Heinemann

BIOLOGY 2

5TH EDITION

VCE Units 3 & 4
Written for the VCE Biology Study Design 2017–2021

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ALWAYS LEARNING
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Some of the images used in *Heinemann Biology 2* 5e might have associations with deceased Indigenous Australians. Please be aware that these images might cause sadness or distress in Aboriginal or Torres Strait Islander communities.

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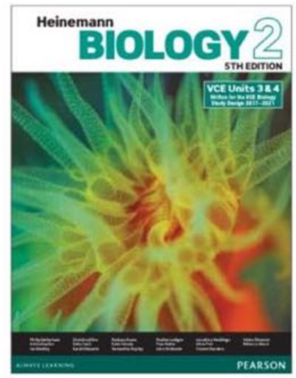

Contents

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Unit 4 How does life change and respond to challenges over time?

AREA OF STUDY 1

How are species related?

AREA OF STUDY 2

How do humans impact on biological processes?

AREA OF STUDY 3 *Heinemann Biology 2 5th Edition ProductLink* provides extensive support material for Unit 4 Area of Study 3 Practical Investigation.

How to use this book

Heinemann Biology 2 5th edition

Heinemann Biology 2 5th edition has been written to the new VCE Biology Study Design 2017–2021. The book covers Units 3 and 4 and is an easy-to-use resource. Explore how to use this book below.


CHAPTER 05 Energy transformation in cells

Learning outcomes

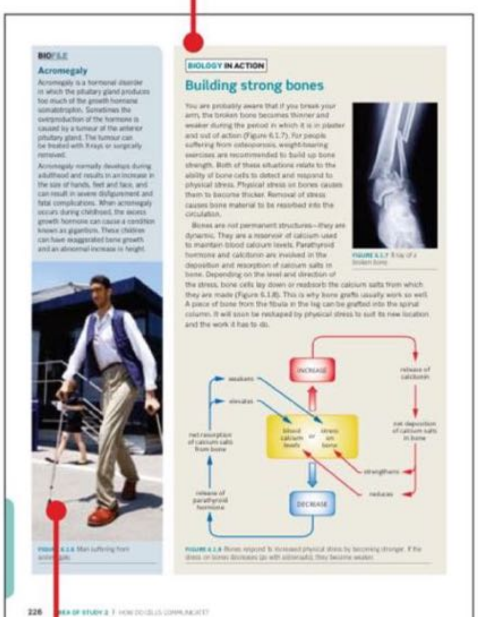
Key knowledge

Chapter opener

Chapter opening pages link the Study Design to the chapter content. Key knowledge addressed in the chapter is clearly listed.

Biology in Action

Biology in Action places biology in an applied situation or relevant context. Text and artwork refer to the nature and practice of biology, applications of biology and associated issues, and the historical development of biological concepts and ideas.


BIOFILE

Acromegaly

BIOLOGY IN ACTION

Building strong bones


EXTENSION

Treatment for allergic reactions

Medications

Allergen immunotherapy

Highlight

Focus on important information such as key definitions and summary points.

BioFile

BioFiles include interesting information and real world examples.

Extension

Extension goes beyond the core content of the Study Design. Material is intended for students who wish to expand their depth of understanding.

Chapter review

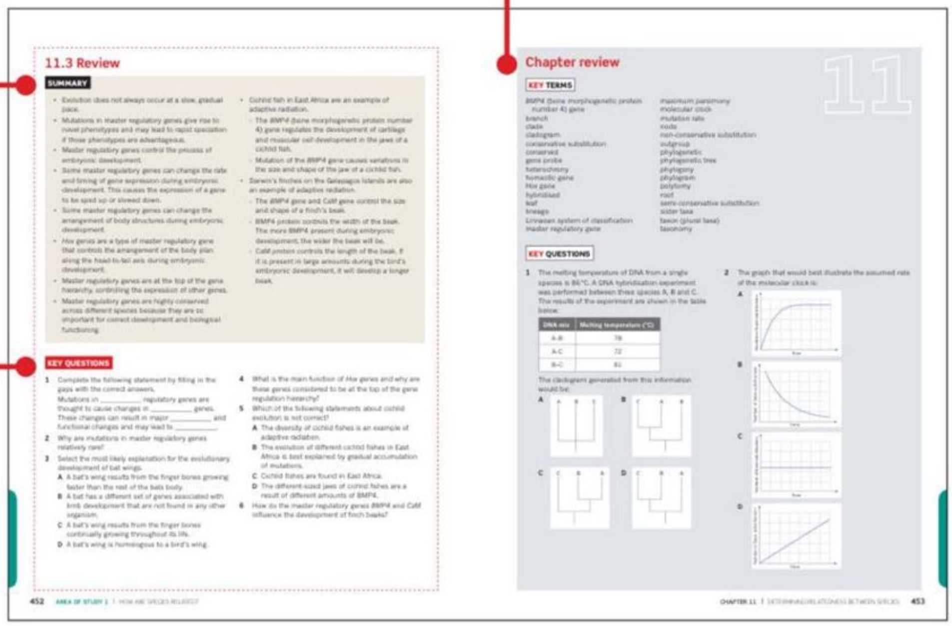
Each chapter concludes with a set of higher-order questions to test students' ability to apply the knowledge gained from the chapter.

Section summary

Each section includes a summary to assist students consolidate key points and concepts.

