NELSON
A Cengage Company

INVESTIGATING SCIENCE IN FOCUS

YEAR 11

Dr Silvia Rudmann
Sarah Collins
Kirstin Ellard
Bill Matchett

CENGAGE Learning™

This is a legal agreement between the you, (the "Customer") and Cengage Learning Australia Pty Limited (ABN 14 058 280 149) (the "Licensor") which provides the terms and conditions of this non-exclusive licence and the limited warranty for the Product. Use of the Product indicates an acknowledgement that the Customer has read and agreed to be bound by the terms and conditions of this Agreement. If you do not agree to these terms and conditions, return the Product to the place of purchase within 15 days of the date of purchase (with proof of purchase) for a full refund

1. **Licence Grant**
   You do not receive title to the Product. Copyright in the Product (which includes all images, photographs, video, animations, audio, music and text incorporated in the Product, including all of the accompanying printed material) is owned by the Licensor and/or its suppliers and is protected by Australian copyright laws. The Licensor grants you a non-exclusive licence to use the Product subject to the restrictions and terms set out in this Agreement.

2. **A Licence allows you to:**
   Use the Product on your computer. The Customer represents that they shall in no way place the Product in the public domain or in any way compromise our copyright in the Material. You agree to take reasonable steps to protect our copyright.

3. **You may not:**
   Alter, modify, translate, reverse engineer, decompile, or adapt the software or create derivative works based on the Product. Make further copies by any means technological, electronic, digital whatsoever without the written permission of the Licensor. Rent or transfer all or any part of your rights under this Agreement. Remove or alter any copyright or other proprietary notice or label attached to the software.

4. **Termination**
   Any failure to comply with the terms and conditions of this agreement will result in the automatic termination of this licence. Upon termination of this licence for any reason, the Customer must destroy or return to the Licensor all copies of the software and accompanying documentation.

5. **Warranties**
   To the extent permitted by law, the Licensor's liability for any breach of the warranty or any term implied by law into this licence is limited to the lowest cost of replacing the goods, acquiring equivalent goods or having the goods repaired.

INVESTIGATING SCIENCE IN FOCUS

YEAR 11

Dr Silvia Rudmann
Sarah Collins
Kirstin Ellard
Bill Matchett

NELSON
A Cengage Company

Investigating Science in Focus Preliminary
1st Edition
Dr Silvia Rudmann
Sarah E. Collins
Kirstin Ellard
Bill Matchett

Publishing editor: Eleanor Gregory
Project editor: Simon Tomlin
Editor: Kirstie Irwin
Proofreader: James Anderson
Indexer: Don Jordan, Antipodes Indexing
Cover design: Chris Starr (MakeWork)
Text design: Watershed Design
Art direction: Aisling Gallagher
Cover image: iStock.com/gremlin
Permissions researcher: Catherine Kerstjens/Corrina Gilbert
Production controller: Erin Dowling
Typeset by: Macmillan Publishing Solutions

Any URLs contained in this publication were checked for currency during the production process. Note, however, that the publisher cannot vouch for the ongoing currency of URLs.

For product information and technology assistance,
in Australia call **1300 790 853**;
in New Zealand call **0800 449 725**

For permission to use material from this text or product, please email **aust.permissions@cengage.com**

National Library of Australia Cataloguing-in-Publication Data
A catalogue record for this book is available from the National Library of Australia.

Cengage Learning Australia
Level 7, 80 Dorcas Street
South Melbourne, Victoria Australia 3205

Cengage Learning New Zealand
Unit 4B Rosedale Office Park
331 Rosedale Road, Albany, North Shore 0632, NZ

For learning solutions, visit **cengage.com.au**

Printed in China by 1010 Printing International Limited.
1 2 3 4 5 6 7 21 20 19 18 17

CONTENTS

9780170411196

6 MODULE 4 THEORIES AND LAWS 146

INTRODUCTION

Preface

Investigating Science in Focus has been written to meet the requirements of the NESA NSW Syllabus for the Australian Curriculum – Investigating Science Stage 6 Syllabus. Each page has been carefully considered to provide students with all of the information they need to meet the content and skill requirements of the new syllabus including opportunities for inquiring further.

With the introduction of the student-focused depth studies, *Investigating Science in Focus* includes scaffolds for a range of depth studies at the end of each module of work. Additional ideas for depth studies are included in the PowerPoint presentations found on NelsonNet.

About the authors

Dr Silvia Rudmann

Silvia is a passionate science teacher with classroom and executive experience. She is an experienced senior biology teacher, HSC marker and GATS program coordinator.

Sarah Collins

A highly experienced classroom teacher with executive experience, Sarah is the regional representative on the NESA Science Inspector advisory group.

Kirstin Ellard

A highly motivated science teacher, Kirstin has worked with a variety of students, ranging from the gifted and talented to the disengaged.

Bill Matchett

An experienced author, executive and classroom teacher, Bill has also been a school certificate marker and HSC marker.

Review team

The following people have contributed to the review of the *Investigating Science in Focus* series: Lisa Dean, Katherine Mason and Catherine Munro.

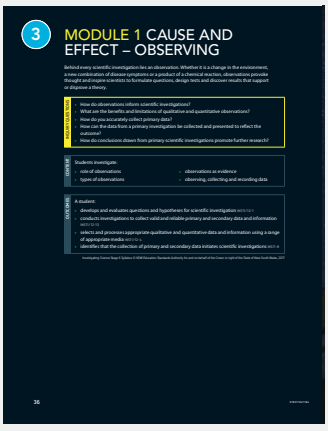
USING *INVESTIGATING SCIENCE IN FOCUS*

At the beginning of the text

- Chapter 1 introduces students to the process of working scientifically.
- Chapter 2 guides students through the key stages when preparing for and completing a depth study.

At the beginning of each chapter

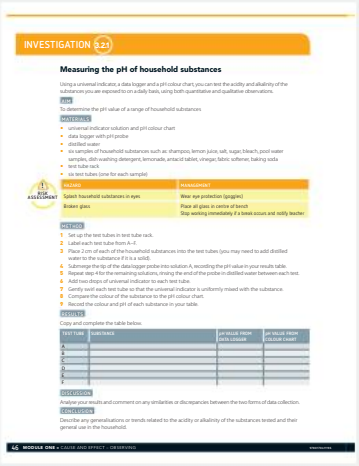
- A short chapter summary for Chapters 3–6 introduces students to the key content and skills covered
- Inquiry questions help engage and pre-test students before introducing them to the content
- Key content and outcomes are listed to contextualise students' learning



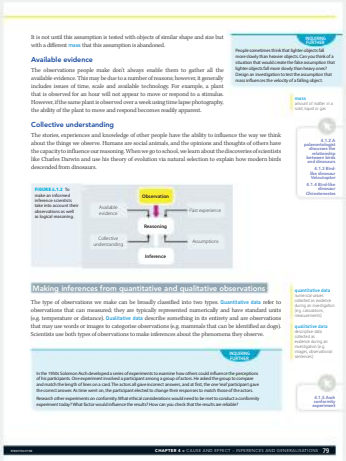
9780170411196

In each chapter

- A step-by-step approach to the content in the syllabus
- Key glossary terms are highlighted in the margin
- Inquiring further provides opportunities for students to further investigate scientific concepts and develop scientific research skills
- Investigations (practical experiments) contain guided instructions on the materials, method collection, analysis of results and discussion


INVESTIGATION 2.1

Measuring the pH of household substances

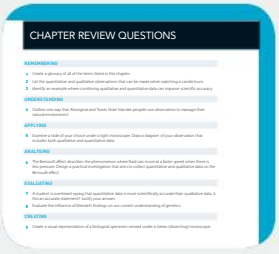

Available evidence

Collective understanding

Making inferences from quantitative and qualitative observations

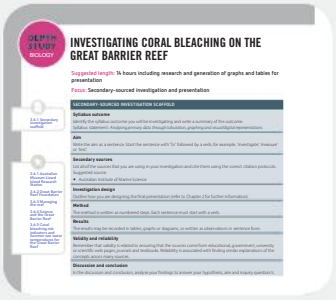
At the end of each chapter

- Chapter review written in the style of Bloom's Revised Taxonomy
- Depth study scaffolds for biology, chemistry, physics and general science topics


CHAPTER REVIEW QUESTIONS

At the end of the book

- Glossary of all of the new terms introduced in the text
- Answers to section and chapter review questions


INVESTIGATING CORAL BLEACHING ON THE GREAT BARRIER REEF

NelsonNet

NelsonNet is your protected portal to the premium digital resources for Nelson textbooks, located at **www.nelsonnet.com.au.** Once your registration is complete, an exciting and stimulating digital is available for each of the chapters. you will have access to a helpful suite of digital resources for each chapter to further enhance and reinforce learning.

Each chapter will be supplemented with the following digital resources.

- Worksheets to review concepts and to practise applying understanding to new examples
- Links to websites that contain extra information. These are hotspotted within the NelsonNetBook.

The NelsonNet teacher website contains:

- Teaching program, in Microsoft Word and PDF formats
- Editable PowerPoints
- Chapter pdfs of the textbook
- Search feature for all NelsonNet resources.

Disclaimer

Please note that complimentary access to NelsonNet and the NelsonNetBook is only available to teachers who use the accompanying student textbook as a core educational resource in their classroom. Contact your sales representative for information about access codes and conditions.

SYLLABUS REFERENCE GRID

OUTCOMES	INVESTIGATING SCIENCE IN FOCUS YEAR 11
SKILLS	
Objective: students develop skills in applying the processes of working scientifically	
Questioning and predicting	
INS11/12-1 Develops and evaluates questions and hypotheses for scientific investigation	Chapter 1, Chapter 2, Chapter 3, Chapter 4
Planning investigations	
INS11/12-2 Designs and evaluates investigations in order to obtain primary and secondary data and information	Chapter 1, Chapter 2, Chapter 4, Chapter 5
Conducting investigations	
INS11/12-3 Conducts investigations in order to obtain primary and secondary data and information	Chapter 1, Chapter 2, Chapter 3, Chapter 5
Processing data and information	
INS11/12-4 Selects and processes appropriate qualitative and quantitative data and information using a range of appropriate media	Chapter 1, Chapter 2, Chapter 3, Chapter 4, Chapter 5
Analysing data and information	
INS11/12-5 Analyses and evaluates primary and secondary data and information	Chapter 1, Chapter 2, Chapter 6
Problem solving	
INS11/12-6 Develops and evaluates questions and hypotheses for scientific investigation	Chapter 1, Chapter 2, Chapter 6
Communicating	
INS11/12-7 Communicates scientific understanding using suitable language and terminology for a specific audience or purpose	Chapter 1, Chapter 2, Chapter 6
Knowledge and understanding	
Objective: students develop knowledge and understanding of cause and effect	
INS11-8 Identifies that the collection of primary and secondary data initiates scientific investigations	Chapter 3
INS11-9 Examines the use of inferences and generalisations in scientific investigations	Chapter 4
Objective: students develop knowledge and understanding of models, theories and laws	
INS11-10 Develops, engages with, modelling as an aid in predicting and simplifying scientific objects and processes	Chapter 5
INS11-11 Describes and assesses how scientific explanations, laws and theories have developed	Chapter 6

9780170411196

1 WORKING SCIENTIFICALLY

We often work scientifically in our daily life without realising that we are applying scientific skills. For example, when we cook a new recipe we collect the ingredients and follow a method, we take care with safety hazards and create a delicious meal. Hence, we follow the scientific method and intuitively, we apply scientific skills. In science, we move from the intuitive aspects of our everyday life to more structured and explicit skills, to research inquiry questions and inferences which arise to understand the world around us.

In today's world the practice and nature of science is more interconnected and less linear than it has been in previous centuries. Hypotheses and methods are redefined and modified depending on the analysis of data. Collaboration amongst scientists from across different scientific disciplines helps to deepen knowledge about the science behind the investigation, and consolidates the understanding of scientific concepts and processes.

Shutterstock.com / 26kot

9780170411196

1.1 Questioning and predicting

inquiry question
driving force of the research and can be investigated scientifically

In science, the question is more important than the answer. The first time a phenomenon is observed in the natural world, questions form in an attempt to develop an explanation for, and consequently understand, what is happening. **Inquiry questions** in science are formulated to try to explain an idea and inferences about an observed phenomenon. To create or formulate a scientific question or inquiry question, it is vital to understand that the question should be able to be investigated scientifically following the steps in the scientific method.

A good research inquiry question has the following characteristics:

- should be able to be investigated by gathering data
- does not have a pre-set or determined answer
- is the driving force of the research
- provides structure to the research.

1.1.1 Questioning

INQUIRING FURTHER

Imagine you are observing an eagle flying in circles on the top of grasslands. How many scientific questions can you formulate? Refer to the characteristics of a good research inquiry question above as you formulate your response.

Formulating hypotheses

Once the question is formulated, a **hypothesis** is created. A hypothesis is an educated (informed) guess that is tested through experimentation to answer a scientific question. In the hypothesis, the **independent variable** (factor that changes) and **dependent variable** (factor that is measured or tested) are related in a simple statement (Table 1.1.1).

hypothesis
educated guess tested through experimentation to answer the inquiry question; states the relationship between the independent and dependent variables

independent variable
factor deliberately changed during an investigation to obtain data

dependent variable
factor measured in the investigation (e.g. plant growth, boiling point, speed)

TABLE 1.1.1 From an idea to a hypothesis

RESEARCH IDEA	RESEARCH QUESTION	HYPOTHESIS
Television and consumer behaviour	How does the number of repetitive advertisements affect consumerism in adolescents?	Adolescents buy more products if there are more advertisements for those products on television.
Tyre pressure and speed in cycling	How does tyre pressure affect the speed of a bicycle?	The speed of the bicycle will increase when the tyre pressure increases.
Soil acidity and plant growth	Why does the acidity of the soil affect the number of flowers?	Soil that is more acidic will have fewer flowers.

Writing a hypothesis

A hypothesis is a statement or assertion. In the hypothesis statement, the dependent and independent variables are related. As a general rule, to write a proper hypothesis both variables must be in the hypothesis statement. For example, writing a hypothesis that says, 'Sunlight burns leaves' is a factual statement. If the same sentence is written combining the dependent and independent variables, it would read, 'The amount of sunlight (independent variable) will affect the process of photosynthesis (dependent variable)'. The second statement shows the relationship between the two variables.

The more specific the hypothesis, the easier it will be to design the experiment.

KEY RULE

To write a hypothesis statement use the scaffold:

The … (independent variable) will affect, increase or decrease the … (dependent variable).

9780170411196

WORKED EXAMPLE 1.1.1

1 A farmer is growing a new variety of lettuce, and has the following question:
How much fertiliser do I need to apply to get the most leaves from lettuces?

2 The farmer passed on the question to the local research centre and the following hypothesis was created:
An increased amount of fertiliser (independent variable, what is changing) will increase the number of leaves (dependent variable, what is being measured) in lettuces.

3 In this hypothesis, the independent variable will be the different amounts of fertiliser and the dependent variable is the number of leaves in the lettuce.

Modification of questions and hypotheses

Sometimes, over the course of the data collection and analysis, new hypotheses and questions arise. This is a common consequence of the nature and practice of science and it is not considered a problem. It is common to see scientists changing their ideas and refining their hypothesis over the course of the investigation as a result of new evidence. However, it is important to keep in mind the focus of the investigation because time and resources may be wasted if the new hypothesis is very remote from the original researched topic. For example, if the hypothesis is about how the quality of light affects photosynthesis rate and over the course of the experiments the evidence shows that light quality is not showing any difference in photosynthesis rates, a new hypothesis might arise to test the position of the plants towards the light. This revised hypothesis is a good one as it takes into account the observations while also keeping in mind the original focus (in this case, photosynthesis rates).

Data collection

Now that the hypothesis is clear, the next step will be to think about the type of **data** that needs to be collected to test that hypothesis. There are two main types of data: primary and secondary data. Primary data refers to the **empirical data** collected from experiments, and tests done in the laboratory and on field trips. The data could be as simple as a list of observations or as complex as numerical measuring data. The numerical data is organised in tables or graphs for further analysis or for application in mathematical equations. When the collection of data is coming from experiments that the scientists themselves have collected, the investigation is called a primary investigation.

data
numerical or observational facts collected together as evidence for analysis

empirical data
information collected by observations or measurements during an investigation

iStock.com/IPGGutenbergUKLtd

Imagefolk/Photofusion/UIG

FIGURE 1.1.1 Primary data is collected from primary investigations; for example, from experimental methods or field trips. Samples collected in the field are then processed in the laboratory for further analysis.

Secondary data refers to previous data published in scientific literature related to the topic that the investigation is based on. It is data that other scientists have already collected to test a similar hypothesis. Secondary sources include web pages, books and articles published in journals. The most important thing when using secondary sources for data collection is that they are **valid**. The validity of secondary data relies on the sources coming from educational, government or scientific institutions where the data is evaluated by a board of scientists before it is published. This ensures that the data and information is accurate and reliable. When the data collected comes from secondary sources, the investigation is called a secondary investigation.

valid
extent to which a report or investigation contains accurate data, inferences and conclusions

1.2 Planning investigations

Once the research inquiry question and the hypothesis have been established, the next step is to create a design or plan for the investigation and the collection of data. Starting an investigation without a plan will not only waste time and effort but is also unlikely to deliver valid results. Before beginning an investigation, you should consider the following questions.

