is• difficult to tell if information is accurate• hard to tell who has responsibility for authorship• information may not be well ordered• less than 10% of sites are educational

Evaluating books and journals

Your textbook should be your first source of reliable information. Other information should be consistent with it. Articles published in journals and magazines often present findings of new research, which may or may not be confirmed later, so be careful not to treat such sources of information as established fact. Scientific journals are **peer-reviewed** (critically reviewed by other specialist scientists), which gives them more credibility than other sources.

Evaluating websites

Remember that anyone can publish anything on the internet, so it is important to evaluate the credibility, currency and content of online information. To evaluate online information, follow the checklist below.

- ☐ **Credibility**—consider who the author is, their qualifications and expertise; check for their contact information and for a trusted abbreviation in the web address, such as .gov or .edu; websites using .com may have a bias towards selling a product (but this product could be a reputable science magazine or journal), and .org sites might have a bias towards one point of view (although these sites can be a good starting point for general information).
- ☐ **Currency**—check the date the information you are using was last revised.
- ☐ **Content**—consider whether the information presented is fact or opinion; check for properly referenced sources; compare information to other reputable sources, including books and science journals.

ETHICS

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

Applying ethical principles means to:

- consider the implications of investigations of organisms and the environment—you should aim to maximise benefit while minimising harm and risk
- recognise the intrinsic value of life and respect the welfare, autonomy, beliefs, perceptions and customs of others
- use integrity when recording and reporting the outcomes of your investigation, and also when using other people's data (such as in a literature review)
- form a conclusion about science-related ethical issues using scientific knowledge and skills, whilst also considering the needs of all parties involved
- recognise the importance of social, economic and political values in forming conclusions using scientific understanding.

Ethics approval

If you work with animals as part of your studies, you may need to obtain a licence. Check with your school, teacher or laboratory technician. All animal use should follow the Victorian Government's guidelines for the care and use of animals in schools. These guidelines recommend that schools consider the '3Rs rule':

- Replace the use of animals with other methods where possible.
- Reduce the number of animals used.
- Refine techniques to reduce the impact on animals.

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

If human volunteers are needed, then the participants need to be fully briefed on the aim of, and methods involved in, the study, and they must give informed consent. They should also be given the opportunity to see the results of the study and their potential impact on the science community.

● You will now be able to answer key question 4.

OCCUPATIONAL HEALTH AND SAFETY

While planning for an investigation in the laboratory or outside in the field, it is important for your safety and the safety of others that you consider the potential risks.

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

To identify risks, think about:

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

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

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

- Elimination—eliminate dangerous equipment, methods or substances.
- Substitution—find different equipment, methods or substances to use that will achieve the same result, but have less risk associated.

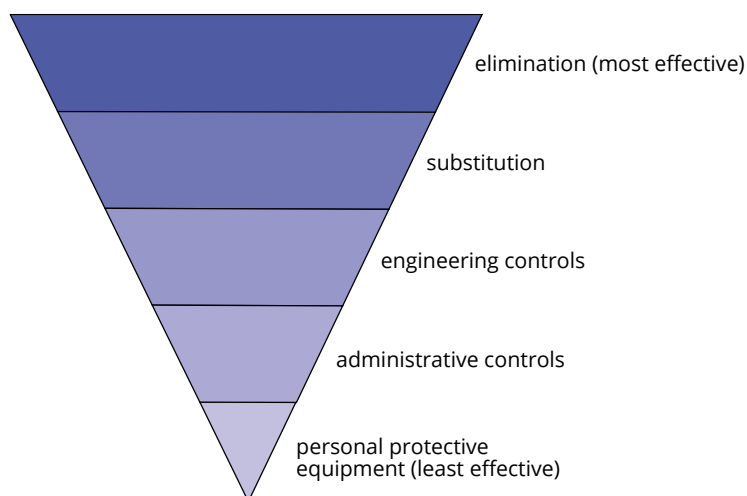


FIGURE 1.2.3 The hierarchy of risk control in this pyramid is shown from top to bottom in order of decreasing effectiveness.

- Engineering controls—modify equipment to reduce risks. Ensure there is a barrier between the person and the hazard. Examples include physical barriers, such as guards in machines, or fume hoods when working with volatile substances.
- Administrative controls—provide guidelines, special procedures, warning signs and safe behaviours for any participants.
- Personal protective equipment (PPE)—wear safety glasses, lab coats, gloves, respirators and any other necessary safety equipment where appropriate, and provide these to other participants. As PPE can be damaged, it is considered the least effective control measure, but it remains an essential safety feature after other control measures are in place (Figure 1.2.4).



FIGURE 1.2.4 A lab coat, gloves and safety glasses are essential items of personal protective equipment in the laboratory.



FIGURE 1.2.5 Researchers excavating human fossils at a cave in Atapuerca, Spain. Hard hats, ropes, harnesses, strong clothing and footwear are essential during fossil research in the field.

Science outdoors

Your investigation may involve outdoor fieldwork (Figure 1.2.5). All the potential risks, and ways to minimise them, must be considered when planning fieldwork. Ways to reduce risk include use of suitable protective clothing, knowledge of the terrain, having up-to-date maps, and checking predicted weather and fire risk.