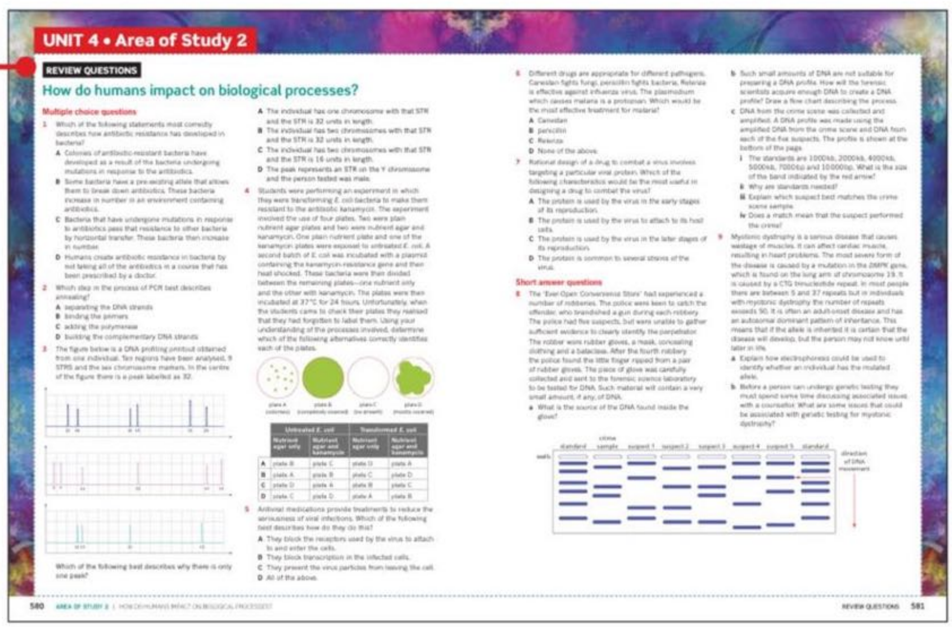
Section review

Each section concludes with questions to test students' understanding and ability to recall the section's key concepts.



Area of Study review

Each Area of Study concludes with a comprehensive set of exam-style questions, including multiple choice and extended response, that assist students in drawing together their knowledge and understanding and applying this to these question styles.



Answers

Comprehensive answers for all section review, chapter review and Area of Study review questions are provided via *Heinemann Biology 2 5th edition ProductLink.*

Glossary

Key terms are shown in **bold** throughout, and listed at the end of each chapter. A comprehensive glossary at the end of the book defines all key terms.

Heinemann Biology 2
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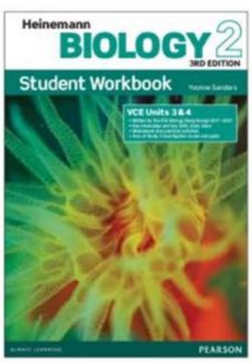
Student Book

Heinemann Biology 2 5th edition has been written to fully align with the VCE Biology Study Design 2017–2021. The series includes the very latest developments and applications of biology and incorporates best practice literacy and instructional design to ensure the content and concepts are fully accessible to all students.

Pearson eBook 3.0

Pearson eBook 3.0 is the digital version of the student book. It retains the integrity of the printed page and is available online or offline on PCs, Macs, Android tablets and iPads.



Student Workbook

A new edition of *Heinemann Biology 2 Student Workbook* gives students the edge in preparing for all forms of assessment. Key features include study notes, worksheets, practical activities and guidance, assessment practice and opportunities to develop and apply key skills.

ProductLink

Heinemann Biology 2 5th edition ProductLink provides comprehensive support for teachers and students, completely free of charge. ProductLink includes comprehensive answers to all Student Book and Student Workbook questions, plus tests, quizzes, practice exams, teaching programs and risk assessments.

Heinemann Biology 2 5th edition ProductLink provides extensive support material for Unit 4 Area of Study 3 Practical Investigation. This includes teacher notes and advice, logbook template and sample logbook, poster template and sample poster, rubrics, checklists and more.

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CHAPTER 01

Biology keystones — Foundation skills

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. The opportunity to develop, use and demonstrate these skills in a variety of contexts is important ahead of 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. It also contains useful checklists to assist when drawing scientific diagrams, graphing and completing aspects of your report. Similarly, when performing a first-hand investigation, refer to this chapter to make sure you collect data properly and that your data is of high quality.

Key skills

Develop aims and questions, formulate hypotheses and make predictions

- determine aims, hypotheses, questions and predictions that can be tested
- identify independent, dependent and controlled variables

Plan and undertake investigations

- determine appropriate type of investigation: conduct experiments (including use of controls); solve a scientific or technological problem; use of databases; simulations; access secondary data, including data sourced through the internet that would otherwise be difficult to source as raw or primary data through fieldwork, a laboratory or a classroom
- select and use equipment, materials and procedures appropriate to the investigation, taking into account potential sources of error and uncertainty

Comply with safety and ethical guidelines

- apply ethical principles when undertaking and reporting investigations
- apply relevant occupational health and safety guidelines while undertaking practical investigations, including following relevant bioethical guidelines when handling live materials

Conduct investigations to collect and record data

- work independently and collaboratively as appropriate and within identified research constraints
- systematically generate, collect, record and summarise both qualitative and quantitative data