- What kind of data do you need to collect?
- What equipment or materials do you need?
- How many variations of the independent variable will you test?
- What are the safety issues that you should consider?
- How are the results going to be recorded and analysed?
- What steps are you going to follow to test the hypothesis?

To answer those questions, you need a plan and a **log book** to keep track of the progress of your research. A log book is an important tool in research because it allows you to keep records, identify **errors** and change or improve methods if needed. It is the journal of your research. Every scientist around the world has a research log book. Log books are very valuable because if a scientist wants to repeat experiments or come back to the 'raw data' collected, all the information is recorded and readily available.

log book
journal taken during the investigation where all data, observations, results, inquiries and conclusions are registered

error
measure of the estimated difference between the observed or calculated value of a quantity and its true value

Aim

Writing an **aim** for the investigation is important. This statement, together with the hypothesis and the inquiry question, helps to keep the investigation focused.

To write the statement for an aim, start with a verb; for example, 'To investigate; To measure; To collect', then add the relationship between the variables from your hypothesis; for example, 'To investigate the effect of high levels of CO_2 (independent variable, different levels of CO_2) on the length of the leaves (dependent variable, plant growth) of grasses'.

aim
purpose of the investigation

accuracy
level to which a measurement, calculation, or specification conforms to the correct value or a standard

true value
measurement with no errors

Selection of materials, technologies and identification of safety risks

So far the question, the hypothesis and the aim should all show the relationship between what is going to be investigated and how. When these statements have been clearly written, the selection of equipment or materials to perform a primary investigation (experiments) or review secondary sources (theoretical research) can take place.

The equipment selected to be used in the experiment should accurately measure and collect data. Because **accuracy** is defined as how close a result is to the **true value**, an accurate data set will have minimal errors. Therefore, the measurements should be taken with equipment that is made and calibrated for its purpose. For example, measuring the length of a plant with a ribbon is less accurate than measuring with

a ruler, and testing the pH (acidity) of a substance with litmus paper is less accurate than measuring with a **data logger**.

The **safety hazards** associated with an investigation must be identified before any experimentation takes place and statements explaining how to avoid those hazards are explicitly written. For example, a few safety hazards to keep in mind when designing experiments include: chemical spillages, electric shocks, chemical fumes, broken glassware, allergic reactions, and eye and skin contact with chemicals. Once those hazards are identified, a **risk assessment** takes place to avoid or deal with them. For instance, taking the example of broken glassware, the risk assessment statement should say, 'Handle glassware with care, in case of broken glassware notify the teacher'. The risks in science are correlated by their likelihood and severity of consequences, as shown in Table 1.2.1. For example, a strong acid spillage may be considered to have a possible likelihood of occurring with either moderate or major consequences.

data logger
electronic or digital device that records data either with a sensor or digital aid

safety hazard
expected risk during an investigation

risk assessment
evaluation of the risks of an investigation

TABLE 1.2.1 Risk assessment matrix.

Risk matrix		Likelihood				
		Rare	Unlikely	Possible	Likely	Almost certain
Consequence	**Severe:** For example, potentially fatal or causing an injury or illness with permanent disability	MEDIUM	MEDIUM	HIGH	EXTREME	EXTREME
	Major: For example, causing a 'potential time lost' injury, but non-permanent disability	LOW	MEDIUM	MEDIUM	HIGH	EXTREME
	Moderate: For example, an injury or illness requiring moderate medical treatment but no lost time	LOW	LOW	MEDIUM	MEDIUM	HIGH
	Minor: For example, an injury potentially requiring application of first aid	LOW	LOW	LOW	MEDIUM	MEDIUM
	Minimal: For example, a hazard or near-miss that requires reporting and follow-up action	LOW	LOW	LOW	LOW	LOW

Ethical issues

Ethical issues should also be considered during the planning of the investigation. For example, if the experiment involves animals, their welfare should be kept in mind and methods to follow should be discussed with the teacher and school authorities.

INQUIRING FURTHER

More information and research about ethical issues in science can be investigated from the J. Reilly Center, University of Notre Dame, Indiana, USA.

If the collection of data will involve interviewing people or they have to answer surveys, the questions should avoid bias or inappropriate comments. A valid questionnaire for interviews or surveys must be objective and with the hypothesis to test in mind.

ethical
relating to moral principles and values

Method and variables

Method

A **method** is written in numbered, chronological steps. Each step starts with a verb followed by clear, simple instructions that indicate how to perform the experiment. The more meticulous the instructions in each step are, the easier and more repeatable the investigation is. The validity of the method relies on the clarity of the steps and ensures that the hypothesis is tested fairly. A valid method can also ensure the experiment is **reliable** because other scientists are able to repeat it, and obtain similar and comparable results.

If the data collected is for a primary or secondary investigation, the steps in the method are slightly different. In a primary investigation, the steps should specify variables but in a secondary investigation the steps are related to how the secondary resources are going to be managed.

method
experimental steps to follow to collect data and test the hypothesis of an investigation

reliability
extent to which an observation and/or measurement can be repeated under the same circumstances and produce similar results

variable
measurable factor that can be changed or maintained in an experiment

treatment
variation of the independent variable

control
experimental set-up where the independent variable is not applied

voltage
force pushing electrons around the circuit

controlled variable
factor that is kept constant during the experiment

1.2.1 Virtual lab – dependent and independent variables

1.2.1 Designing investigations

Variables, control and treatments

As part of the method, the **variables** should be clearly identified to ensure the validity and reliability of the experiment. There are three types of variables: the dependent, independent and controlled variables. The identification of those variables and how they are going to be managed during the collection of data are the key to a successful experiment.

The independent variables are those factors that you change in the experiment. In the independent variable, the variations are called **treatments**. There is one treatment that does not have the independent variable which is called the **control**. The control treatment is the one that takes out the effect of the independent variable on the measurements, it is the one used to compare with the other treatments to see if the effects of the independent variable are valid. The different amounts of fertiliser, the different concentrations of chemicals reacting and the different heights that a ball is dropped are all examples of independent variables.

The dependent variables are the features or factors that are measured or tested in the experiment. For example, plant growth, density of a material and **voltage** in a conductor. The changes in the dependent variable are influenced by the different treatments (variations) of the independent variable.

The **controlled variables** are all the factors that are kept the same to reduce error in the experiment. For example, the same equipment is used to measure across all the treatments, the amount of heat, the amount of light, the temperature of the room, the amount of water, the timing of the experiment. Keeping other variables constant ensures that the changes in the dependent variable are only influenced by one independent variable. If the results of the experiment do not look as expected usually it is because there were some controlled variables that were not kept the same for the entire experimental time.

It is very important to be clear about the differences in terminology. Controlled variables are variables kept constant during the experiment and a control is a treatment without the independent variable.

WORKED EXAMPLE 1.2.1

QUESTION

Observe the images of an experiment and identify the dependent, independent and controlled variables, as well as the control and treatment.

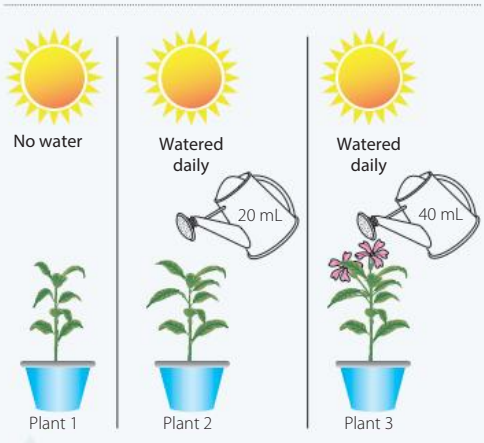


FIGURE 1.2.1 Investigating the effect of the amount of water on plant growth.

ANSWER

The experimental design can be deconstructed as follows:

- independent variable: amount of water (0, 20 and 40 mL)
- dependent variable: plant growth
- controlled variables: type of plant, room temperature, amount of sunlight, soil type, pot size, watering time
- control: Plant 1 (no water)
- treatments: Plant 2 (20 mL of water) and Plant 3 (40 mL of water).

9780170411196

Sample size and replications

The reliability of the design, and consequently the results, depends on the amount of data collected and the number of replications of both the individual treatments and of the entire experiment. A large **sample size** is also important to reduce the impact of unusual results and allows for averages. For example, if testing the effect of the amount of water on plant growth, it is best to test it on many plants so that if one plant dies there are others that can be used to keep the measurements going.

sample size number of observations or replications in an experiment

The number of samples in an experiment is determined by the nature of the experiment, in some cases five samples is enough but in others more than a hundred are needed. As a rule of thumb, the bigger the sample size the better.

Replications are done in two ways: replicating each treatment and replicating the entire experiment. For example, to test the hypothesis, 'Increasing the amount of water will increase the height of plants' you will need five plants per treatment and a control. You also need to repeat the experiment three times to increase the reliability. Averages are calculated from all the data collected ensuring statistical validity.

Modifying and evaluating the investigation

An investigation is not a linear process. During the course of the collection of data, new evidence may emerge that does or does not support the hypothesis. Another issue is that the variables chosen may be difficult to measure with the technology available. Consequently, the original investigation plan is re-evaluated and a new plan is constructed.

Critical thinking is crucial to evaluate the investigation, and consultation with other researchers is important because an open collaboration helps accelerate the evaluation process and the resulting plan is more refined.

1.3 Conducting investigations

Conducting an investigation refers to the testing of your hypothesis statement by collecting data. The nature of the investigation may be primary (collecting empirical data from experiments) or secondary (collecting theoretical data from bibliographic references and previous work conducted on the researched topic by other scientists). In primary investigations, secondary sources are referenced as a way to compare the empirical results with previous findings by other researchers.

The data and results must be methodically recorded in the log book for later analysis. Safety procedures and risk assessments are followed to ensure a safe work practice. It is important to keep the inquiry question and hypothesis in mind so that no unnecessary data is collected and no time is wasted. Accuracy and reliability of the conducted investigation are ensured by using appropriate technologies and replications.

The work in the investigation may be done individually or in teams. This will depend on the nature of the work. However, it is very important to work collaboratively and share the information gathered from the investigation. This allows for a better review of the methods, and analysis of data and evidence that support the hypothesis.

1.3.1 Conducting investigations

Safe work practices

Safety is the first and most important consideration in conducting any investigation. The management of chemicals, equipment and practices done in the laboratory or in the field must follow safety procedures and risk assessments to ensure a safe environment for everyone.

Personal protective equipment

Personal protective equipment (PPE) must be used at all times when dealing with experimental practices. Some examples of PPE include: safety glasses or goggles, enclosed-toe safety shoes, disposable gloves, disposable apron or lab coat, hard gloves, long pants and a mask.

Assessing risks

Risk assessments are used to identify, assess, reduce and control safety hazards when conducting investigations. Risk assessments are completed for every investigation. To start writing a risk assessment, the following questions are answered:

- What are the hazards in this experiment that can cause injury?
  For example, chemicals, heat, broken glass, poison, animals in the field and tripping over things.
- What are the risks to consider for the environment, people or animals involved in the investigation?
- How serious are the risks and how likely are those risks?
  A risk assessment matrix should be created in the log book for further reference (see Figure 1.2.1 on page 5).

Chemical safety

Chemicals used in investigations can be harmful, corrosive, irritant, poisonous or flammable. Those hazards are identified on the bottle of the chemical with a diamond symbol. Some common chemical hazard symbols are shown in Figure 1.3.1.

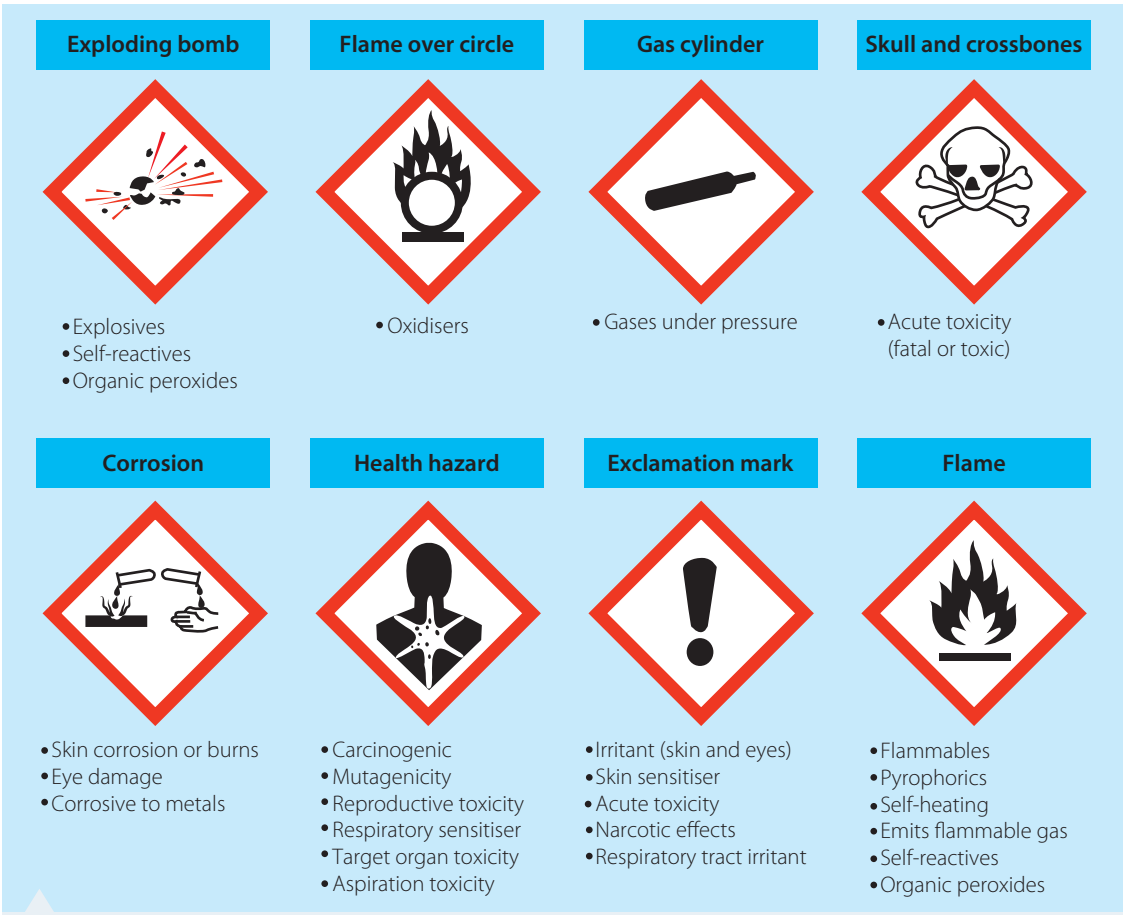


FIGURE 1.3.1 Pictograms from the Global Harmonised System used to label chemicals at school.

Each chemical has a material safety data sheet in which important information about the chemical is described; for example:

- chemical and generic name of all the ingredients in the substance
- chemical and/or physical properties of the substance
- health hazard information
- safe handling of the substance
- manufacturer's name and contact details
- first aid information
- storage conditions.

Always consult with the teacher and/or laboratory assistant before using the chemicals in your investigation and always read the labels.

1.3.1 Model code of practice: preparation of safety data sheets for hazardous chemicals

Safe use and disposal of living samples

Hazards and risks when dealing with living samples are avoided by using protective gloves and masks. For example, wear gloves and a mask when handling pollen to reduce the risk of an allergic reaction. Dissections should be conducted with care. Scalpels and glass slides to observe tissue samples under the microscopes must be handled with care. Cultures in agar plates should never be open when bacteria or contaminated samples are used in the investigation as the bacterial cultures may be pathogenic.

Shutterstock.com/Billion Photos

FIGURE 1.3.2 Observe that the researcher is wearing gloves when handling the agar culture.

To avoid contamination of a cell culture, a laminar flow cabinet can be used and all the surfaces must be cleaned with ethanol 80%. Flaming the inoculation loops on the Bunsen burner kills all the bacteria, while the hot flame creates an updraft and also kills the surrounding airborne contaminants.

After the work with living samples is finished, they should be autoclaved and then disposed. This reduces the risk of environmental contamination. All equipment used in dissections of animal and plant tissues must be cleaned thoroughly before storage.

If the investigation involves the handling of animals, the welfare of vertebrates and invertebrates is protected by state and federal laws, and they must be treated respectfully. Collection of live specimens from the field needs to follow the specific regulations for that area to protect native **species**. Be aware of the laws in the local area and consider if an alternative type of investigation can be conducted instead of using living samples.

species group of living organisms with similar characteristics that can interbreed

Technologies and accuracy

Different technologies and equipment are used to collect data when conducting an investigation. The type of equipment and the technologies to measure and collect data depends on the nature of the investigation. The aim in selecting and choosing different equipment is focused on how well that equipment or technology will ensure accuracy in the investigation.

The selection of an appropriate technology to measure or carry out the experiment accurately, and therefore collect valid data to test the hypothesis, is very important. For example, if the experiment requires a measurement of pH, it is better to use a pH data logger probe connected to a computer

than litmus paper. This is because the data logger collects specific numerical data of pH, whereas the litmus paper changes colour to give an estimation of pH. However, if a data logger is not available, the measurements can be done with a universal indicator and comments can be made in the discussion of the investigation about how to improve the measurements using more accurate technologies.