Chemical safety

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

- ingestion—chemicals that have been ingested (eaten) may be absorbed across cells lining the mouth or enter the stomach, and may then be absorbed into the bloodstream
- inhalation—chemicals that are breathed in (inhaled) can cross the thin cell layer of the alveoli in the lungs and enter the bloodstream
- absorption—some chemicals are able to pass through the skin in a process called absorption.










When working with any type of chemical you should:

- identify the chemical codes and be aware of the dangers they are warning about
- become familiar with the relevant safety data sheets (SDS), formerly known as material safety data sheets (MSDS)
- use personal protective equipment
- wipe up any spills
- wash your hands thoroughly after use.

Chemical codes

The chemicals in laboratories, supermarkets, pharmacies and hardware shops have warning symbols on their labels. These are a chemical code indicating the nature of the contents (Table 1.2.5). From 1 January 2017, the Globally Harmonised System of Classification and Labelling of Chemicals (GHS) pictograms were introduced into Australia. This system is used for labelling containers and in safety data sheets. Some of the pictograms that you may see denote chemicals that are corrosive, pose a health hazard or are flammable. These chemical codes will need to be analysed and addressed when you are planning and conducting scientific investigations. You will perform a risk assessment in which these chemical codes will be provided, then after analysing them, you may need to modify your experimental plan so that safety is improved.

TABLE 1.2.5 GHS pictograms used as warning symbols on chemical labels

GHS pictogram	Use	GHS pictogram	Use	GHS pictogram	Use
	flammable liquids, solids and gases; including self-heating and self-igniting substances		oxidising liquids, solids and gases, may cause or intensify fire		explosion, blast or projection hazard
	corrosive chemicals; may cause severe skin and eye damage and may be corrosive to metals		gases under pressure		fatal or toxic if swallowed, inhaled or in contact with skin
	low level toxicity; this includes respiratory, skin and eye irritation, skin sensitisers and chemicals harmful if swallowed, inhaled or in contact with skin		hazardous to aquatic life and the environment		chronic health hazards; this includes aspiratory and respiratory hazards, carcinogenicity, mutagenicity and reproductive toxicity

Safety data sheets

Every chemical substance used in a laboratory has a **safety data sheet (SDS)**. This contains important information about the possible hazards in using the substance and how it should be handled and stored. An SDS states:

- the name of the hazardous substance
- the chemical and generic names of certain ingredients
- the chemical and physical properties of the hazardous substance
- health hazard information
- how to store the chemical safely
- precautions for safe use and handling
- how to dispose of the chemical safely
- the name of the manufacturer or importer, including an Australian address and telephone number.

An SDS contains important safety and first aid information for teachers and technicians about each chemical you commonly use in the laboratory.

The SDS provides employers, workers and emergency crews with the necessary information to safely manage the risk of hazardous substance exposure.

- You will now be able to answer key questions 5 and 8.

1.2 Review



SUMMARY

- A research question is a statement that broadly defines what is being investigated.
- The three types of variables are:
 - independent—a variable that is controlled by the researcher (the one that is selected and manipulated)
 - dependent—a variable that may change in response to a change in the independent variable, and is measured or observed
 - controlled variables—variables that are kept constant during the investigation.
- A hypothesis:
 - is a statement that can be tested and is based on previous knowledge and evidence or observations, and addresses the research question
 - often takes the form of a proposed relationship between two or more variables in a cause and effect relationship
 - must be testable; that is, able to be supported (verified) or not supported (falsified) by investigation.
- An aim is a statement describing in detail what will be investigated.
- Primary sources of information are created by a person directly involved in an investigation. Secondary sources of information are a synthesis, review or interpretation of primary sources.
- Ethical and safety considerations must be of the highest priority at all times during a scientific investigation.

KEY QUESTIONS

Knowledge and understanding

- 1 Define the following terms.
 - a research question
 - b hypothesis
 - c aim
 - 2 Which of the following is a research question?
 - A What is the sodium content of baby foods?
 - B The sodium content of baby food is less than 100 mg per 100 g.
 - C Babies need to have a low sodium diet.
 - D Sodium can be measured using gravimetric analysis and atomic absorption spectroscopy.
 - 3 Select the best hypothesis and explain why the other options are not good hypotheses.
 - A If light and temperature increase, the rate of photosynthesis increases.
 - B Transpiration is affected by temperature.
 - C Light is related to the rate of photosynthesis.
 - D If bread is exposed to high light intensities, then it will grow mould faster than bread that is exposed to lower light intensities.
 - 4 Explain the reasons for having a safety data sheet (SDS) for every chemical used in the laboratory.
- Analysis**
- 5 The following inferences may explain why grass growing near the edge of the concrete path remains green in summer.

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

 - a This grass receives the rain runoff from the path when it rains.
 - b The concrete path insulates the grass roots from the heat and cold.
 - c People do not walk on this part of the grass.
 - d The soil under the path remains moist while the other soil dries out.
 - e More earthworms live under the path than under the open grass.
 - 6 You are conducting an experiment to determine the effect of the pH of water on mussel shell mass. Identify:
 - a the independent variable
 - b the dependent variable
 - c at least one controlled variable.
 - 7 Distinguish between ingestion, inhalation and absorption.
 - 8 Decide whether each of the following is a primary or a secondary source.
 - a a newspaper article about global warming
 - b an experiment to investigate chemical changes when mixing combinations of chemicals
 - c an interview with a forensic scientist about using science in tracking criminals
 - d a website with information about genetic engineering