KEY SKILLS CONTINUED

Analyse and evaluate data, methods and scientific models

- process quantitative data using appropriate mathematical relationships and units
- organise, present and interpret data using schematic diagrams and flow charts, tables, bar charts, line graphs, ratios, percentages and calculations of mean
- take a qualitative approach when identifying and analysing experimental data with reference to accuracy, precision, reliability, validity, uncertainty and errors (random and systematic)
- explain the merit of replicating procedures and the effects of sample sizes in obtaining reliable data
- evaluate investigative procedures and possible sources of bias, and suggest improvements
- explain how models are used to organise and understand observed phenomena and concepts related to biology, identifying limitations of the models

Draw evidence-based conclusions

- determine to what extent evidence from an investigation supports the purpose of the investigation, and make recommendations, as appropriate, for modifying or extending the investigation
- draw conclusions consistent with evidence and relevant to the question under investigation
- identify, describe and explain the limitations of conclusions, including identification of further evidence required
- critically evaluate various types of information related to biology from journal articles, mass media and opinions presented in the public domain
- discuss the implications of research findings and proposals

Communicate and explain scientific ideas

- use appropriate biological terminology, representations and conventions, including standard abbreviations, graphing conventions and units of measurement
- discuss relevant biological information, ideas, concepts, theories and models and the connections between them
- identify and explain formal biological terminology about investigations and concepts
- use clear, coherent and concise expression
- acknowledge sources of information and use standard scientific referencing conventions.

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, carried out 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.

FIGURE 1.1.1 Biological research may employ diverse approaches and procedures, such as molecular biology. 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.

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 green, 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 cellular structure of plant and animal cells, as well as the specialisations in the cells of a particular organism. Observational studies are a common research method, but they do not explain all the details of how organisms function.

First-hand investigations

The idea for a first-hand 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.

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.

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?
- Are there differences between cellular processes in plants, animals, bacteria, fungi and protists?
- 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?
- What is the molecular basis of heredity and how is this genetic information decoded?

Many of these questions cannot be answered by observation alone, but they can be answered through scientific investigations. Many great discoveries have been made when a scientist has been busy investigating another problem. 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.

● *You will now be able to answer Key Question 1.*

BIOLOGY IN ACTION

Observation and discovery

Scottish physician Alexander Fleming was growing cultures of *Staphylococcus* bacteria in his laboratory in the 1920s (Figure 1.1.3a). Some of the agar plates he was growing the bacteria on became contaminated with a fungus called *Penicillium notatum*. From his observation that the bacteria were unable to grow in the region around the contaminating fungus, Fleming inferred that the fungus was releasing a substance that killed the bacteria. Experiments followed that used extracts from the fungus, and when a paper disc was soaked in this extract and applied to an agar plate culture of *Staphylococcus*, a clear zone appeared around the disc (Figure 1.1.3b). The bacteria could not grow in this area, demonstrating the antibacterial properties of this substance. Fleming named it penicillin after the type of fungus producing the chemical.

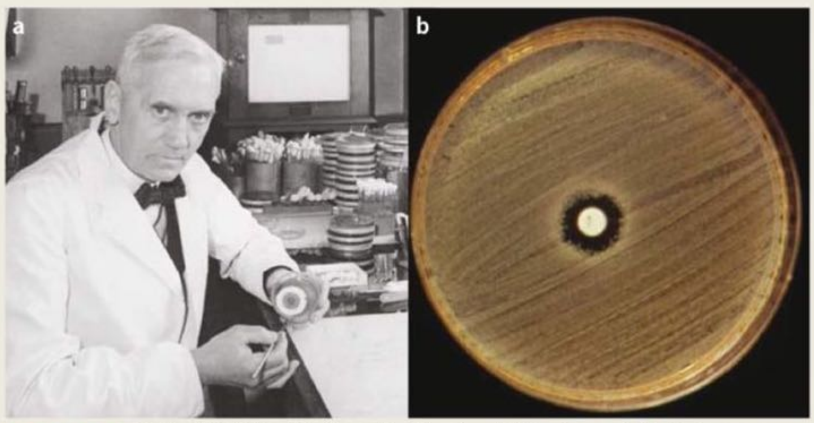


FIGURE 1.1.3 (a) Scottish biologist Alexander Fleming. (b) A culture of *Staphylococcus aureus* bacteria with a white disc containing penicillin placed at the centre. *Staphylococcus aureus* has not been able to grow near the penicillin disc.

After Fleming made the initial key observation that led to the discovery of naturally occurring antibiotics, the Australian scientist Howard Florey (then working at Oxford, England) and his colleagues further developed the methods for extracting penicillin on a large scale, and showed it was effective against staphylococcal and pneumococcal infections. Following the success of penicillin, pharmaceutical companies searched for other naturally occurring antibiotics, many of which were found in fungi (Figure 1.1.4).

FIGURE 1.1.4 An agar plate with fungal colonies. Many naturally occurring antibiotics now used as medications were discovered by studying fungi.

LEARNING BY EXPERIMENTATION

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 possible explanation to a research question that can be used to make predictions, which can often be tested experimentally. This is the basis of the **scientific method** (Figure 1.1.5).