Information from secondary sources

During the design, carrying out and analysis of the investigation, secondary sources are consulted to gather theoretical data and information about the researched topic. The selected and extracted information is reliable when the secondary sources are published by scientific, government and education institutions where the information has been assessed and evaluated by scientists and experts before being made available to the public. Table 1.3.1 compares some of the different types of secondary sources.

TABLE 1.3.1 Comparison of secondary sources

VALID AND RELIABLE SECONDARY SOURCES	
ARE ✓	ARE NOT ×
Educational textbooks	General fiction books
Education and government institution web pages	Non-educational web pages
Scientific journals and articles	Articles in popular magazines
Encyclopedias	Discussion blogs in social media

Once the secondary sources are selected and information is extracted, they have to be cited correctly in alphabetical order in a reference list or bibliography. It is good practice to cite them as soon as they are used to avoid misplacing information and data. Creating a reference section in the log book is a handy idea.

There are different formats to cite secondary sources. Each educational institution follows specific formats which depend on the type of secondary source used: such as web pages, books, articles or journals. But as a general example, a good secondary citation follows the following format:

KEY FORMULA

Author/s surname, Initial of first name. (published year). *Title of the book section or web page section*. Name of the book, scientific journal or web page. City: Publisher name (for a book)/ page numbers (for a journal) / URL (for a web page).

For example:

- **Book**

  Diamond, J. (2000). *Guns, Germs and Steel: A Short History of Everybody for the Last 13 000 Years*. London: Vintage Publishing.

- **Article from a scientific journal**

  Brack, A., & Eliazer, S. (2016). Stem cells: Cause and consequence in aged-muscle decline. *Nature*, 349–350.

9780170411196

- **Web page**

  Howard, J. (2016). *Seven Ways Astronauts Improve Sleep May Help You Snooze Better on Earth.* Retrieved from International Space Station NASA: https://www.nasa.gov/mission_pages/station/research/astronauts_improve_sleep

1.4 Processing data and information

There are two types of data that can be collected in an investigation: qualitative and quantitative data. **Qualitative data** refers to non-numerical data and **quantitative data** are data that can be quantified or numerically collected and recorded (Figure 1.4.1).

qualitative data descriptive data collected as evidence during an investigation (e.g. images, observational sentences)

quantitative data numerical values collected as evidence during an investigation (e.g. calculations, measurements)

The way that data are organised, displayed and represented helps in the interpretation and analysis of the results. Organising data aids scientists to observe trends and patterns, and to reach conclusions about the hypothesis being investigated.

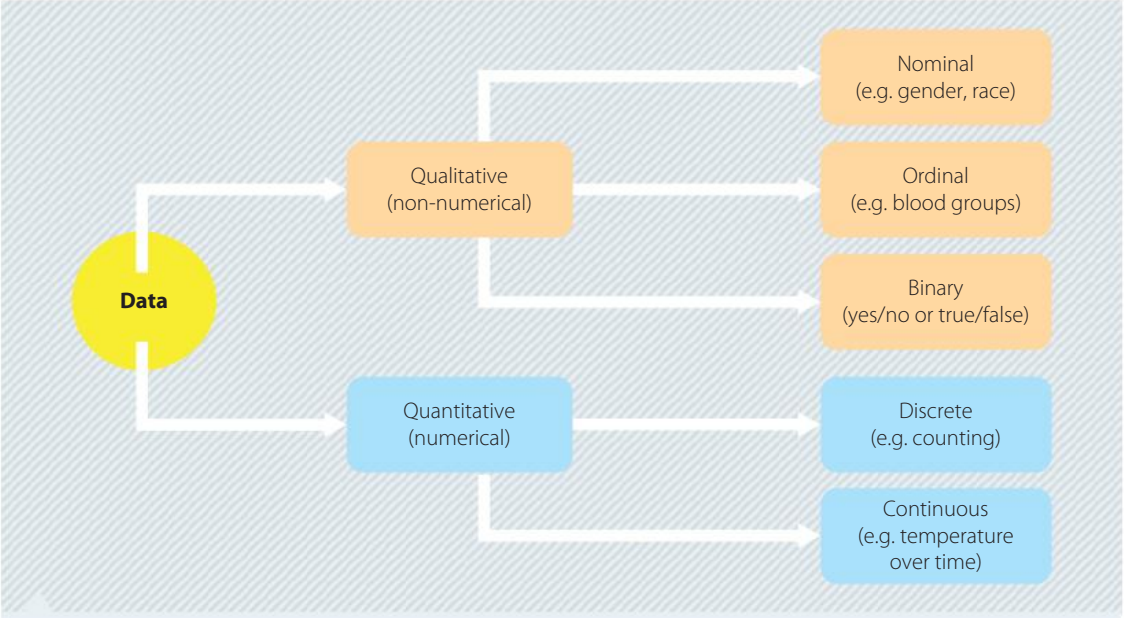


FIGURE 1.4.1 Classification of the types of data that can be collected during an investigation.

To represent and organise the data different types of tools can be used: tables, graphs, infographics, diagrams, flow charts or digital media. The type of tool used depends on whether the type of data collected is qualitative or quantitative. The selection of how data will be represented is essential because from that representation inferences can be made and errors can be identified.

Representing quantitative data

Tables are the best representation for numerical data. All the information collected in the experiment can be organised in tables where the relationship between the independent and dependent variable can be observed clearly. In tables, any unusual results can be identified, and inferences about the method used to collect that data or how other variables were not controlled properly can be made. A table consists of rows and columns, with appropriate headings and units of measurement in each heading (Figure 1.4.2)

Table 1. Title of table

TIME (MIN)	TEMPERATURE (°C)
0	25
1	38

Headings with units →

Data →

Independent variable ↑

Dependent variable ↑

FIGURE 1.4.2 Example of how to construct a table.

Graphs are visual representations of data and show the relationship between the independent and dependent variables. Graphs help to identify patterns and trends that may not be noticeable from a table. It is a common rule to represent the average of the results in a graph and always calculate an equation of the **line of best fit** to see what plotted data is 'out' from the common pattern or trend. Data outside the line of best fit helps to identify mistakes in measurements or equipment for that particular investigation.

line of best fit trendline that best fits the plotted data, it goes through the centre of the plotted data

The rules to follow in order to construct a graph can be remembered by using the acronym TALS (Figure 1.4.3).

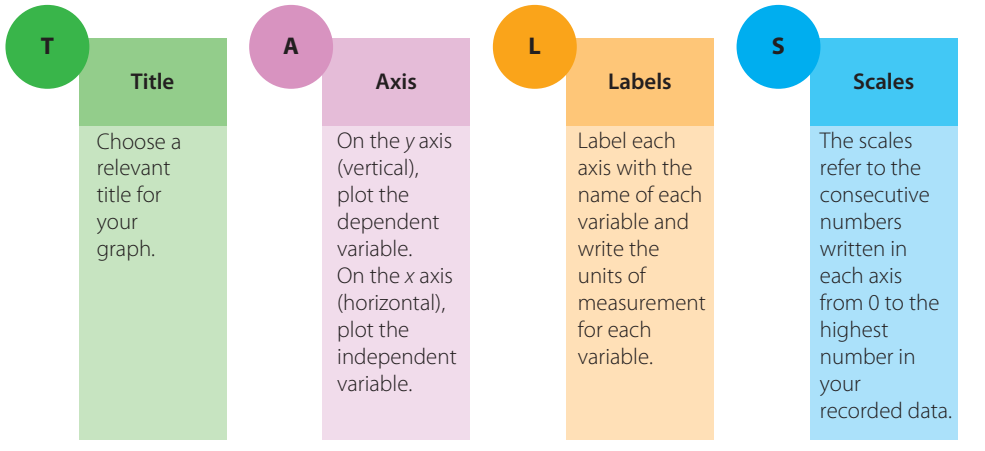


FIGURE 1.4.3 TALS, an acronym to remember how to draw a graph.

9780170411196

Types of graphs for quantitative data

Quantitative data can be separated into two categories: discrete and continuous. The type of graph used to represent these categories is different (Figure 1.4.4). Line graphs are better suited to represent continuous quantitative data such as temperature over time, speed over time or reaction rate over temperature. However, for discrete quantitative data, pie charts and column graphs represent the measured points better.

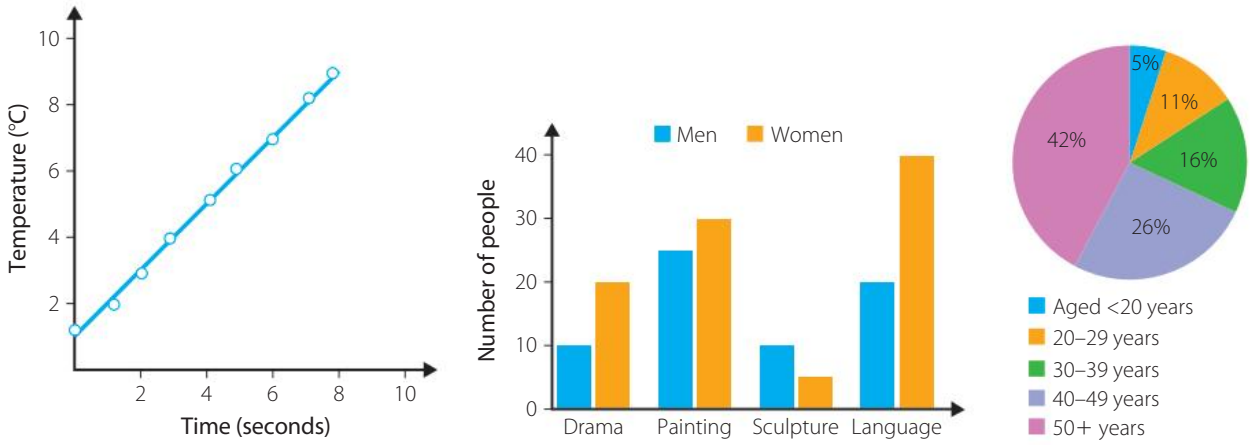


FIGURE 1.4.4 Different types of graphs to represent continuous (line graph) or discrete (pie and column graphs) quantitative data.

Representing qualitative data

Qualitative data is represented in different formats from quantitative data because the data collected is not numerical. The most suitable formats are lists, tables, flow charts and diagrams. Digital technologies, such as video clips, animations and PowerPoints, can also be useful methods to present the data collected.

In qualitative data, the non-numerical data may be represented as numerical data. This is done by assigning a numerical representation to each observed response in the investigation. For example, if the data collected is coming from a survey, each response can have a numerical value and in this way the analysis of the responses becomes easier from a statistical point of view. Representing qualitative data as numerical data also makes it easier to represent data in a graph to observe patterns and trends.

WS
1.4.1 Graphing skills

Evaluate and improve the quality of data

Data collected during an investigation is evaluated for its quality. This uncovers data defects such as errors related to the technology used, sampling techniques or sample size. To improve the quality of data, the sample size should be big enough so that there is sufficient statistical data to manipulate and reduce the error.

The identification of unusual data (i.e. data that is very different from the average calculated value) is important to reduce the statistical error and improve the consistency of the results. Taking out the unusual data from the data pool allows a much better picture of patterns and trends in the data analysis.

Sometimes, measurements will need to be taken again to improve the quality of the data because a new technology has been improved or the technology used was not calibrated properly for the particular data collected.

1.5 Analysing data and information

A more thorough analysis of the data collected in an investigation is needed to ensure that the hypothesis was tested fairly and is supported by the results of the research. The examination of patterns, trends and relationships from the information gathered during the investigation, the identification of error, uncertainty and limitations in data, and the evaluation of relevance, accuracy, validity and reliability of the primary and secondary data collected is crucial for the analysis of the investigation.

uncertainty interval (±) around the measured value compared to the true value

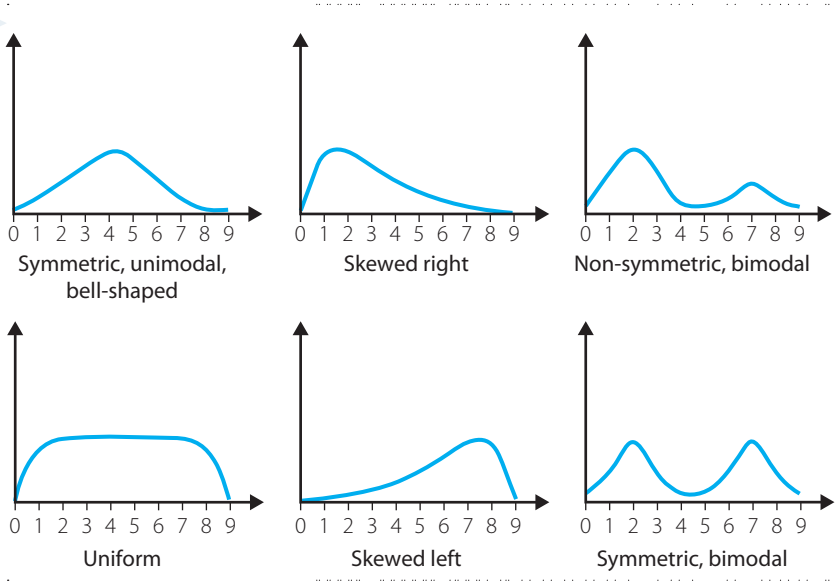
Derive patterns, trends and relationships

The best way to interpret data is to plot it. The visual representation of the line in the graph will indicate the patterns and trends between the dependent and the independent variable and therefore their relationship.

Patterns

A pattern from a graph is represented by the 'shape of the curve' or the distribution of the data. For example, the distribution can be bell-shaped, symmetric, spread, centred or repetitive (with 'up and down' points). The pattern can be uniform if all the dots are spread evenly across the graph or skewed if the dots have an uneven distribution across the graph (more dots to one side or peaks at different levels). Figure 1.5.1 shows the different possible patterns observed from graphs.

FIGURE 1.5.1
Patterns in graphs



Sometimes, there are plotted data points that are 'out of the pattern'. These data points might be related to a mistake in the collection of data, or due to an unseen or uncontrolled variable.

Trends

A trend in a graph is the direction or the tendency of the line created by the plotted dots. Once the data is plotted, the line of best fit is traced over the dots to see the trend in the data. The trend can be ascending (increasing), descending (decreasing), stable or variable (Figure 1.5.2). All of the measured points that fit between the minimum and the maximum values plotted can be interpolated.

interpolation estimating new data points within the range of data points

9780170411196

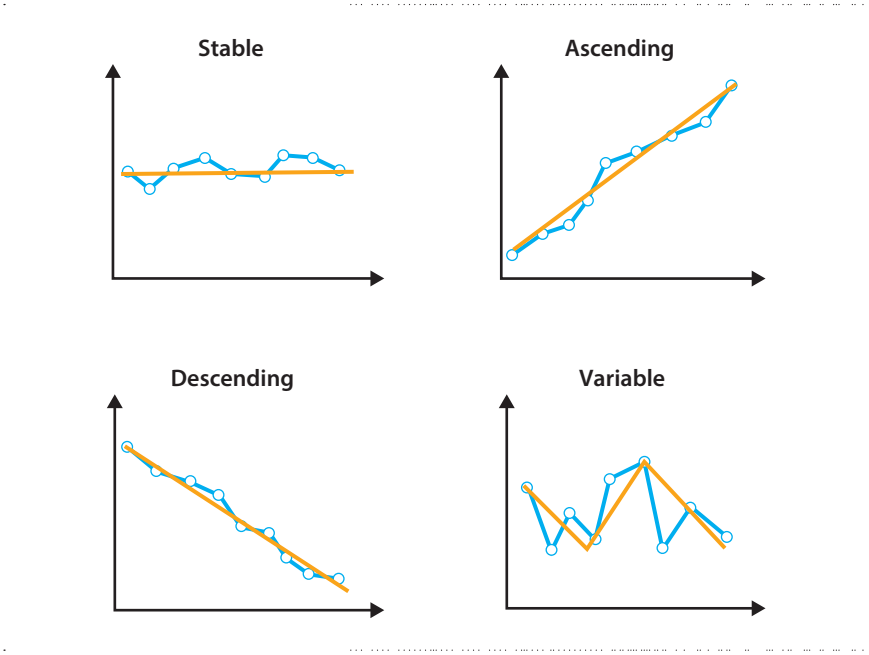


FIGURE 1.5.2 Trends in data. The orange lines are the lines of best fit for each plotted data set. The lines of best fit represent ascending, descending, variable and stable data trends.

For example, if your data measurements are 25, 38 and 45 g, the numbers between those measured numbers can be identified using the graph. The line of best fit can be extended beyond the measured points in the graph; this is called **extrapolation**. However, inter- and extrapolations should be used cautiously because you cannot be certain that the experimental system behaves in the same way at that point as for the other measured points.

extrapolation extension from a range of plotted data to infer new values from the known ones

Relationships between variables

The relationship between the dependent and the independent variable is represented by the patterns and trends. The relationship can be:

- positive – for every increasing value of the independent variable, the dependent variable increases. For example, the higher the amount of fertiliser the higher the plant growth is.
- negative – for every increasing value of the independent variable, the dependent variable decreases. For example, as the environmental temperature increases the number of hot chocolates sold decreases.
- no relationship – the values of the independent and dependent variable are scattered across the graph showing no pattern or trend. For example, the amount of time listening to music does not affect the science test marks.

Error, uncertainty and limitations in data

Error

Identifying errors, uncertainty and limitations in the experimental data collected aids in ensuring the validity of the results. There are two types of error in experiments: systematic and random. A systematic error is a mistake when taking the measurements and usually relates to the technology or equipment not being calibrated properly for the purpose of the measurement, or that the equipment is not suitable for those measurements. Systematic errors are difficult to identify because the data seems to have a pattern and trend but usually the hypothesis is not supported by those results. A random error is easy to identify because it is an unpredictable fluctuation in the measurements due to malfunction of the equipment at the moment the data was collected for that point. Repetitions of the measurements will show if the error is systematic or random.

Another type of error is related to the acceptance of the hypothesis being investigated. Those errors are called type I and type II errors. A type I error refers to the rejection of a hypothesis when the hypothesis is true (e.g. telling a woman that she is not pregnant when in reality she is pregnant). A type II error refers to the acceptance of a hypothesis when the actual hypothesis is wrong (e.g. telling a man that he is pregnant). Table 1.5.1 compares the differences between these two types of errors.

TABLE 1.5.1 Difference between type I and type II errors.

		REALITY OF HYPOTHESIS	
		TRUE	**FALSE**
Results or findings from the research	**TRUE**	Acceptance of a true hypothesis	Type II error (β) Acceptance of a hypothesis that is false (false negative)
	FALSE	Type I error (α) Reject a hypothesis that is true (false positive)	Rejecting a wrong hypothesis

Uncertainty

1.5.1 Statistics in science

No physical or chemical quantity can be measured with perfect certainty so there is always some uncertainty in the measurement. The uncertainty is the best estimate of how far an experimental quantity might be from the 'true value'. For example, a measurement of 7.05 g ± 0.02 g means that the experimenter is confident that the actual value for the quantity being measured lies between 7.03 and 7.07 g.

Uncertainty is reduced when the entire experiment is repeated following a valid method and using suitable equipment. The more repetitions of the entire experiment, the less the uncertainty in the results. At this point, it is important to distinguish between standard deviation and standard error. Standard deviation is how 'spread' a measurement is from the average of measurements. A standard error is how 'spread' the average of the repetitions of the entire experiment is; therefore, the standard error is a statistical measurement of uncertainty.

KEY FORMULA

Measurement = best estimate ± uncertainty

where

Measurement refers to the type of data collected (e.g. height, distance)

Best estimate refers to the numerical measurement taken

± **uncertainty** is the distance around the estimated value

Limitations in data

Data collected can have limitations due to the nature of the experiment, equipment used or unforeseen variables when the experiment has taken place. In primary investigations, the limitations in data are usually related to the type of equipment used or the environmental conditions where the experiments have taken place. For example, the equipment can take measurements to a certain value and some data cannot be collected below or above that value, or if the experiment is carried out in the field the weather conditions cannot be predicted or controlled.

In secondary investigations the limitations are related to the type of tool used to collect data; for example, a survey, focus groups, interviews or secondary sources of information. In this case, there is not much control over the responses from individuals and there can be bias.

Relevance, accuracy, validity and reliability in data

In primary or secondary sourced data, the relevance, accuracy, validity and reliability are important aspects to consider ensuring that the data can support the hypothesis being tested. Table 1.5.2 shows the differences between those parameters.

1.5.1 Analysing

TABLE 1.5.2 Evaluation of primary and secondary data in terms of relevance, accuracy, validity and reliability.

PARAMETERS EVALUATED	PRIMARY DATA	SECONDARY DATA
Relevance: data shows how close it is to the tested hypothesis	Data tested the hypothesis to be investigated	Data shows a close relationship with the topic investigated and tested the hypothesis
Accuracy: data is close to the 'true value' of the measurements	Data shows little error	Data from different secondary sources shows little variation in information
Validity: data is collected using a valid method and suitable equipment	Methods and equipment used did not limit the data collected and tested the hypothesis	Data comes from valid sources (educational, government and scientific institutions publications)
Reliability: data collected is similar for each repeated measure	Data shows little uncertainty	Small variation of information across secondary sources used in the investigation

1.6 Problem solving

Scientific research can be very challenging because unexpected problems may arise at any time. Problems in conducting investigations can be related to the equipment, technologies, environmental hazards or variables that cannot be controlled or managed. To solve these problems different strategies can be applied, such as to create a model, apply a mathematical calculation, re-create the experiment, change equipment or improve the method. Identifying the cause-and-effect relationship in the problem can also help to contextualise the problem and therefore allow a solution to be found (Figure 1.6.1). Critical thinking and creativity are additional important processes when trying to understand a problem, and in designing the steps to overcome the issue and solve it.

Sometimes reaching a solution from a scientific problem is difficult. In this case, predictions are made using explanations based on scientific theories and principles that support the evidence for the investigation.

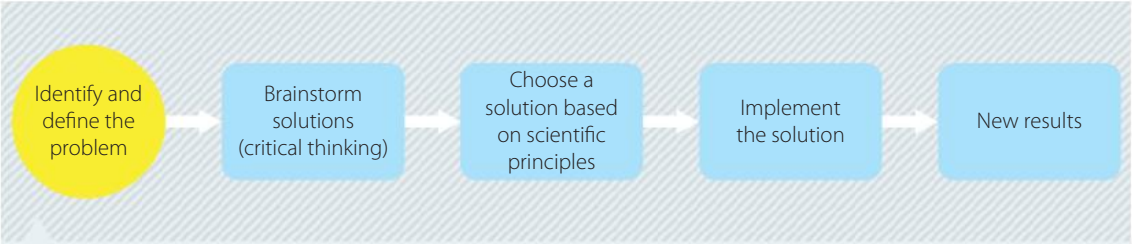


FIGURE 1.6.1 Steps in problem solving. The first step is to identify and define clearly the problem. This is followed by critical thinking to brainstorm solutions which are chosen based on scientific principles . When the solution is implemented, new results are achieved.

Models in solving problems

model
two- or three-dimensional representation or description of a process, system or idea

Models can be used to simplify and solve complicated scientific problems such as molecular structures, complex biochemical processes or large scale phenomena. A model can be a mathematical equation, a two- or three-dimensional representation or come in a digital computerised form. Models have limitations because sometimes they are too simple and detailed information is not represented, but they are a good strategy to make predictions and analyse solutions in a simple way.

Critical thinking skills to solve problems

Critical thinking is often used to solve problems and reach conclusions about the world around us. Critical thinking is not the simple, straightforward idea that comes to mind when someone tries to understand and solve a problem. Critical thinking refers to the more complex process of reasoning to merge ideas and concepts from different disciplines to form a comprehensive solution to the problem encountered. A good critical thinker solves the problem using systematic collection of information rather than using intuition. Consequently, solving problems arising in scientific investigation requires critical thinking to select the best change in the investigation and reach the most effective outcome.

1.6.1 Solving problems

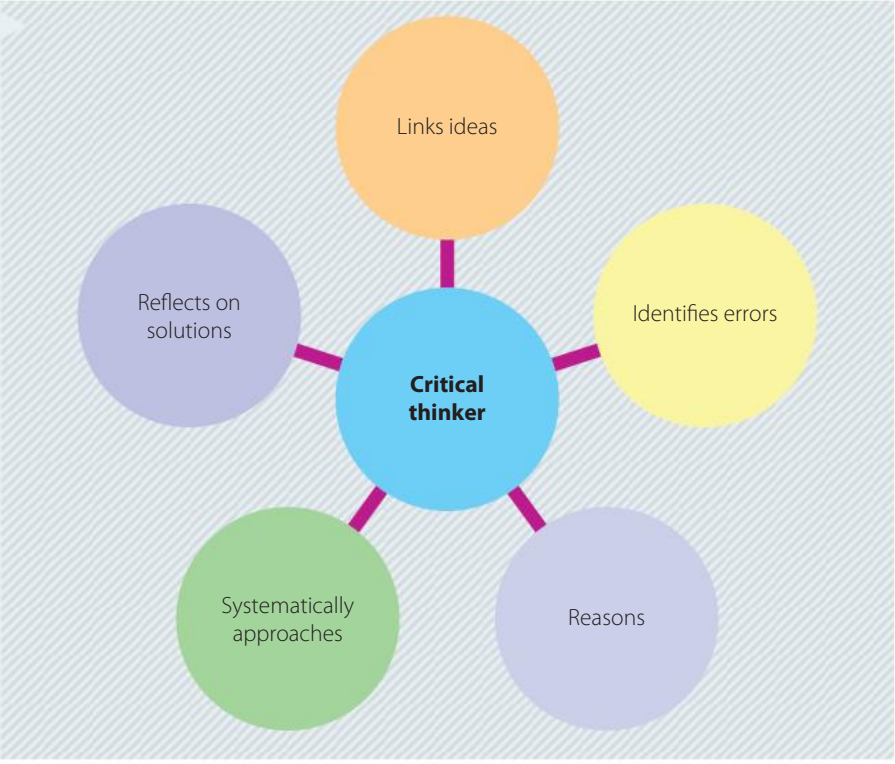


FIGURE 1.6.2
Characteristics of a critical thinker that allows problem solving using a holistic approach of ideas.

1.7 Communicating

A scientific investigation is completed when it is published and other scientists are learning from it. A written report is usually the most common form of communication but is not the only one. Table 1.7.1 shows the components of a scientific report and how to write them. It is important that concepts are expressed succinctly and that the report follows a flow of ideas from the inquiry question to the final conclusion, making it is easy to read and understand.

9780170411196

TABLE 1.7.1 Definition and features of research report sections. The features of each section are not limited to those listed here; more or less information can be added in each section depending of the nature of the research.

REPORT SECTION	DEFINITION	FEATURES
Abstract	A summary of the entire investigation.	▪ Includes the inquiry question and hypothesis, brief description of the method, results and conclusion.
Introduction	Background information that was used to research the inquiry question.	▪ Description of what and why the research was taken. ▪ Includes explanation of scientific theories and principles used in the research to answer the inquiry question. ▪ Summary of similar investigations supporting the research.
Method	Detailed procedures followed in the investigation.	▪ The method followed is written in chronological, numbered steps starting with a verb. ▪ Statements are as clear as possible so other scientists can understand and repeat the experiments. ▪ Diagrams and mathematical calculations are included. ▪ Variables and treatments are specified.
Results	Findings of the investigation.	▪ Results are represented in tables, graphs and diagrams. ▪ Observations are written as lists or descriptions.
Analysis and discussion	Analysis of data and arguments that support the hypothesis.	▪ Explanation of the meaning of the results and data collected, related to the hypothesis and inquiry questions. ▪ Relate to secondary sources which support the research. ▪ Difficulties encountered during the investigations and improvements are discussed. ▪ Future research inquiry questions are suggested.
Conclusion	Summary of results and judgement about the hypothesis.	▪ Brief summary of the meaning of the results and aim. ▪ State if the results support the hypothesis and/or inquiry question.
Acknowledgements	Recognition to the people who collaborated in the research.	▪ Thanking all the people who contributed to the research, from the equipment suppliers to the people who shared their ideas and personal support.
References	Secondary sources used in the research.	▪ Alphabetical list of all the secondary sources consulted for the research. ▪ Include references from the introduction and discussion. ▪ References are cited following a particular reference format or style.
Appendix	Supplementary section to the written research.	▪ Additional information about raw data. ▪ Calculations or list of mathematical formulae. ▪ Extra diagrams or photographs of the experimental site. ▪ Any relevant information that can help the reader to understand the research.

Other ways of communicating the findings from an investigation can be in the form of a poster or presentation at a conference, or an article published in a scientific journal or website. These ways of communication often limit the amount of the research that can be presented about the topic. However, in today's society scientists choose to present their investigations in different formats to reach the majority of audiences and promote their passion for science.

Whatever method is used to communicate research it is important to keep in mind the type of audience who is going to read it so that the work is understood, and it can be critiqued fairly and constructively for future improvements.

peer review
process in which experts review and critique the work and research of others in the same field

1.7.1 The importance of science communication

Peer review

One reason for communicating the findings of an investigation is the feedback received by other researchers. Peer review helps to improve the current investigation, to further pursue new areas to investigate and for self-evaluation.

The feedback can be done verbally or in a written form, with the objective being to evaluate the argument discussed in the conclusion of the investigation. Feedback should be constructed using evidence-based statements.

2 PREPARING FOR A DEPTH STUDY

Alamy Stock Photo / Science

9780170411196

2.1 Devising and conducting investigations

Before you conduct an investigation you need to carefully plan what you are going to do. You must ensure that your investigation will be a fair and **valid** test. That is, one that tests your **hypothesis** and can easily be reproduced.

For an investigation to be **reliable** you must have repeated your investigation a number of times, and received consistent results. This doesn't mean you get the same result every time, but rather, that your results do not vary by a significant degree.

If the results do vary by a great degree, then there may be parts of your investigation that are flawed. You may need to go back and think of ways of improving your investigation. For example, an investigation to test the claims of stain removers would only be valid if it tested how much of the stain was removed compared to other products tested under the same test conditions.

valid
extent to which a report or investigation contains accurate data, inferences and conclusions

hypothesis
educated guess tested through experimentation to answer the inquiry question; states the relationship between the independent and dependent variables

reliable
extent to which an observation and/or measurement can be repeated under the same circumstances and produce similar results

Controls and variables

A fair test should only test one variable, which is the only factor that is deliberately changed in your investigation. This is called the **independent variable**, and in the example given previously, the independent variable is the different types of stain remover.

You should also endeavour to measure one variable: the **dependent variable**. In the previous example of the stain remover, the dependent variable is the amount of stain that is removed. While some investigations might measure more than one variable, most of the time it is just one variable being tested.

All other aspects of the investigation should remain constant, such as the size and type of the original stain, the size and type of the material, the length of time the stain remover is left on the stain and the length of the wash cycle. These constants are the **controlled variables**, and they are the parts of an investigation that must be kept the same for each of the independent variables and during any replications of the investigation. For example, if testing the effect that the different stain removers might have on the stain, the stain remover should be the only factor changed. If you change the amount of water used in each sample, or change the type of material that it is tested on, it can be difficult to eliminate these as potential causes of the results.

iStock.com/sanjeri

FIGURE 2.1.1 Investigations are an important part of the scientific process of testing a hypothesis.

2.2 Testing a claim or device

Many commercial products, machines and devices will make claims about their performance to appeal to consumers. Often the claims are full of language designed to evoke emotions. Many of these claims are hard to prove without buying all of the available products and making your own comparisons. For example, a washing powder may claim that it makes clothes 100% brighter than other powders, while a washing machine may claim that it makes clothes 100% cleaner than another machine. Assessing these claims and finding secondary sources can be very difficult as there are many variables that need to be considered; for example, the type of soiling/staining on clothes, the type of material being washed, the length of the wash cycle, the quality of available water and the temperature of the water.

independent variable
factor deliberately changed during an investigation to obtain data

dependent variable
factor measured in the investigation

controlled variable
factor that is kept constant during the investigation

To successfully test a claim or device it is important to identify:

- what you want to learn from testing the claim or device
- what you already know about the topic
- the research that already exists (secondary sources)
- the dependent and independent variables
- what you think will happen in the test
- how you will record the data
- how you can repeat the test to ensure it is fair and valid.

2.3 Making documentaries and reports

Documentaries

2.3.1 Making documentaries and reports

A documentary film is factually based and usually reflects an area of interest of the film maker. A good documentary will critically evaluate the evidence for a concept and make a judgement. It might show examples of how a particular concept works, including positive and negative aspects, and make an overall judgement. Documentaries may be subject to criticism, so it is important to present the information factually and without **bias**. Any bias may negatively impact the perception of the documentary and a lack of facts will lead to the documentary lacking credibility.

bias when personal opinion affects how a person weighs the validity of evidence

When creating a documentary it is a good idea to complete the following steps:

- identify an area of interest
- complete an extensive secondary source study that investigates the subject broadly and deeply
- create an outline for the documentary including a storyboard and a draft script
- identify and rectify any legal, ethical and copyright issues
- revise the script
- film the documentary
- edit the documentary
- show the first edit to others for **peer review**
- refine the documentary based on feedback
- present the final documentary.

2.3.1 Making documentaries step-by-step
2.3.2 How to make a documentary part 1
2.3.3 How to make a documentary part 2
2.3.4 How to make a documentary part 3
2.3.5 Simple mistakes documentary filmmakers make

peer review process in which experts review and critique the work and research of others in the same field

Alamy Stock Photo / ZUMA Press, Inc.

FIGURE 2.3.1 A documentary can be used to present data about a topic or attempt to highlight an important issue.

INQUIRING FURTHER

- View some YouTube documentaries and TED presentations related to a topic of your interest.
- Assess whether the documentaries and presentations are factual or have bias. Present a report to your class on what you have found.

9780170411196

Reports

A report can be written, verbal or visual and aims to provide the intended audience with information on a particular topic. As with a documentary, it is helpful if the person writing the report is interested in the topic, the report is factually based, the research is broad and deep, and the information is free from bias. A report should be written in an active voice. For example, 'We set up the equipment as shown in the diagram' and 'We repeated the procedure three times'.

Your report should include the following sections.

- Title
- Abstract (or summary)
- Introduction
- Materials
- Method
- Results
- Discussion
- References

Shutterstock.com/stock_photo_world

FIGURE 2.3.2 Many reports can be given as lectures.

2.4 Conducting a literature review

A literature review investigates scientific articles, compares their conclusions, and often evaluates the conclusions based on the validity and reliability of the investigation. A literature review is usually written in an essay format with an introduction, body, conclusion and reference section.