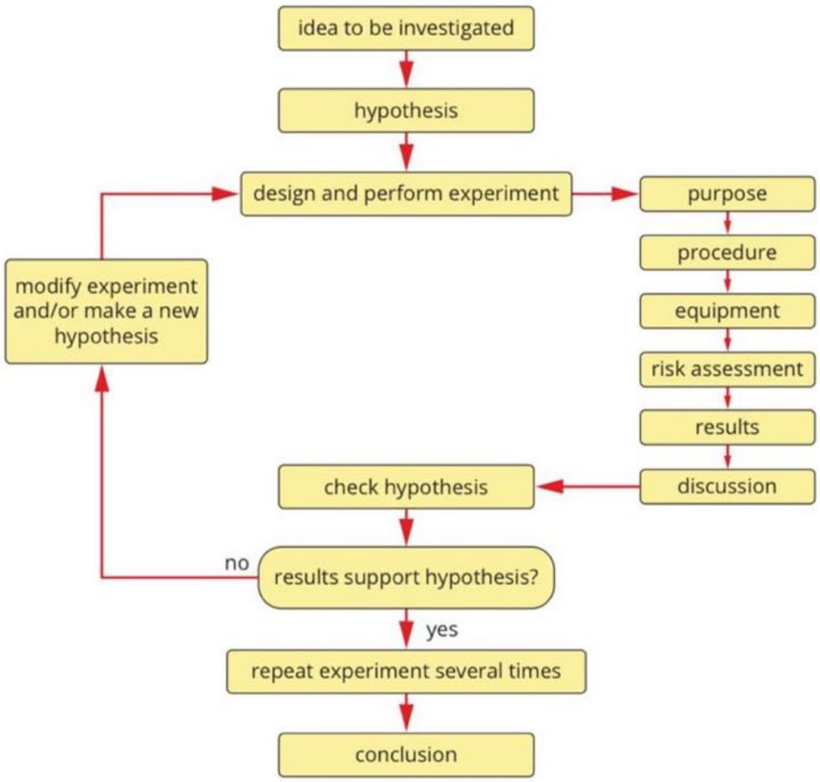


FIGURE 1.1.5 The scientific method.

Carefully designed experiments are carried out 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 experimental approach to the study of science that is called 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.*

ASKING THE RIGHT QUESTIONS

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

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 that 'Hydrogen peroxide is a toxic by-product of respiration that is broken down by catalases. As all eukaryotes undergo respiration they will all 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 3.*

HAVING A GOOD METHOD

Methods must be described clearly and in sufficient detail to allow other scientists to repeat the experiment. If other scientists cannot obtain similar results when an experiment is repeated, then the experiment is 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 experiment must be clearly stated and must be separate from any discussion of the conclusions that are drawn from the results.

In science, doing an experiment once 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%, referred to as $p < 0.05$) 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 4.*

THE NEED FOR EXPERIMENTAL CONTROLS

It is difficult—sometimes impossible—to eliminate all **variables** that might affect the outcome of an experiment. 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.

The variable that the experimenter is testing 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**.

● *You will now be able to answer Key Question 5.*

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.

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

> In an experiment, controlled (fixed) variables are kept constant; only one variable (the independent variable) is changed, and the dependent variable is measured to determine any effect of the change. Experiments and their results must be able to be repeated by other scientists to be validated.

MAKING VALID CONCLUSIONS

Conclusions are based on results and other knowledge. Making valid conclusions depends on the reliability of results and whether they are correctly interpreted. 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 Fleming, that *Penicillium notatum* produced a substance that can kill bacteria, was valid. It has been repeated many times and the principle generalised to the search for other antibiotics in a range of fungi and other organisms including bacteria and plants.

Experiments and their results must be able to be repeated by other scientists to be validated.

BIOFILE

Detecting antibiotic resistance

The conclusion made by Fleming was valid and led to the development of standard operating procedures for detecting antibiotic sensitivity and resistance in bacteria. If a bacterium is susceptible to an antibiotic, its growth around a disc containing the antibiotic is inhibited and observed as a clear zone on the agar plate, called the zone of inhibition. The greater the zone of inhibition, the more sensitive the bacteria are to the antibiotic. If a bacterium has developed resistance to an antibiotic it can grow around its antibiotic disc. Sometimes there is still a small zone of inhibition, but the bacteria are not sensitive enough for the antibiotic to be effective, so they are still considered to be resistant (Figure 1.1.6). The spread of antibiotic resistance by gene transfer between different species of bacteria is an important healthcare problem today. In 2015, the World Health Organization endorsed a global action plan to tackle antimicrobial resistance.

FIGURE 1.1.6 A microbiologist holding two Petri dish culture plates growing bacteria in the presence of discs containing various antibiotics. In the left plate bacteria are not growing around the discs because they are susceptible to the antibiotics on the discs. The plate on the right was inoculated with a carbapenem-resistant Enterobacteriaceae (CRE) bacterium that proved to be resistant to, and therefore able to grow well around, all of the antibiotics tested. Photographed at the Centers for Disease Control (CDC), USA.

LIMITATIONS OF THE SCIENTIFIC METHOD

The scientific method is not perfect; however, it remains the best way to understand our 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, and 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 it depends on being able to grow all fungi and all potential bacterial targets in the laboratory to test this hypothesis.

It is also important to understand that although science can prove a particular hypothesis wrong, it cannot prove that hypothesis to be true in all circumstances—only 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.