The introduction states your aim in writing the literature review. It answers the question, 'Why are you writing this review?' In the introduction you should describe your aim and briefly talk about the areas you are going to discuss.

Once your introduction is complete, you need to focus on the body of your review. In the body section you articulate your arguments and give evidence to support them. Each body paragraph should include the information you have researched and summarise your main ideas. For example, several paragraphs could discuss the historical background of the topic, such as in the history of ideas on atoms. Others could discuss further research in the area, such the development of cochlear implants. Others may discuss advantages and disadvantages of the concept being discussed, such as whether an area should consider nuclear power. Essentially this is where you are outlining your ideas.

Once you have discussed, outlined and assessed the topic in the body of your review, you will need to summarise your argument(s) and make a conclusion.

In the research phase of the literature review it is important to accurately record all of the literature you are reading either by hand, in an electronic document or using the features of your chosen software. You should include a list of all of the literature you discuss in the reference section of your review.

2.4.1 Sydney University literature review tutorial

atom
from the Greek word 'atomos' meaning cannot be divided

2.4.1 Critical evaluation of scientific articles

2.5 Developing evidence-based arguments

An evidence-based argument is a piece of writing designed to influence people's thoughts on certain topics. You start by choosing an area of interest, researching this area and then presenting a point of view. From here you develop an argument supporting your claim. Each point is supported and elaborated on with evidence

from reliable sources. It is important that you cross-reference that the evidence has been checked and verified many times. It may also be appropriate to discuss opposing views and use evidence to show why your idea is correct. There may be some areas where the arguments for both sides are strong, and both have valid points. In this case, show both sides of the argument and provide evidence for why you think a point of view is correct. A process to follow when developing an evidence-based argument is to:

- identify the issue
- understand the scientific, social, ethical, environmental, economic and other important aspects of the issue
- identify, research and analyse the existing information
- evaluate the research and form an opinion/develop a position
- organise the argument
- write the first draft
- submit the draft for peer assessment
- review the peer assessment and prepare the final argument
- publish or present the final argument.

For example, the following outlines how to begin an evidence-based argument concerning genetically modified (GM) crops.

1 Identify the issue.

- People should support the development and production of GM crops.

2 Show an understanding of the scientific, social, ethical, environmental, economic and other important aspects of the issue.

- GM crops produce more seed, and therefore, they can feed a higher number of people (e.g. social, ethical, economic).
- Impacts of climate change may impact on food crops, thus plants need to be genetically modified to allow them to survive in harsher weather (e.g. scientific, social, environmental, economic).
- Certain GM crops are pest resistant which reduces the need for pesticides (e.g. scientific, environmental, economic).

iStock.com/ -MG-

FIGURE 2.5.1 GM crops are designed to overcome difficulties such as poor soil or increases in temperature. While this may allow more crops to be grown, many people have concerns about the long-term effects of eating these foods.

2.6 Writing a journal article

Often after completing their research a scientist will publish their results. This is usually done through journal articles. The publication of journal articles is an important process in science as it allows other scientists to look at how the scientist conducted their research, whether their investigations were fair and valid, and whether the conclusions made from their investigations were valid. A journal article should methodically explain each step in detail, so that other scientists have a guide for repeating the investigations. Other journal articles may use secondary sources. However, they should follow the same methodical approach.

Before the journal article is published it should be peer reviewed. In this process other scientists assess the methodology and analysis of results, and make a judgement about the validity and reliability of the research. If it doesn't appear to have a solid scientific methodology then it may be rejected for publication.

9780170411196

In most cases a journal article will have a structure similar to that of a standard scientific investigation.

- Question
- Background research
- Hypothesis
- Conduct an investigation
- Analyse data and draw conclusions
- Construct a new hypothesis (if the results do not align with the hypothesis)
- Draw a conclusion (if the results align with the hypothesis)

2.7 Writing an essay

An essay is a piece of writing that usually presents arguments, and assesses the reliability and validity of these arguments which then leads to a conclusion. This conclusion should be supported by the evidence given in the body of the essay.

The introduction gives a basic rundown of the main points of the essay and indicates the argument; in other words, the introduction summarises what the author is attempting to show in the rest of the essay.

The main body of the essay examines the evidence that the author is using to back up their argument. In most cases, each piece of evidence should have its own paragraph outlining the main points with examples.

The final paragraph will be the conclusion, where the author briefly summarises the main points, with a statement talking about the argument.

An approach to writing an essay includes:

- choosing a topic
- conducting research into the topic
- scaffolding the development of the essay based on research
- writing a thesis (introductory) statement
- writing the main body of the essay
- writing the introduction and conclusion
- submitting the draft for peer review
- revising the essay
- publishing the final essay.

2.7.1 Essay scaffold

2.8 Developing an environmental management plan

An environmental management plan describes how an activity, such as a new housing development, might impact on the local environment. The plan should ensure that best practice is employed during the activity, that all legislation is adhered to and assess the risks associated with the planned activity.

The management plan should be impartial and have qualified experts from a number of fields involved in its development. For example, archaeologists may be called upon to assess if there are any significant cultural or heritage risks associated with the planned activity.

There are many different types of environmental management plans, but the basic structure consists of:

- an introduction to the activity, the objectives of the plan and any environmental policies
- who is responsible for the environmental management, any licences that are required, reporting requirements and training requirements
- details on the implementation, including a risk assessment, the environmental activities/controls, the management plan, and appropriate maps and schedules
- how the plan will be monitored, audited and reviewed, and identifying any corrective actions that may need to take place.

2.9 Analysing a narrative

Many movies claim to use science, or scientific concepts, as a central part of their plot. In analysing a narrative, you may look at books or movies and analyse the science used. This might involve doing background research on the 'science' in the narrative and critically analysing its accuracy. For example:

- The movie showed a volcano that was emitting a runny lava as well as a pyroclastic flow. It would be unlikely that both would occur simultaneously from the same volcanic source.
- The movie showed small spacecraft firing loud laser blasts. In space, lasers would be silent, as there is no air to carry the sound. Lasers are invisible unless passing through particles that reflect the light.
- The characters in suspended animation would most likely awake with brain damage, as brain function was stopped for a long period of time.

2.10 Creating visual representations

Conducting and presenting a secondary-source investigation involves hours of delving through information and re-writing text to present a case that appropriately addresses your research question or inquiry. To complement the written text, it is beneficial to include visual representations as an alternative way of communicating information. Visual representations can also be included in depth studies that are design-based or as a way to display the results obtained by field work or a primary investigation.

Examples of visual representations that can be used exclusively or as part of a depth study may include:

- concept maps
- labelled diagrams
- diagrams of experimental set-up
- graphs and tables
- timeline of technological advancements
- taxonomic keys
- scientific drawings of biological specimens
- design briefs for a model
- drawings of chemical structure
- phylogenetic (or evolutionary) trees
- genetic pedigrees
- cartograms.

Visual representations are a powerful scientific tool as they allow complex scientific concepts to be shown diagrammatically. Imagine this book with no images, diagrams or concept maps and you will

soon appreciate the purpose of visual representations. By including a visual element to your depth study, the written text is strengthened with further evidence.

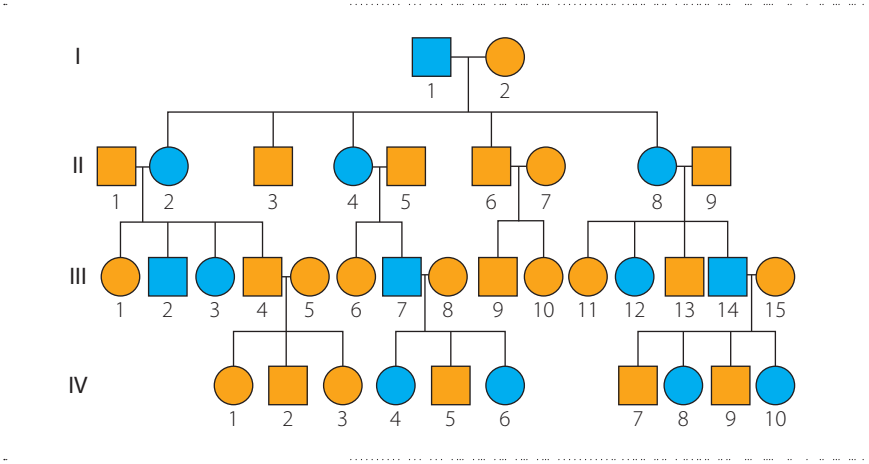


FIGURE 2.10.1 Pedigrees are an example of a visual representation that may be included in a depth study focusing on applying the conclusions of Mendelian genetics to investigate a heritable characteristic in your family.

2.11 Investigating emerging technologies

From Galileo's telescope and van Leeuwenhoek's microscope to the **Large Hadron Collider**, advances in technology are closely associated with sophistication in scientific thought. As new technologies are constantly emerging, a depth study is an opportunity to investigate and evaluate the potential of recent innovations.

Large Hadron Collider particle accelerator that propels subatomic particles (hadrons) at high speed

Your investigation may aim to investigate emerging scientific technologies strictly related to the work of scientists or scientific technologies affecting other target audiences such as the community, public health or even business owners. Regardless of the proposed technology, the following process can be used to initiate your investigation:

- choose an area of science that interests you
- research new or emerging technologies in that area
- relate the technology to an outcome in the *Investigating Science* syllabus
- determine your target audience/s
- evaluate the technology in terms of the target audience selected
- discuss the benefits and limitations of the technology
- include visual representations of the technology.

As there is a constant turnover in new technological products, the ability to assess and evaluate the potential of new scientific equipment and medical technology is an invaluable skill. By selecting this form of depth study, you will develop your ability to analyse a product beyond its face value to make a holistic judgement on its quality and ability to contribute to the industry it claims to benefit.

FIGURE 2.11.1 Food scanners are an emerging technology that have recently been the subject of discussion. The scanner claims to analyse the ingredients and additives in certain foods and is being pitched as an essential device for those with life-threatening allergies as well as a tool for those seeking to make better health choices.

2.12 Designing and inventing

Those with interests in engineering may wish to design their own invention or improve an existing one. The design element of the invention may be a proposal that encompasses visual representations of the invention or it could be a prototype for the invention itself.

If you choose to create an invention, you must consider the following issues:

- time to complete the task
- availability and cost of the materials to make your invention
- appropriateness of the invention in an educational setting (must not be offensive or associated with violence)
- expertise required to construct the invention
- whether your proposed invention has already been patented.

This choice of depth study provides the ultimate platform to apply scientific inquiry. For those who are always thinking of new ideas, this is an opportunity to finally transform your vision into something more concrete. Of course, if you are considering this form of depth study, it is important to consult your teacher and complete a lot of background research to ensure that it is plausible.

Getty Images/Michel Porro

Getty Images/REMKO DE WAAL/Stringer

FIGURE 2.12.1 Nineteen-year-old Boyan Slat invented a device to clean up plastic waste floating in the ocean while allowing marine life to pass through unharmed.

2.13 Creating a working model

Modelling is used extensively across the disciplines of science to illustrate a concept or process, or as a representation of complex scientific equipment. Additionally, if a proposed invention is not feasible due to lack of time or resources, then you can construct a model that depicts your idea.

All models do not have to be physically built; they can also be mathematical, diagrammatic, computer-generated or abstract. However, if you wish to construct a model as your depth study, it must be a working model. That is, it must include some degree of interaction in which it actively demonstrates a process.

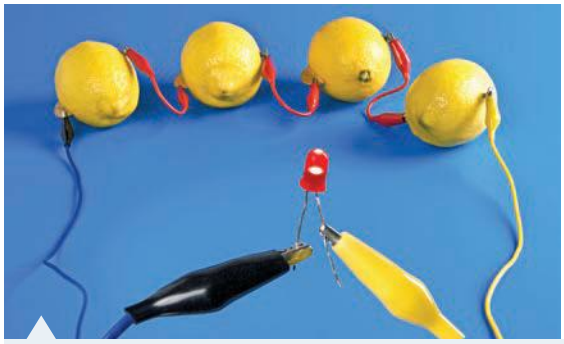
A simplified example to demonstrate the discrepancy between a model and a working model may be demonstrated through a model of the planets in the Solar System. In this instance, the model is considered a working model when it demonstrates not only the relative size and order of each planet but also the orbital properties of the moons and planets in relation to the Sun. Figure 2.13.1 also demonstrates an example of a working model.

In order to construct a scientific model, you should ensure that you:

- conduct a lot of background research on the chosen phenomenon
- draw a draft of your model that includes the dimensions to scale
- complete a detailed risk assessment if chemicals or electricity are involved
- select materials that are appropriate for what is being modelled
- consider the cost of those materials.

Models are an important scientific device as they can represent phenomena that are difficult to observe, including those that:

- are too large or small to see
- occur too slow or too fast to observe



Science Photo Library/MARTYN F. CHILLMAID

FIGURE 2.13.1 The 'lemon battery' electrical circuit is an example of a working model that may be used to demonstrate how the electrolytes found in fruit can facilitate electron movement.

9780170411196

- no longer exist or happened in the past
- have not yet been invented (prototypes).

Models simplify complex processes, and by doing so, they are likely to increase your understanding of difficult concepts. Creating a model allows you to put theory into practice and is a perfect choice of depth study for those who prefer the practical, more tactile elements of the course.

2.14 Creating a portfolio

A portfolio is compilation of work that aims to provide multimodal evidence for a particular purpose. In this case, a portfolio may be used to compile all the elements of an investigation, whether it is a primary or secondary one.

The portfolio can be used to compile:

- research
- reflective journal entries
- drawings, diagrams and photographs
- timelines
- maps
- tables and graphs
- spreadsheets
- responses from survey questionnaires
- transcripts from interviews with experts
- the primary investigation itself (i.e. research question, aim, hypothesis, materials, risk assessment, method, results, discussion and conclusion)
- conclusions drawn from related investigations.

Your portfolio should be presented in a folder with a table of contents at the beginning outlining the type of evidence included and with the associated page number/s labelled (Figure 2.14.1).

Table of contents

Investigating the impact of coral bleaching on biodiversity in the Great Barrier Reef since 2010

	Page/s
Background information on coral bleaching	1–3
Awareness of coral bleaching: Survey results	4–5
Distribution graphs	6–8
Statistical analysis	9
Interview transcript: Marine biologist	10–11
Photographs over time	12–13
Conclusions	14

FIGURE 2.14.1 A portfolio should include a table of contents at the beginning.

2.15 In the field

fieldwork
investigation conducted outside the laboratory

The general process of **fieldwork** refers to observations that are collected and recorded in a natural environment, as opposed to a relatively controlled environment such as a laboratory. Fieldwork is essential in many areas of science. For example, in trying to gain an understanding of some ecological relationships such as those between biotic and abiotic factors in a natural setting.

iStock.com/RainervonBrandis

FIGURE 2.15.1 Specialised technology has allowed scientists to conduct fieldwork in the ocean, such as this scientist researching coral bleaching.

Primary scientific investigations comprising fieldwork not only increase our understanding of the world around us, they also have great economic importance. An example is soil testing which includes the collection and analysis of a sample of soil for nutrients, pH, salinity, organic matter and contaminants such as heavy metals. In testing these factors, environmental scientists can provide farmers and other land users with feedback on how to increase the efficiency of their soil. These programs are essential in the agricultural industry in order to maintain healthy and fertile soils that encourage the rapid growth of crops.

In terms of the depth study, field work does not always have to consist of an entire field study; it can also include designing field trips, conducting surveys and interviewing experts.

If you choose the main component of your depth study to be based in the field, you may either plan and perform your own field study, or design a field trip that aims to educate selected members of the public.

Considering your local environment

Local environments such as bushland, river banks or tidal zones are the most appropriate location to conduct a field study. Whether you are conducting the field study yourself or planning a field trip for the location, local areas are familiar and relevant to your life.

iStock.com/istock80

FIGURE 2.15.2 Rock platforms in tidal zones, such as this one at Bateau Bay on the New South Wales Central Coast, are an example of an environment you could use for your field study.

If you wish to design a field trip, an example may be to educate students from your local primary school about the aspects of a local ecosystem such as an area of bushland, river bank or tidal zone. Alternatively, if you reside in a heavily urbanised area, there may be museums close by that could be used as the basis of a field trip.

Once you have an idea of the types of environments or facilities you might be able to use, you need to reflect on what it is you want students to learn during this field trip. At each step of planning your field trip, it is important that what the students will learn is at the forefront guiding what you plan.

You might talk to your teacher about areas of the year 7 curriculum that could be used to introduce primary school students to the concepts they will be learning when they go to high school. In doing so, the field trip is relevant to the students.

Planning a field trip

Many facilities such as museums will require school groups to book into the centre, even if it is free to enter, to ensure the centre is not overcrowded when you visit.

Once the venue has been decided, it is important that you visit there to get an idea of how your field trip will progress. If you are entering an ecosystem you will need to ensure that it is easy for the students you intend to take there to move around, take rest breaks and have access to a toilet. For example, a bush track with steep inclines may not be suitable for younger students.

Another crucial step to planning any field trip is completing a risk assessment. A risk assessment allows you to foresee any potential problems before they happen. The following describes the different components of a field trip risk assessment.

- Identify: What is potentially going to be a problem?
- Assess: Is it a low risk, a medium risk, or a high risk?
- Control: How can you minimise the degree of risk?

If you complete the risk assessment and think there is a high risk of an incident occurring, then you should reconsider the suitability of your field trip.

Planning a field study

If you wish to examine a local environment yourself, then you may plan and perform your own field study. A field study is a research project carried out in the natural environment and looks at the many interacting factors of an ecosystem.

An example may be to examine the abiotic and biotic interactions within a rock platform ecosystem. A field study of this nature may include:

- assessing water quality, turbidity, salinity and pH
- listing the abiotic factors influencing the ecosystem
- identifying **species** and constructing a food web of the ecosystem
- using quadrats and line transects to determine the distribution and abundance of particular organisms
- examining the human impacts on the ecosystem.

Information collected in a field study may be presented in a portfolio with related research and data or could act as evidence for an environmental management plan.

WS
2.15.1 Field study of an ecosystem

species
group of living organisms with similar characteristics that can interbreed

2.16 Engaging with experts

Conducting field work can also involve seeking opinions and expertise from those who specialise in the area of your investigation.

Engaging with experts may take place through informal conversations, structured interviews, local tours, email correspondence, scientific forums or social media. Interviewing is a useful way to obtain information from experts. When planning and conducting an interview, it is beneficial to:

- conduct the interview in a public place such as a library conference room or university
- carefully plan the questions before meeting and have them written down
- ensure most of your questions are open-ended; that is, they encourage explanations rather than yes/no answers
- bring a voice recorder and transcribe the interview later
- ask the expert if there is anything else they would like to add.

CROSS-CURRICULUM

If your chosen depth study focuses on Indigenous perspectives of a scientific concept, such as natural medicine, Aboriginal education officers and community groups may be able to put you in contact with local elders in the community.

Meeting face-to-face with an expert in close proximity to your local area may be difficult, especially if your chosen field is a niche market. To overcome this, you may choose to conduct interviews or contact local agencies via email.

If you live close to a university, you may also be able to collaborate with scientists who are working in areas that you are interested in. Additionally, you may be able to use programs such as Scientists in Schools, run by the CSIRO.

Alamy Stock Photo/Bjorn Svensson

FIGURE 2.16.1 Local elders are knowledgeable sources of information, particularly in regards to your local area.

2.17 Analysis

Irrespective of your chosen depth study, you will have to undertake some form of analysis. Analysis is a detailed examination of the components in your investigation. You may undertake data analysis if you have chosen to perform a primary scientific investigation which also involves constructing tables and graphs to determine any relationships in your data. If you have selected to do a secondary investigation, the analysis may involve examining current research published in your area of study for its reliability and relevance to your aim.

Data analysis

Data analysis is also referred to as the 'discussion' in a primary scientific investigation. It is the component of your investigation where you link the results to the hypothesis and aim.

Data analysis can involve:

- identifying trends and relationships
- comparing results to similar research
- commenting on reliability and validity in relation to the variables of the investigation
- recognising any limitations in your investigation
- accounting for any discrepancies in your data
- suggesting how your findings can be used in future investigations.

Completing data analysis and including it as a reflection of your investigation allows those who are reading your research to evaluate its purpose and determine if it effectively addressed the aim. It also provides an opportunity for you to explain your findings and account for any problems that may have occurred throughout the investigation.

9780170411196

2.18 Constructing graphs and tables

Tables and graphs are usually included in the results section of a primary investigation as a simple and effective way to organise and display the data collected. Once the data from tables are transformed into the most appropriate graph type, any trends or relationships can be identified and explanations devised.

qualitative data descriptive data collected as evidence during an investigation (e.g. images, observational sentences)

quantitative data numerical values collected as evidence during an investigation (e.g. calculations, measurements)

Tables

Tables are used to systematically record and manage data. If you intend to submit a primary investigation for your depth study, displaying your results in a table provides readers with a snapshot of the outcome to your investigation. There are many ways in which a table can be constructed and there are slight differences depending on the type of data you are collecting. Figures 2.18.1 and 2.18.2 can be used as scaffolds to display the results from investigations that collect **qualitative data** and **quantitative data**, respectively.

When collating quantitative data, make the columns your dependent variable and ensure the units of measurement are in brackets

Table 1. Heart rate following 15 minutes of exercise

	Heart rate (BPM)			
	Trial			
Participant	1	2	3	Average

When collating quantitative data, make the rows your independent variable

Trials improve reliability as they depict consistency

Reporting on an average from multiple trials makes the data more reliable

FIGURE 2.18.1 A table scaffold for recording quantitative data.

Collating data from different groups addresses consistency and improves reliability

Table 2. Product of chemical reaction with unknown chemicals

	Group					
	1		2		3	
Chemical reaction	Colour	Precipitate (Y/N)	Colour	Precipitate (Y/N)	Colour	Precipitate (Y/N)
Chemical 1 + Chemical 2						
Chemical 2 + Chemical 3						
Chemical 1 + Chemical 3						

The independent variable is addressed in the rows

When collecting qualitative data, columns show the dependent variable/s

FIGURE 2.18.2 A table scaffold for recording qualitative data.

Graphs

You may be able to identify a relationship from simply looking at numbers in a table but the best way to determine the strength of that relationship is to plot a graph. As is explained in Chapter 3 and summarised in Figure 2.18.3, there are many types of graphs and each has a specific purpose.

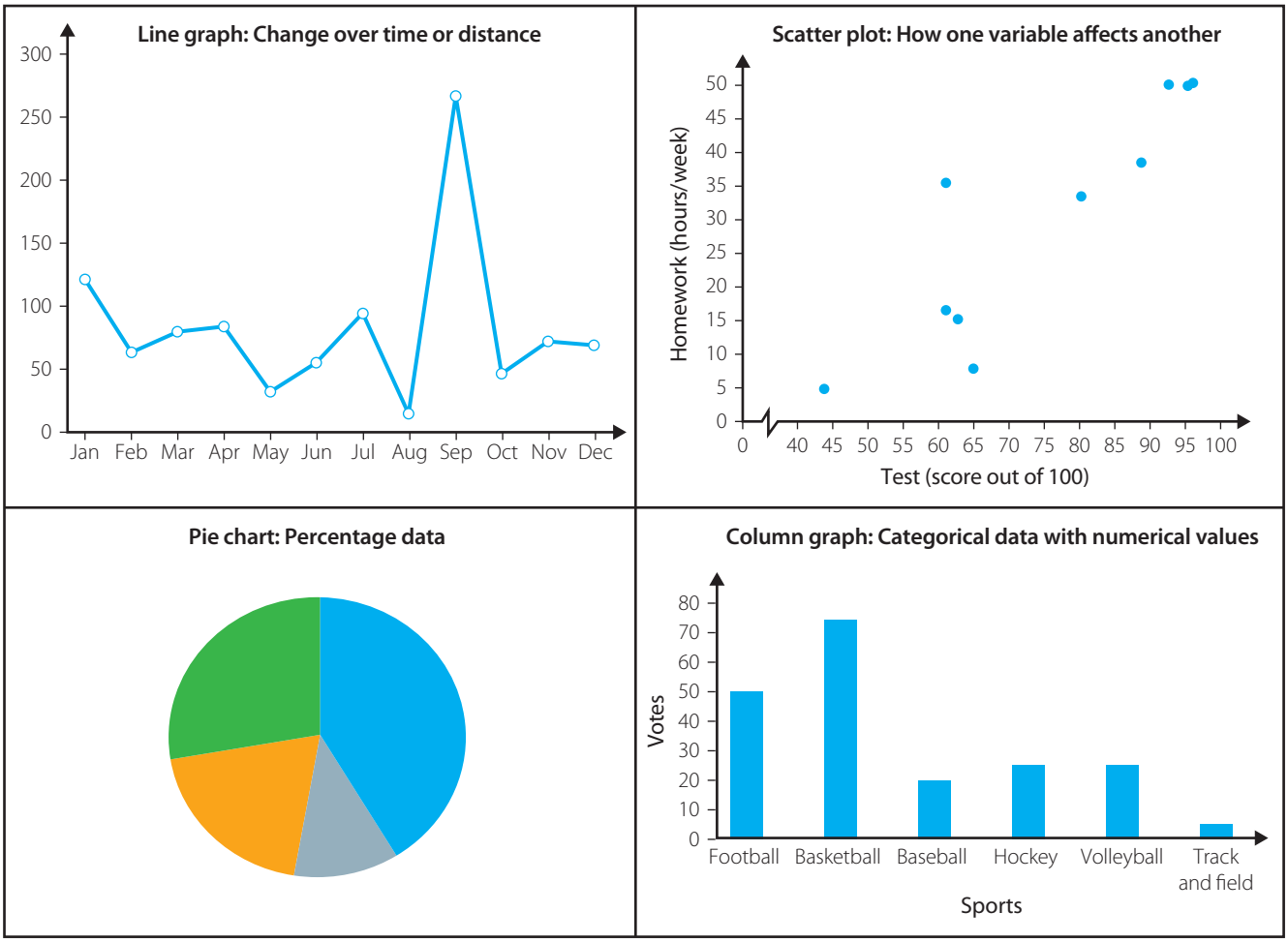


FIGURE 2.18.3 Each type of graph has a specific purpose. This figure shows how the most appropriate graph type to include in your analyses is determined by the manner in which your data is collected.

When constructing a graph, consider the following points.

- All graphs should be large and clear with a scale so that the data takes up most of the plot area.
- The independent variable is usually placed on the *x* axis and the dependent variable on the *y* axis.
- Axes must be labelled with the names of the variables and their units.
- The title of a graph should include the name of the independent and dependent variables.
- Scatter plot points should not be joined together but can include a line of best fit.

If your depth study includes primary research then it is beneficial to include a graph depicting your findings. In doing so, the results are succinctly presented and accessible to all readers, and can also be used as a reference point in your discussion (analysis).

9780170411196

Identifying trends

Line graphs and scatter plots are constructed to determine whether a trend (or correlation) in the data exists.

To describe a trend, describe the behaviour of the dependent variable as the independent variable changes. In Figure 2.18.4 the trend would be written as follows: the data collected from this investigation shows that the more hours students spent studying, the higher their test score.

When identifying trends, it is important to keep in mind that correlation does not always equal causation. You may identify a relationship between the variables, but this does not always imply that one causes the other. For example, Figure 2.18.4 shows a positive correlation between hours spent on homework and the scores in a test, but this does not mean that homework is the only cause for increased test scores.

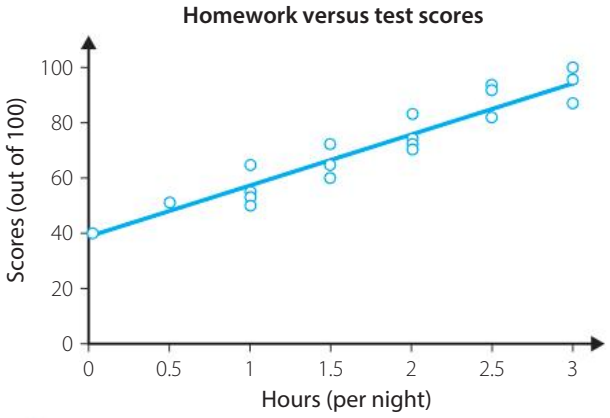


FIGURE 2.18.4 This graph shows a positive correlation between the amount of hours spent completing homework and scores on a test.

2.19 Analysing a variety of sources

Similar to a literature review, analysing a variety of sources allows a scientist to examine current texts and research to discuss conflicting ideas or gather evidence for your hypothesised theory.

Analysing secondary sources

Secondary sources are those that are published by any individual who did not personally participate in the event or research being examined. Analysing secondary sources may include examining the information contained within:

- textbooks
- magazines
- websites
- videos
- newspapers.

These sources can provide background information and context to your investigation, form the foundations for evidence-based arguments, and act as an inspiration for creative tasks.

WS
2.19.1 Secondary investigation scaffold
2.19.2 Primary investigation scaffold

Analysing research

Primary sources are those that are published by an individual who was actively involved in the study or research. The most reliable form of primary scientific research is peer-reviewed articles. When research becomes subject to peer-review, it means that it has been evaluated by several academics in the specific area of research. Peer-reviewed articles have therefore been affirmed as being of exceptional quality and in adherence to the standards of the scientific journal in which it has been published.

Analysing peer-reviewed articles demonstrates a sophisticated ability to select and evaluate relevant scientific sources and therefore adds complexity to your study.

3

MODULE 1 CAUSE AND EFFECT – OBSERVING

Behind every scientific investigation lies an observation. Whether it is a change in the environment, a new combination of disease symptoms or a product of a chemical reaction, observations provoke thought and inspire scientists to formulate questions, design tests and discover results that support or disprove a theory.

INQUIRY QUESTIONS

- How do observations inform scientific investigations?
- What are the benefits and limitations of qualitative and quantitative observations?
- How do you accurately collect primary data?
- How can the data from a primary investigation be collected and presented to reflect the outcome?
- How do conclusions drawn from primary scientific investigations promote further research?

CONTENT

Students investigate:

- role of observations
- types of observations
- observations as evidence
- observing, collecting and recording data

OUTCOMES

A student:

- develops and evaluates questions and hypotheses for scientific investigation INS11/12-1
- conducts investigations to collect valid and reliable primary and secondary data and information INS11/12-13
- selects and processes appropriate qualitative and quantitative data and information using a range of appropriate media INS11/12-4
- identifies that the collection of primary and secondary data initiates scientific investigations INS11-8

9780170411196

Shutterstock.com / Songkris Khunkham

9780170411196

3.1 Role of observations

Forms of observation

Usually the word observation is associated with something that has been seen. However, as shown in Figure 3.1.1, observations actually include information that has been acquired through any of the senses; including sight, hearing, taste, feeling and smell. People make unique observations related to their life on a daily basis. For example, you may observe that it is raining by listening to the rain drops on your roof or feeling a rise in the humidity.

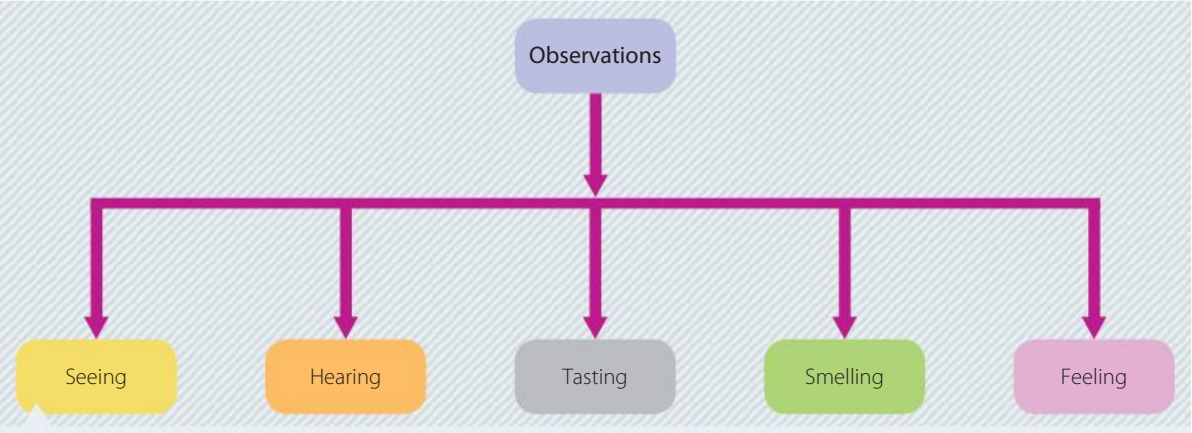


FIGURE 3.1.1 Observation comes in many forms.

chemical reaction chemical process that involves the rearrangement of the elements of the reactants into new products

Having many forms of observation is imperative to scientists as it allows them to gain information in a variety of ways. For example, chemists may regularly use a combination of sight and smell to determine the nature of a chemical reaction whilst biologists and environmental scientists may rely more heavily upon sight and hearing to work out specific ecological interactions. By combining different forms of observation, scientists are able to make conclusions that support or disprove scientific hypotheses and encourage further research.

Observations and inferences

inference conclusion that is rationally and logically made based on observations and available information

After observing an interaction, relationship or phenomenon, it is natural to make assumptions as to why it occurred. These assumptions are known as inferences and are an attempt to explain an observation using reasoning.

People make inferences based on the observations that they make every day. For example, it could be inferred that someone has bad eyesight if they are wearing glasses, is happy if they are smiling or late if they are running at a train station.

Because inferences are based on assumptions, making too many without questioning can be problematic. For this reason, scientists investigate the cause of an observed effect through extensive testing which allows them to make informed conclusions.

3.1.1 Observation and inference

3.1.1 African animals live webcam

9780170411196

INVESTIGATION 3.1.1

Making inferences

AIM

To demonstrate that the difference between an observation and an inference can be completed without the use of any scientific equipment

METHOD

1 Copy and complete the table below to record six observations and inferences.

ITEM	OBSERVATION(S)	INFERENCE

2 Select six items from your backpack and lay them out in front of you.

3 Use different forms of observation to investigate your partner's items and write your observations in the appropriate column.

4 Use reasoning to infer why your partner has each item and write it in the 'Inference' column in your table.

5 Discuss the items with your partner to determine if your inferences were correct.

Recording data from observations

No matter how a practical investigation is designed, scientists always rely on the data collected from observations to inform their results. There are two ways in which data is collected from any form of observation; **qualitative data** collection and **quantitative data** collection. Depending on the way in which data is collected, an observation is categorised as being inherently qualitative or quantitative.