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 6 and 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 on 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 1.1.7).

Using digital modelling software to develop physical or mathematical models has enhanced our understanding in many areas. For example, dissection and surgical simulations can replace the practice of dissecting living organisms. As another example, computational modelling enables scientists to handle the huge amounts of data, such as that generated by genome sequencing.

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.

FIGURE 1.1.7 A model of the brain's wiring pattern explored in the Human Connectome Project.

Visual models

Visual models are used to represent concepts. Diagrams and flow charts are examples of visual models (Figure 1.1.8). Computer animations of these structures and processes can give a more dynamic view.

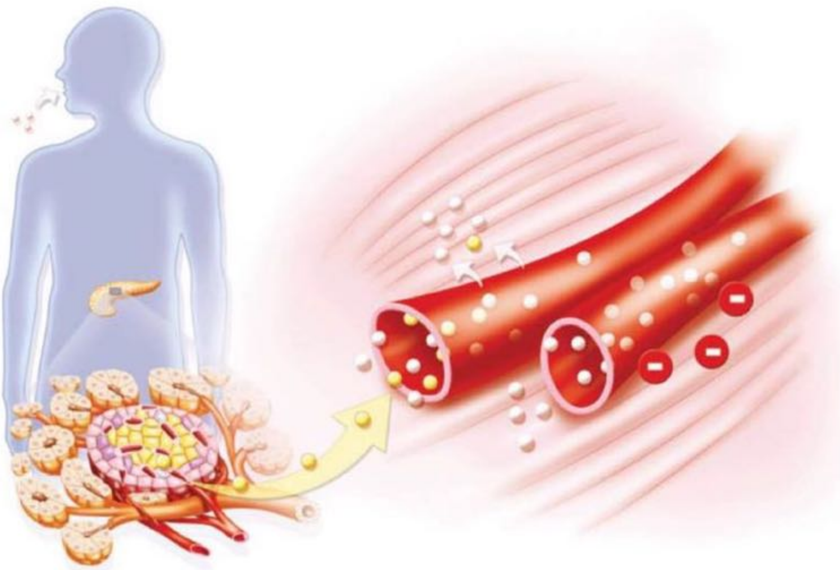


FIGURE 1.1.8 A diagram of a human body with a pancreas, showing aspects of internal structure and an indication of the organ's function, is an example of a visual model. This visual model of the human pancreas has multiple levels of detail. It illustrates the location in the body, the external structure of the organ and its internal cellular architecture, including the islets of Langerhans. It also represents functional elements, in this case release of the hormone insulin from islet beta cells into the blood. Insulin is a signalling molecule that promotes cellular glucose uptake and metabolism.

Physical models

Physical models can be scaled-up or scaled-down three-dimensional versions of reality. You have probably already used physical models many times in the classroom without being aware of it. The human skeleton is a physical model often seen in classrooms.

Although models help us to understand concepts, they are limited in how well they can represent what they are modelling. For example, although a plastic model of a lung does inflate and deflate, it does not take in oxygen and release carbon dioxide, and it is hard and solid instead of soft and flexible.

When making physical models (Figure 1.1.9), it is important to consider what materials are used to represent reality, so that the model has fewer limitations. The materials you use to construct your model should relate to what you are modelling.

FIGURE 1.1.9 A physical model of a pancreas used in a clinical setting to help explain to a patient what is happening in that part of their body.

Computer and mathematical models

The complexity of biological systems has led to the use of mathematical modelling and computer simulations for testing hypotheses and conducting virtual experiments.

Computer simulations and mathematical models are being developed to model the complexity of whole cells, systems, organs or organisms, and allow virtual experimentation. Examples include:

- the bacterium *Mycoplasma genitalium* virtual cell
- connections between cells, for example all of the neural connections in the brain referred to as the connectome
- whole organs (virtual liver and heart)
- whole organisms such as the nematode worm *Caenorhabditis elegans*
- mathematical modelling of the way in which immune cells attack other cells
- gene interactions using data from the human genome project
- relationships between genotype and phenotype, using gene and protein sequence databases
- protein structure and function, using protein sequence databases and three-dimensional molecular modelling.

Bionic models

Physical models are often used as a prototype for developing replacement organs, such as prosthetic limbs. However, the complexity of biological systems limits the capacity of physical models to replace non-functioning organs. Research to make functional models focuses on single functions. Combining physical concepts with computer modelling of biochemical and physiological processes enables the development of models that mimic biological function.

For example, the pancreas is a complex organ with many different specialised cells and functions. Among these, it is the endocrine cells that detect blood glucose levels and release hormones to control blood glucose that are of interest when modelling diabetes. There is a bionic pancreas in development for the treatment of type 1 diabetes, which occurs when insulin-releasing beta cells are damaged. The bionic pancreas uses a glucose sensor to monitor blood glucose and a computer-controlled algorithm to direct the amount of insulin to be delivered by an insulin pump (Figure 1.1.10). Years of research and development are needed to gain enough understanding of the biological processes to develop such devices.