Quantitative observations are those that rely on the measurement and use of scientific equipment to collect data. Qualitative observations are those that rely on personal opinions and/or descriptions during data collection. Practical investigations can focus on recording qualitative data, quantitative data or a combination of both.

qualitative data
descriptive data collected as evidence during an investigation (e.g. images, observational sentences)

quantitative data
numerical values collected as evidence during an investigation (e.g. calculations, measurements)

Qualitative and quantitative observations in behavioural science

The field of behavioural science is built upon observing biological interactions. Behavioural science laboratories often involve many hours of attentively recording interactions between **species** such as the number of times a male fish swims toward a female fish, or the manner and direction in which a spider weaves its web.

Alamy Stock Photo / Gallo Images

FIGURE 3.1.2 Behavioural scientists also work in the field to observe interactions between species.

species
group of living organisms with similar characteristics that can interbreed

INVESTIGATION 3.1.2

Burning a candle floating in a closed container

AIM

To make observations of a burning candle floating in a closed container

MATERIALS

- floating candle
- trough
- water
- matches
- large beaker
- stopwatch

FIGURE 3.1.3 Experimental set-up

METHOD

1. Pour enough water in a trough to cover the base.
2. Place the candle on top of the water.
3. Light the candle using match.
4. Place the large beaker upside down over the candle.
5. Record quantitative and qualitative observations in a table.

RESULTS

Copy and complete the table below.

QUANTITATIVE OBSERVATIONS	QUALITATIVE OBSERVATIONS

DISCUSSION

1. Select one qualitative observation and infer why it occurred.
2. Select one quantitative observation and infer why it occurred.

9780170411196

INVESTIGATION 3.1.3

Qualitative and quantitative observations

This practical highlights how qualitative and quantitative observations are made in behavioural science by recording the behaviours of slaters in wet and dry environments. It is best to complete this practical in groups with each member responsible for a particular role, such as 'observers' and 'recorders'.

AIM

To determine differences in behaviour of slaters in wet and dry environments

MATERIALS

- two slaters
- dry soil
- water
- two petri dishes
- tablespoon
- stopwatch

METHOD

1. Place 2 tablespoons of dry soil in each petri dish.
2. Add 1 tablespoon of water to one petri dish and label it 'W' (wet).
3. Label the second petri dish 'D' (dry).
4. Place one slater in each petri dish.
5. Start the stopwatch.
6. Create a tally in the appropriate column each time the slater moves and record the time of the movement in minutes and seconds.
7. Stop recording after 10 minutes.
8. Discuss which slater's movement was faster or slower with your group and record your observations in the appropriate column.
9. Compare your findings with other groups.

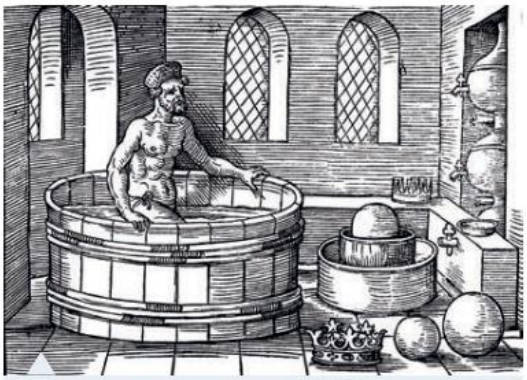
RESULTS

Copy and complete the following table.

	QUALITATIVE OBSERVATIONS	QUANTITATIVE OBSERVATIONS	
	Speed of movement (fast/slow)	**Number of movements**	**Time of each movement (min/sec)**
Wet environment			
Dry environment			

DISCUSSION

Infer why each slater behaved in the manner observed.



Imagefolk/Image Asset Management

FIGURE 3.1.4 Archimedes developing the Archimedes' principle through observation and inference.

Scientific observations in history

Many of history's greatest scientific breakthroughs have been the result of a simple observation that sparked inquiry and experimentation.

Without these initial observations made by scientists such as Archimedes, Galileo and Fleming much of our understanding of pivotal concepts underpinning the interactions of our daily lives would not be understood.

Archimedes: Observing water displacement

If you're planning on taking a bath, you know that you can't fill the water right up to the top because once you get in, the water will topple over the sides and spill on to the floor. While you can easily identify that your body volume is the reason for the increase in water level, it was the mathematician Archimedes who applied this everyday observation to formulate a theory he named Archimedes' principle.

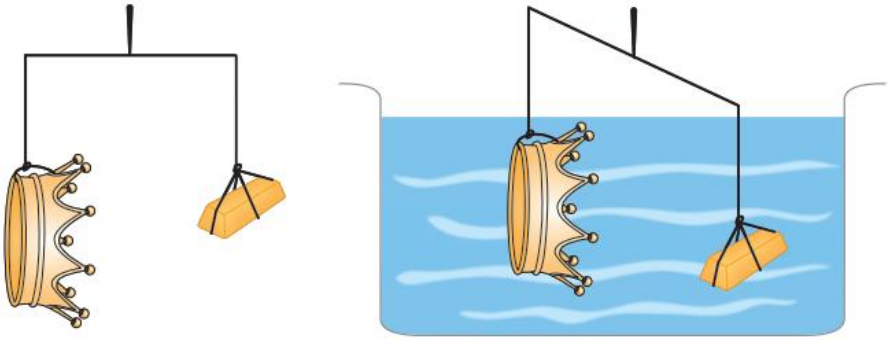
Believed to have occurred around 265 BCE, the motivation behind his principle came about when Archimedes was summoned by King Hiero II to investigate his suspicion that a goldsmith replaced some of the gold in his crown with silver. With no way to easily determine it at the time, Archimedes was asked to find a solution to the dilemma. It was during his routine bath that Archimedes had an epiphany: the amount of water displaced was equal to the volume of an object and that this volume could be used to determine density. With this knowledge, he investigated samples of known gold and silver. Once he figured out the density of both he submerged the crown in water and used its **mass** to determine whether its density was equal to gold or silver. Archimedes found the density of the crown higher than that of silver but less than gold, confirming the King's suspicions that a mixture of the two was used.

mass
amount of matter in a solid, liquid or gas

3.1.2 Water displacement simulation

3.1.3 How taking a bath led to Archimedes' principle

3.1.4 the real story behind Archimedes' Eureka!



The crown and the gold have equal mass.

The crown displaced more water than the gold.

FIGURE 3.1.5 By submerging a fragment of gold with the same mass as the crown, Archimedes was able to determine that the two were not equal in density.

KEY FORMULA

$$\text{Density} = \frac{\text{mass}}{\text{volume}}$$

Alexander Fleming: Observing the effect of mould on bacterial growth

In 1928, after Alexander Fleming left his workbench scattered with poorly sealed petri dishes containing cultured staphylococci bacteria, he returned from holiday to make a crucial observation. Shown in Figure 3.1.7, Fleming noticed that one of the petri dishes had been contaminated by a mould (*Penicillium notatum*) and around the mould was an area clear of bacteria. Interested and wanting to find out

Imagefolk/World History Archive/Ann Ronan Collection

FIGURE 3.1.6 Alexander Fleming's observation was essential to modern medicine.

9780170411196

more, he isolated the mould and experimented on a range of different bacterial groups to see if it had the same effect. He published his findings in the *British Journal of Experimental Pathology* in 1929; however, it was another ten years before a group of scientists at Oxford University transformed this laboratory mistake into the life-saving antibiotic that is still used today: penicillin.

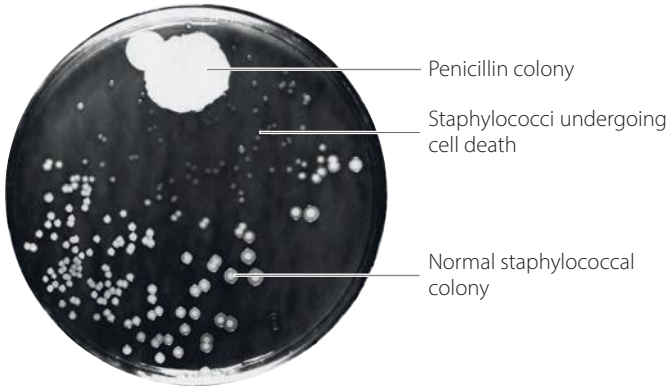


FIGURE 3.1.7
In Fleming's culture of staphylococcal bacteria he observed a reduction in bacterial growth surrounding the penicillin mould.

Galileo: Observing the movement of Jupiter's moons

Over 400 years ago Galileo Galilei made a series of observations that shifted scientific thought and formed the basis of modern cosmology. While viewing Jupiter through his homemade telescope, Galileo saw what he thought were three fixed stars in a line through the planet. After a month of observations, Galileo found there were in fact four objects and that these 'stars' were carried along with Jupiter as it orbited, changing positions along the way (Figure 3.1.8). The stars appeared to be orbiting Jupiter; an observation that contested traditional cosmology's idea that there was only one centre of motion in the Solar System.

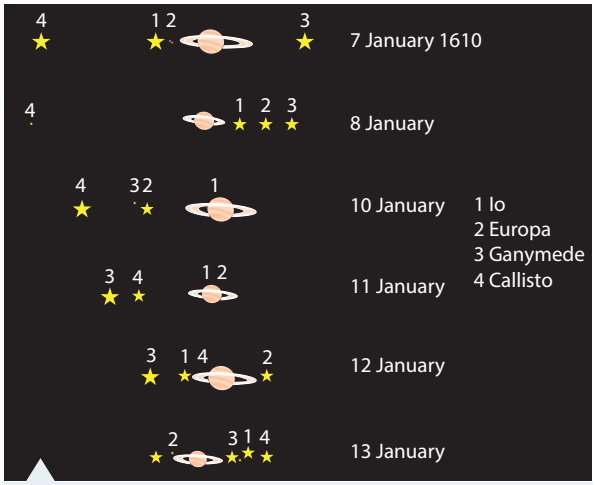


FIGURE 3.1.8 Galileo's observations of Jupiter's moons

Galileo's discovery came at a time where there were two conflicting models of our Solar System: the geocentric (Earth-centred) model and the heliocentric (Sun-centred) model. As technology was limited, there was conflict over which system should prevail. The geocentric model was based upon the belief that Earth was different to other planets as it clearly had an orbiting moon. However, Galileo's discovery confirmed that Earth was not the only planet to have objects in its orbit, which suggested that our Solar System may be arranged differently to what was accepted at the time and eventually provided support for the later devised heliocentric model.

Observations by Aboriginal and Torres Strait Islander peoples

3.1.5 Traditional Indigenous land management

For tens of thousands of years, Aboriginal and Torres Strait Islanders peoples have been applying observations of their natural environment to ensure their use of the land was carried out sustainably.

One way of managing land is through the use of fire. Fires are lit on mornings in the cooler months of the year, and in conditions where there is low cloud and little to no breeze. Aside from reducing the risk of spontaneous wildfires in the hotter months, controlling fire in this manner also increases the nutrient availability in the soil to encourage fresh growth and germinates seeds that are triggered by heat and smoke.

INQUIRING FURTHER

Investigate how traditional land management is being trialled in New South Wales. Present your findings in an essay format as a justification for the re-introduction of Indigenous land management.

SECTION REVIEW 3.1

REMEMBERING

1 Identify five ways in which you can make an observation.

2 Define:

a 'quantitative observation'. **b** 'qualitative observation'. **c** 'inference'.

UNDERSTANDING

3 Illustrate how Archimedes proved that the crown of King Hiero II wasn't made of solid gold.

4 Describe how experimentation was used by two scientists to determine the cause of a known effect.

APPLYING

5 Examine Figure 3.1.9 and determine whether each of the following statements is a qualitative observation, quantitative observation or an inference.

a The frog is 17.34 mm in length.

b The frog is green.

c A scientist is measuring the length of a frog.

d A digital ruler is being used to measure a frog.

e The frog is a juvenile.

f The frog is about to be returned to its natural environment.

6 Demonstrate how Archimedes' principle could be used in modern science?

7 Explain the importance of plants to modern health.

Photo by Mark Roth, USGS, UMESC, 2007

FIGURE 3.1.9 Scientists use digital rulers to accurately measure small organisms.

3.2 Types of observations

3.2.1 Qualitative and quantitative data

3.2.1 How simple ideas lead to scientific discoveries

Quantitative and qualitative observations

As the name suggests, quantitative data refers to observations that are based on quantities or numerical values. In most cases, quantitative data is collected using scientific equipment. Observing time using a stopwatch, distance using a measuring tape, temperature using a data logger, or volume using a pipette are all forms of quantitative observation.

Unlike quantitative data, qualitative observations rely on personal opinion to describe the results of an investigation. Describing the colour, smell or appearance of an object or substance are examples of qualitative observation.

9780170411196

Observations in everyday life

Humans are known to be curious creatures, with some young children asking a question based on an observation every five minutes. Our naturally inquisitive nature inspires us to try to make sense of our observations by asking questions, developing hypotheses and designing primary investigations.

Observing pH

The term pH relates to the amount of hydrogen ions that are released in a solution; or in other words, it refers to the acidity or alkalinity (baseness) of a substance. As shown in Figure 3.2.1, the pH of a substance is measured on a **pH scale** that usually ranges from 1–14.

pH scale
scale ranging from 1–14 that describes the acidity or alkalinity of a substance

pH	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Description	Strong acid			Weak acid			Neutral	Weak base			Strong base			

FIGURE 3.2.1 pH scale

Finding the pH of a substance is important in many facets of science and everyday life; it can determine whether a plant will grow in a certain soil, a particular facial cream is suitable for use on human skin, pool water is safe to swim in, and even to balance flavour combinations in food.

pH can be measured both quantitatively and qualitatively. Quantitative data collection is enabled through the use of a data logger with a pH attachment to give a digital reading. A combination of qualitative and quantitative data is used when universal indicator is added to a substance and the colour change is compared to a pH colour chart.

Alamy Stock Photo/sciencephotos

FIGURE 3.2.2 Data loggers are used to collect quantitative data.

Photographer: CSIRO Forestry and Forest Products

FIGURE 3.2.3 Universal indicator shows both quantitative and qualitative data.

Imagefolk/Bilderbox

FIGURE 3.2.4 Substances with universal indictor added display different pH values.

INVESTIGATION 3.2.1

Measuring the pH of household substances

Using a universal indicator, a data logger and a pH colour chart, you can test the acidity and alkalinity of the substances you are exposed to on a daily basis, using both quantitative and qualitative observations.

AIM

To determine the pH value of a range of household substances

MATERIALS

- universal indicator solution and pH colour chart
- data logger with pH probe
- distilled water
- six samples of household substances such as: shampoo, lemon juice, salt, sugar, bleach, pool water samples, dish washing detergent, lemonade, antacid tablet, vinegar, fabric softener, baking soda
- test tube rack
- six test tubes (one for each sample)

HAZARD	MANAGEMENT
Splash household substances in eyes	Wear eye protection (goggles)
Broken glass	Place all glass in centre of bench Stop working immediately if a break occurs and notify teacher

METHOD

1. Set up the test tubes in test tube rack.
2. Label each test tube from A–F.
3. Place 2 cm of each of the household substances into the test tubes (you may need to add distilled water to the substance if it is a solid).
4. Submerge the tip of the data logger probe into solution A, recording the pH value in your results table.
5. Repeat step 4 for the remaining solutions, rinsing the end of the probe in distilled water between each test.
6. Add two drops of universal indicator to each test tube.
7. Gently swirl each test tube so that the universal indicator is uniformly mixed with the substance.
8. Compare the colour of the substance to the pH colour chart.
9. Record the colour and pH of each substance in your table.

RESULTS

Copy and complete the table below.

TEST TUBE	SUBSTANCE	pH VALUE FROM DATA LOGGER	pH VALUE FROM COLOUR CHART
A			
B			
C			
D			
E			
F			

DISCUSSION

Analyse your results and comment on any similarities or discrepancies between the two forms of data collection.

CONCLUSION

Describe any generalisations or trends related to the acidity or alkalinity of the substances tested and their general use in the household.

9780170411196

Observing objects falling due to gravity

Sir Isaac Newton was not the first person to observe an object falling towards the earth, but he was the first to thoroughly investigate and draw concrete conclusions from his observations. The legend tells us that gravity was discovered when an apple fell on Newton's head; however, his law of universal gravitation was actually a culmination of years of research based on centuries of observations and the knowledge of many scientists. During his eventual formulation of the law of universal gravitation, Sir Isaac Newton relied on quantitative observations of mass and distance in order to calculate force.

Although the concept of gravity is still not fully understood, the formulation of Newton's law highlighted that gravitational force differs between objects of varying mass and varying distance.

Figures 3.2.6 and 3.2.7 show that quantitative observations of mass, time and distance can be plotted on a graph to provide a visual representation of

Alamy Stock Photo/North Wind Picture Archives

FIGURE 3.2.5 Sir Isaac Newton

KEY LAW

Newton's law of universal gravitation

A particle attracts every other particle in the universe using a force that is directly proportional to the product of their masses and inversely proportional to the square of the distances between them.