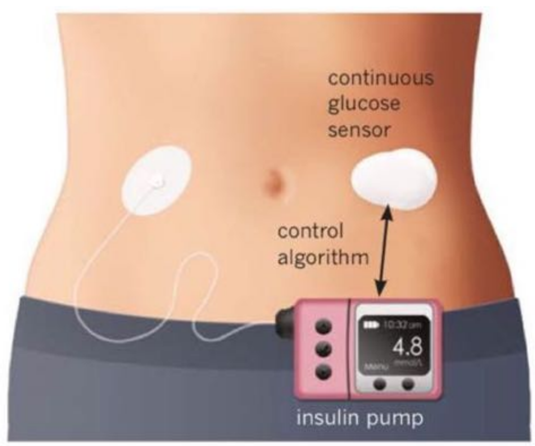


FIGURE 1.1.10 The components of a bionic pancreas developed for people with type 1 diabetes. A glucose sensor samples blood to measure blood glucose concentration. Computations determine whether a signal is sent to the insulin pump, which releases insulin when needed to maintain blood glucose in the normal range.

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 hypotheses in animals 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 1.1.11), rats and mice, the plant *Arabidopsis thaliana*, and the vinegar fly *Drosophila melanogaster*.

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.

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

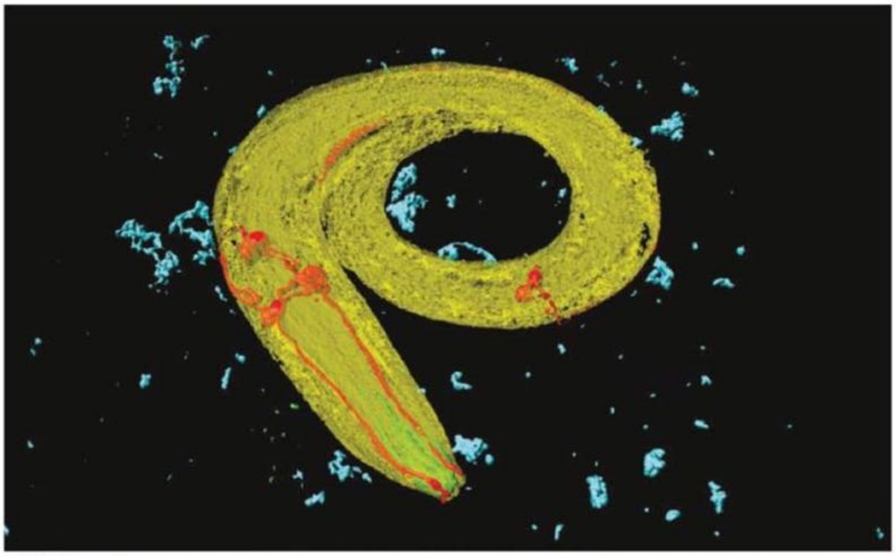


FIGURE 1.1.11 Model organism *Caenorhabditis elegans* worm. Confocal laser scanning micrograph of *C. elegans* with neurons stained green and the digestive tract stained red. *C. elegans* is a soil-dwelling nematode worm about 1 mm long and one of the most studied animals in biological and genetic research. A great deal is known about this organism, including its full genome, details of its life cycle, and the exact number of neurons in its nervous system (302) and how they form the nervous system.

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).

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.

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

- *You will now be able to answer Key Questions 8–12.*

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 experiments.
- 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 the major means of testing hypotheses.
- Science can prove that a particular hypothesis is wrong, but it cannot prove it 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

1 The scientific method is a multistep process. Which two of the following are important parts of the method?
  A observations made by eye and with instrumentation
  B subjective decisions based on data collected
  C careful manipulation of results to fit your ideas
  D the use of prior knowledge to help objectively interpret new data

2 The following steps of the scientific method are out of order. Place a number (1–7) to the left of each point to indicate the correct sequence.

	Form a hypothesis
	Collect results
	Plan experiment and equipment
	Draw conclusions
	Question whether results support hypothesis
	State the biological question to be investigated
	Perform experiment

3 Scientists make observations and ask questions from which a testable hypothesis is formed.
  a Define 'hypothesis'.
  b Three statements are given below. One is a theory, one is a hypothesis and one is an observation. Identify which is which.
    i If skin cells are exposed to UV light, cells will be damaged.
    ii The skin burned when exposed to UV light.
    iii Skin is formed from units called cells.

4 **a** What do 'objective' and 'subjective' mean?
  b Why must experiments be carried out objectively?

5 Define 'independent', 'controlled' and 'dependent' variables.

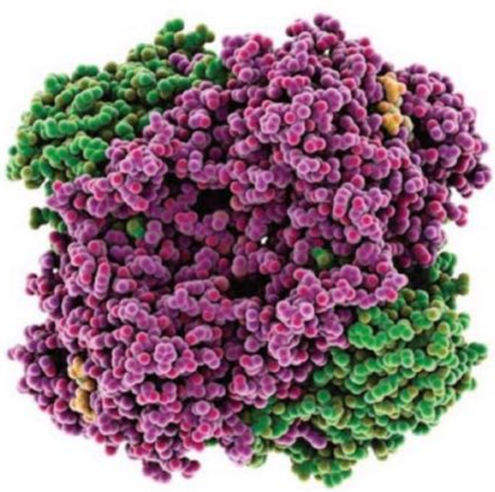
6 **a** Explain what is meant by the term 'controlled experiment'.
  b A student conducted an experiment to find out whether a bacterial species could use sucrose (cane sugar) as an energy source for growth. She already knew that these bacteria could use glucose for energy. Three components of the experiment are listed. Next to each one, indicate the type of variable described.
    i presence or absence of sucrose
    ii measurement of cell density after 24 h
    iii incubation temperature, volume of culture, size of flask

7 A scientist carries out 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 possible reasons that could explain this.

8 Explain what the visual model below represents.

9 The following diagram illustrates a body function involving a feedback loop. Describe what the model shows, and discuss the benefits and limitations of this diagram as a visual model of biological feedback.

10 Below is a molecular model of the enzyme catalase, which converts hydrogen peroxide to water and oxygen. Suggest reasons why scientists construct molecular models in addition to simple diagrams or a written description of its molecular composition.



11 Suggest some limitations of using models. Include examples.

12 Discuss how computer modelling could assist in representing scientific concepts and advancing scientific knowledge.

1.2 Planning investigations

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

First-hand 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 field work) on a range of topics. For Unit 4 Area of Study 3 you are required to design and conduct a practical investigation related to cellular processes and/or biological change and continuity over time.

- 'Cellular processes' are any of the cell processes and biochemical pathways covered in Units 3 and 4, such as respiration, photosynthesis, enzyme regulation, cell signalling via hormones and neurotransmitters, immune responses and gene expression.
- 'Biological change and continuity over time' covers topics in Unit 4 such as changes in allele frequency in populations, impacts of mutation, environmental selection pressures, selective breeding and evolutionary processes.

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. 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 are only suggestions. Select your topic based on what resources are available to you. Before commencing your project, 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
- reagents needed to perform the experiments, such as biochemical test strips (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.

Laboratory experiments may be used to investigate factors affecting cellular and/ or biochemical processes.	Possible topics for laboratory investigation include: • phagocytosis or endocytosis in living cells • photosynthesis in plants, algae or cyanobacteria • respiration in plants, algae, bacteria, fungi or yeast • comparison of photosynthetic pigments by chromatography • enzyme activity in living cells or tissues, or purified enzymes • plant and animal response to infection • cell signalling mechanisms—phototaxis and chemotaxis • antibiotics—mode of action and biological effectiveness • enzymes and electrophoresis for DNA manipulation and analysis • transformation of bacteria by plasmid transfer.
Fieldwork may be used for an investigation on cellular processes or for investigating biological change and continuity over time.	Possible topics for fieldwork investigation include: • collecting samples (e.g. for photosynthetic pigment extraction) • surveying populations for phenotypes and phenotypic change • assessing impacts of selective breeding programs • investigating the role of geological change on populations and evolutionary processes.
The use of data from online databases may facilitate, or be central to, your investigation.	Possible uses of online databases include: • bioinformatics using DNA sequence data • comparison of protein structures with digital 3D protein models • global statistics on disease incidence and vaccination • species distribution • characteristics and images of hominin and other fossils • geological sites of fossil evidence.

TABLE 1.2.1 Potential areas for investigation in Units 3 and 4.

DEFINING KEY TERMS

When you begin a research 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.
- The hypothesis is a suggested outcome of the experiment based on previous knowledge, evidence or observations 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, reading 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 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—Your question must be related to your chosen topic. For your practical 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—Your question must be able to 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.

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 changed)
- 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.

Constructing your hypothesis

The hypothesis is an educated guess (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:

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 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 respiration in yeast will decrease when yeast cells are grown in acidic conditions.

A good hypothesis can be tested to determine whether it is true (verified), or false (falsified) by investigation. To be testable, your hypothesis should include variables that are measurable.

Writing a hypothesis from inference

Scientists often develop a hypothesis by **inference** (reasoning) based on preliminary observations. A **valid** inference is one that explains the observations and gives rise to testable hypotheses.

For example, stem cells are of great interest in biomedical science. Embryonic stem cells (ESCs) are pluripotent, meaning they can differentiate into a range of specialised cells. From the early days of ESC culture in 1981 scientists noticed that stem cells will only maintain their pluripotency if grown on a layer of 'feeder cells' such as fibroblasts (Figure 1.2.2).

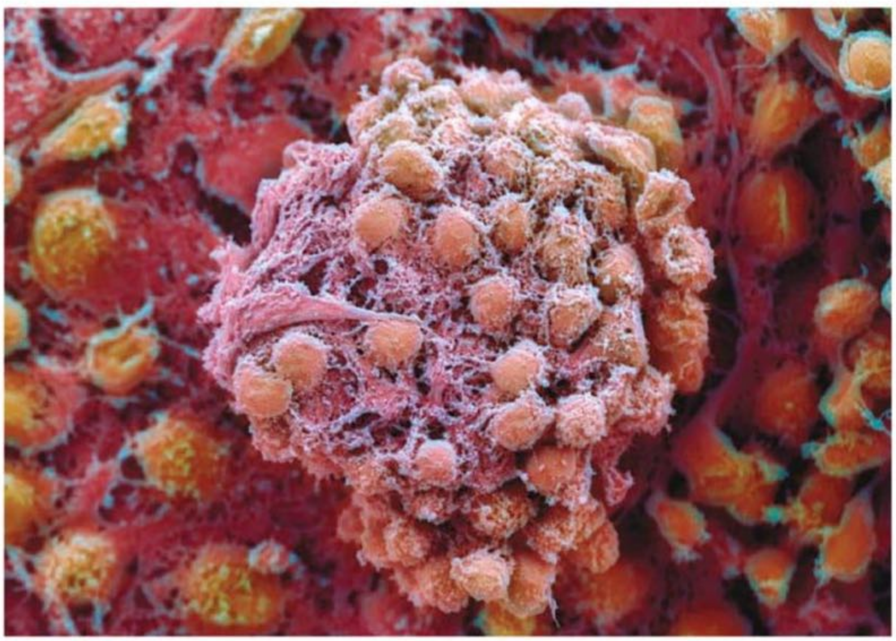


FIGURE 1.2.2 Coloured scanning electron micrograph of human embryonic stem cells that have formed themselves into a round clump. Behind this clump is the 'feeder cell layer' that provides growth signals for the embryonic cells. These cells were grown in 2005 at the Centre for Life, Newcastle Upon Tyne, UK.

Possible inferences about the role of feeder cells in maintaining pluripotent stem cells might be:

- Inference 1: They release molecules that promote cell growth and/or inhibit cell differentiation.
- Inference 2: They alter gene expression in the ESCs.
- Inference 3: Physical contact between the cells is necessary for pluripotency.

Hypotheses formed from these inferences might include:

- that purified molecules from feeder cell cultures will maintain ESC cultures
- that specific genes in ESCs will be turned on or off when grown with feeder cells.

Scientists tested these hypotheses and now know that feeder cells do release signalling molecules that keep the cells in a pluripotent state. You will learn how signalling molecules work in Chapter 6.

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 respiration in yeast.

Research question	If I grow yeast cells in higher amounts of glucose, will they respire faster?
Independent variable	glucose concentration
Dependent variable	rate of respiration (measured as CO_2 release)
Controlled variables	yeast culture volume, temperature, light conditions
Potential hypothesis	The rate of respiration in yeast will increase as glucose concentration increases.

TABLE 1.2.2 Summary table of example research question, variables and potential hypothesis.

● *You will now be able to answer Key Questions 1 and 2.*

Determining your aims

The aims are the key steps required to test your hypothesis. Each aim should directly relate to the variables in the hypothesis, describing how each will be studied or measured. The aims do not need to include the details of the method.

Example 1

- Hypothesis: If a person has a bacterial infection, then the number of neutrophils in the blood will be elevated.
- Aim: To compare microscope slides of blood samples (blood smears) from infected and healthy subjects.
- Variables: blood smears (independent) and number of neutrophils (dependent).

Example 2

- Hypothesis: If algae are exposed to low light levels, 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 3–6.*

SOURCING INFORMATION

When 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 and secondary sources provide valuable information for research.

Sometimes the same type of resource may be classified as both a primary and a secondary source, depending on when and by whom it was written. 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 accurate, reliable and valid sources of information. You will learn about assessing the accuracy, reliability and validity of data in Section 1.4.

	Primary sources	Secondary sources
Characteristics	• first-hand records of events or experiences • written at the time the event happened • original documents	• interpretations of primary sources • written by people who did not see or experience the event • use information from original documents but rework it
Examples	• 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)	• textbooks • biographies • newspaper articles • magazine articles • radio and television documentaries • websites that interpret the scientific work of others • podcasts

TABLE 1.2.3 Summary of primary and secondary sources.

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. Good science magazines are more accessible to a non-expert, because they interpret the complex primary data and present it in a way that is easy to understand.

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). Reputable science magazines you might find in your school library include *New Scientist*, *Cosmos*, *Scientific American* and *The Helix* (Figure 1.2.3).

FIGURE 1.2.3 A reputable science magazine you might find in your school library.

	Book resources	Internet resources
Advantages	• written by experts • authoritative information • proofread, so information is accurate • logical, organised layout • content is relevant to the topic • contain a table of contents and index to help find relevant information	• 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	• may not have been published recently • usable by only one person at a time	• 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

TABLE 1.2.4 Advantages and disadvantages of book and internet resources.

Searching online

Online sources include online magazines, the websites of print magazines such as those described above, the news and education sections of major journals such as *Science* magazine and *Nature-Scitable*, and podcasts and blogs (institutional, company and personal). Bioscience animations can also be found at the Walter and Eliza Hall Institute's WEHI-TV, the Tree of Life web project, and the education and resource sections of museum websites.

Often you will not be able to access journal papers without a journal subscription. 'Open access' sources are science papers and/or databases that are made available to everyone, without needing to purchase a subscription. Open access journals and databases are good sources of primary information. They include the Public Library of Science journals (e.g. PLOS Biology, PLOS Genetics), and the US National Center for Biotechnology Information (NCBI), a source of gene sequences and protein structures.

When searching for relevant information you need appropriate search terms to enter into a search engine. Here are some tips when searching online:

- Break your search statement into concepts and key words.
- Find synonyms, other related terms and concepts that apply to the topic.
- Create concepts of 1–3 words to enter into the search engine.
- Try different combinations of terms.
- Don't settle for the first sites on the list or your first attempt; look through the results for sites from science organisations and research institutions (e.g. CSIRO, WEHI, NIH; .gov, .org), universities (.edu) and science journals and magazines.

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 this checklist:

- ☐ 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 points 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 to other reputable sources, including books and science journals.

Evaluating books and journals

Your textbook should be your first source of reliable information. Other information should be consistent with this. 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.

● *You will now be able to answer Key Questions 7 and 8.*