KEY FORMULA

Newton's law of universal gravitation

$$F = G\left(\frac{m_1 \times m_2}{r^2}\right)$$

F = force

G = gravitational constant

m_1 = mass object 1

m_2 = mass object 2

r = distance between two objects

3.2.2 Misconceptions about falling objects

3.2.3 Isaac Newton: The man who discovered gravity

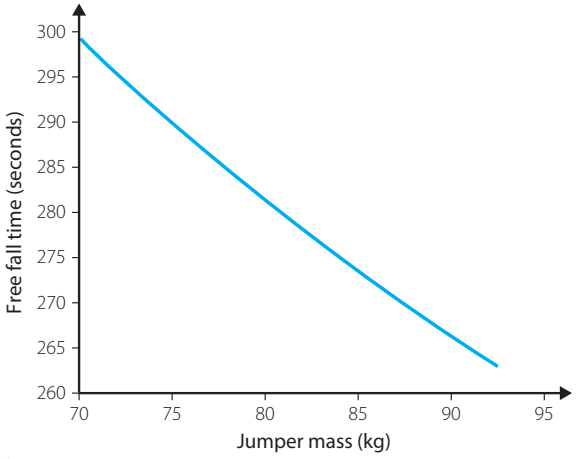
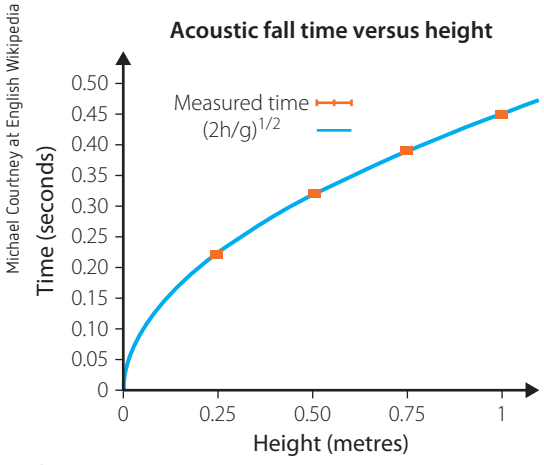


FIGURE 3.2.6 Graph showing the relationship between the mass of a free fall jumper and the time they are in falling motion.



Michael Courtney at English Wikipedia

FIGURE 3.2.7 Graph showing the relationship between the distance of an object from the ground, and the time it takes for the object to hit the ground.

INQUIRING FURTHER

Although it seems like common sense that objects fall towards the earth due to gravity, there was a time before Newton when gravity was poorly understood. Research the myths and misconceptions about gravity to learn more about the theories behind what we now know as the force applied by Earth's mass. Share and compare your research with a classmate.

the relationship between the mass or distance of objects and the time in which it takes them to fall. From graphs such as these, scientists can predict the speed at which the object is falling or the force applied to the falling object.

Describing cells from hand-drawn and digital images

In the 21st century, scientists are fortunate to have relatively easy access to technology that allows them to view objects and specimens on a cellular level. By making qualitative observations of cell characteristics, scientists can propose hypotheses and account for differences in specialised cellular structures according to their function. These observations may include the location and shape of the cell, the types of **cell organelle** present, whether the cell has structures that allow it to move or if it has a membrane-bound nucleus.

cell organelle
cell structure that has a specific function

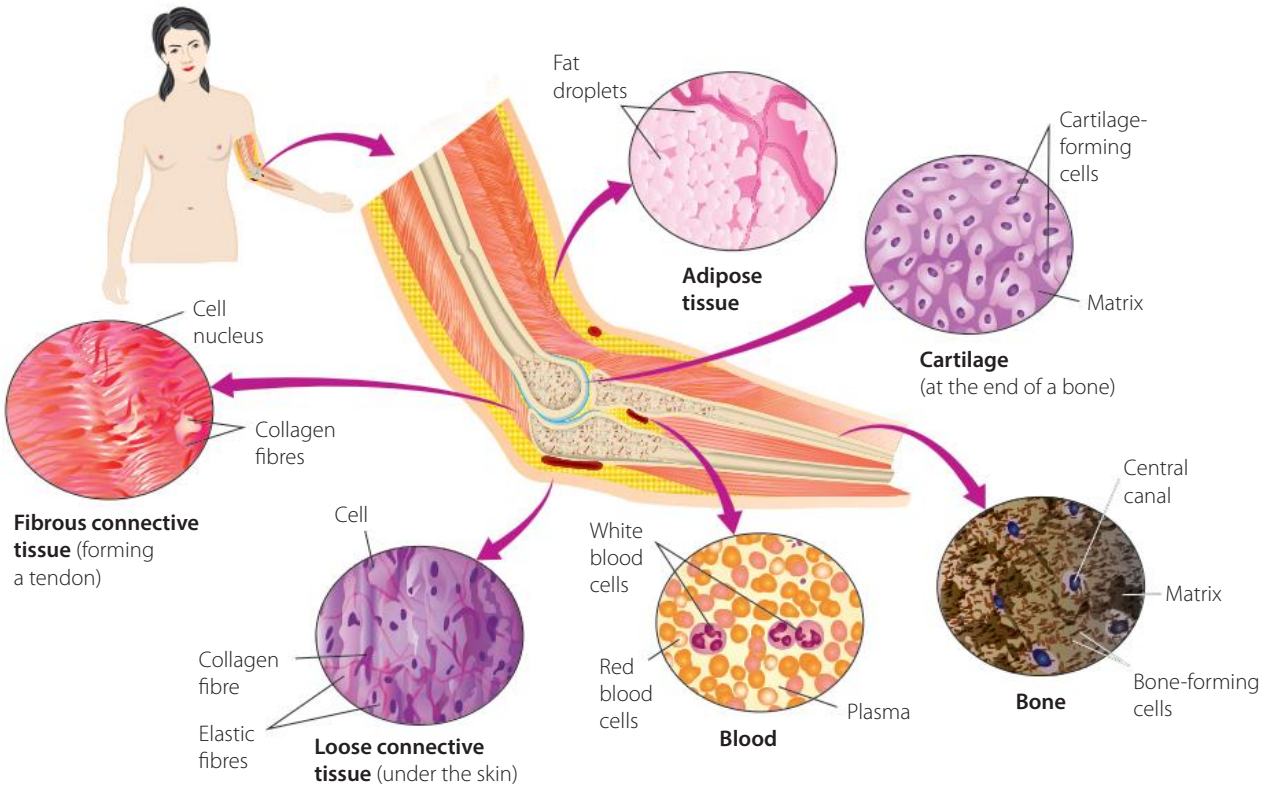


FIGURE 3.2.8 There are many different types of cells in the human body and each is specialised to carry out a specific role. For example, red blood cells lose their nucleus as they mature to provide more space to carry oxygen. This figure shows examples of cell specialisation in human connective tissue.

Collecting quantitative data from images of cells

While examining the qualitative characteristics of cells can indicate specialisation, collecting quantitative data from images of cells can provide scientists with a more sophisticated understanding of the cells' function.

One of the most common forms of quantitative data that scientists need to collect is cell size. Cell size indicates the amount of nutrients and energy the cell requires which can provide information as to how the cell functions in the body. For example, the largest cell observed in the human body is the egg cell, or ovum, which is 0.1 mm in diameter. On the contrary, at just 0.05 mm, sperm cells are the smallest

9780170411196

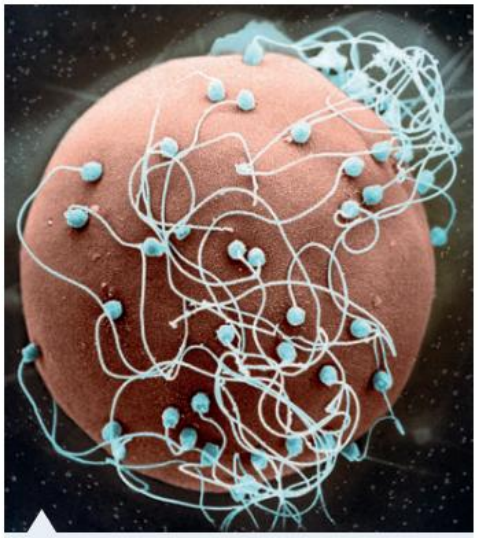
observed cell (Figure 3.2.9). While both contribute an equal amount of DNA to the developing embryo, the ovum also contains all the instructions for embryonic development and must also have enough energy to sustain itself during cellular division and thus must be significantly larger in size. The sperm cell is little more than a nucleus with mitochondria for energy and a flagellum attached; it is small because its function is to deliver DNA to the ovum.

Observing rock strata

Not only have scientific observations led to an increased understanding of the phenomena in our current world, they have also allowed us to gain insight as to how certain environments may have looked before humans were alive to document them.

Geological exploration and examination of fossils found in sedimentary rocks provides scientists with evidence to suggest how the dominant flora, fauna and terrain of an environment have changed over time. Scientific understanding of sedimentary rock formation indicates that the deeper the rock strata, the older the rock and therefore the older any biological material contained within it, such as fossils.

This knowledge of rock formation coupled with **radiometric dating** has contributed to the construction of geological eras and periods shown in Figure 3.2.11. Radiometric dating is a quantitative form of data collection that uses the rate of decay in the radioactive isotopes present in minerals to determine the age of rock strata.



Science Source/David M. Phillips

FIGURE 3.2.9 Ovum and sperm: the largest and smallest observed cells in the human body have a great responsibility in the continuation of human beings.

radiometric dating technique used to date rocks and minerals based on the decay rate of radioactive isotopes

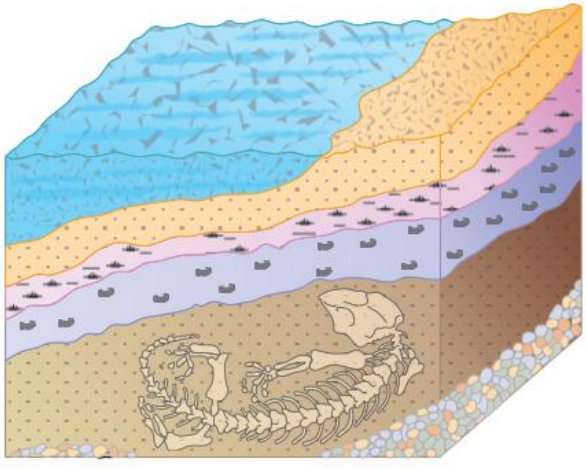


FIGURE 3.2.10 Rock strata showing geological succession.

INQUIRING FURTHER

What do you know about how your local area may have looked in the past? Conduct your own research to determine how your environment may have looked throughout geological time. Present your research as an annotated timeline.

Millions of years before present	PERIOD		REPRESENTATIVE LIFE
	Quaternary period		
1.5	Tertiary period		Primitive horses
Cenozoic era (recent life) 65	Cretaceous period		Last dinosaurs
140	Jurassic period		Quarry dinosaurs
Mesozoic era (middle life) 210	Triassic period		First dinosaurs
245	Permian period		Primitive reptiles
290	Pennsylvanian period		Giant insects
320	Mississippian period		Brachiopods
360	Devonian period		Primitive fishes
Palaeozoic era (ancient life) 410	Silurian period		Sea scorpions
440	Ordovician period		Nautiloids
500	Cambrian period		Trilobites
570	Fossils older than the Cambrian period are rare. This earlier span of time is called the Precambrian period.		

FIGURE 3.2.11 The geological timescale is constructed using geological evidence of major environmental changes.

Limitations of qualitative data

The type of data collection used in a primary investigation is determined by the nature of the hypothesis being tested. While qualitative data allows data to be described, quantitative data collection is regarded as being more scientifically accurate as it reduces the amount of error that may occur between scientists.

Have you ever asked your parents to have a 'small' party only to find out their definition of 'small' is very different to yours? Well, this occurs between scientists too. One scientist may describe the texture of a mineral using the term 'hard' but this can be perceived differently by different scientists. While timber and steel can both be described as 'hard' surfaces, one is actually much harder than the other. For this reason, it is beneficial to combine qualitative data with some form of quantitative measurement such as a scale. Mohs' hardness scale is an example of how one type of qualitative data can become quantitative (Figure 3.2.12).

MINERAL		ABILITY TO SCRATCH	RELATIVE HARDNESS
Talc	 Shutterstock.com/vvoe	Scrapeable with fingernail	1
Gypsum	 iStock.com/MarcelC	Scratchable with fingernail	2
Calcite	 Shutterstock.com/ Jiri Vaclave	Scratchable with copper coin	3
Fluorite	 iStock.com/ BruceBlock	Easily scratchable with knife	4
Apatite	 Shutterstock.com/ Fokin Oleg	Scratchable with knife	5
Feldspar	 Shutterstock.com/ Fokin Oleg	Scratchable with steel file	6
Quartz	 Shutterstock.com/ ArtOfPhotos	Scratches window glass	7
Topaz	 iStock.com/Kerrick	Scratches quartz	8
Corundum	 iStock.com/Iissart	Scratches topaz	9
Diamond	 iStock.com/ Stellar-Serbia	Scratches corundum	10

FIGURE 3.2.12 Mohs' hardness scale

INVESTIGATION 3.2.2

Making qualitative and quantitative observations in a primary scientific investigation

This practical demonstrates examples of qualitative and quantitative observations, and how each type of observation can be applied during one investigation.

AIM

To determine the effect of water and salt solutions on the length and texture of a gummi bear over time

Ben Irwin © 2017

FIGURE 3.2.13 Doing a simple test using gummi bears can easily demonstrate the difference between qualitative and quantitative observations.

MATERIALS

- three gummi bears
- three 50 mL beakers
- distilled water
- salt
- teaspoon
- ruler

METHOD

1. Measure the size of three gummi bears using a ruler and record this in the results table.
2. Feel the texture of the gummi bears and write a description in the results table.
3. Label the beakers: water, salt + water, and no water.
4. Place one gummi bear in each 50 mL beaker.
5. Fill two beakers with 25 mL of distilled water.
6. Add one teaspoon of salt to the beaker labelled 'salt + water'.
7. Leave the beakers in the same environment for 3 days.
8. Record the size and texture of each gummi bear in the results table.

RESULTS

Copy and complete the table below.

	WATER		SALT + WATER		NO WATER	
	Before	After	Before	After	Before	After
Length (cm)						
Texture						

DISCUSSION

1. Which observation was:
   - **a** qualitative?
   - **b** quantitative?
2. Which type of data was easier to observe and record? Justify your answer.
3. What is the purpose of having a beaker with no water?

EXTENSION

Conduct further research to explain your results.

9780170411196

SECTION REVIEW 3.2

REMEMBERING

1 State the limitation of qualitative data.

2 Define radiometric dating as a form of quantitative observation.

UNDERSTANDING

3 Explain how you can qualitatively and quantitatively describe the pH values of acids and bases.

4 Describe the importance of obtaining quantitative data from cells diagrams.

APPLYING

5 Describe an example where it would be more appropriate to use:

- **a** quantitative observation to collect data.
- **b** qualitative observation to collect data.

6 Determine the accuracy of quantitative and qualitative data.

7 Figure 3.2.14 shows three separate rock strata samples. Analyse the diagram and answer the following questions.

- **a** Identify two quantitative observations from this diagram.
- **b** Describe a qualitative observation from Outcrop III.
- **c** Which outcrop is the oldest? Justify your answer.

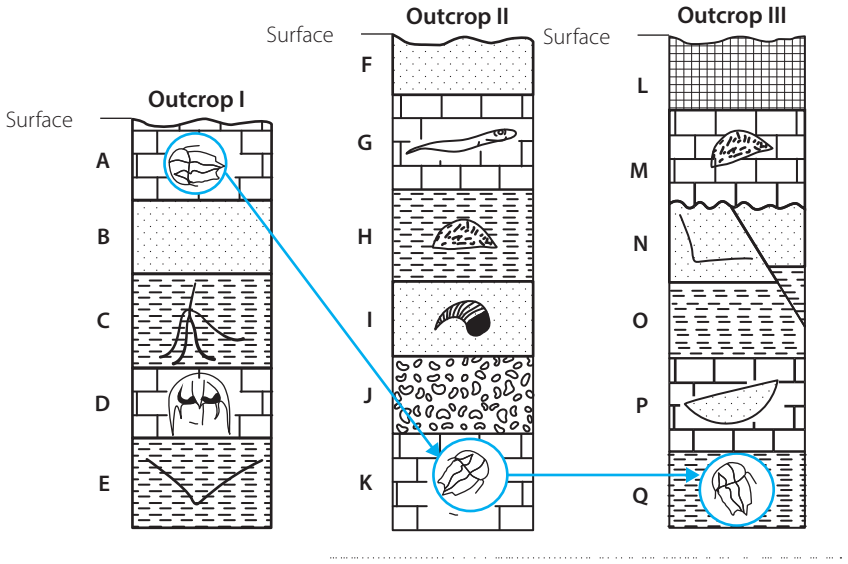


FIGURE 3.2.14 Three samples of rock strata.

8 Construct your own pH scale that includes the value, description, colour and an example of a substance at each number on the scale.

3.3 Observations as evidence

In our daily lives, people form hypotheses and design investigations without even realising. For example, a person may observe that their skin breaks out in a rash every time they use a certain brand of sunscreen, they may then hypothesise that the sunscreen is causing the rash and they may then choose to use a different sunscreen brand in order to support or disprove their **hypothesis**. While the person in the scenario may believe that they have determined the cause of the problem, the results are not deemed accurate unless they have followed every step in the scientific method.

hypothesis educated guess tested through experimentation to answer the inquiry question; states the relationship between the independent and dependent variables

Designing a scientific investigation

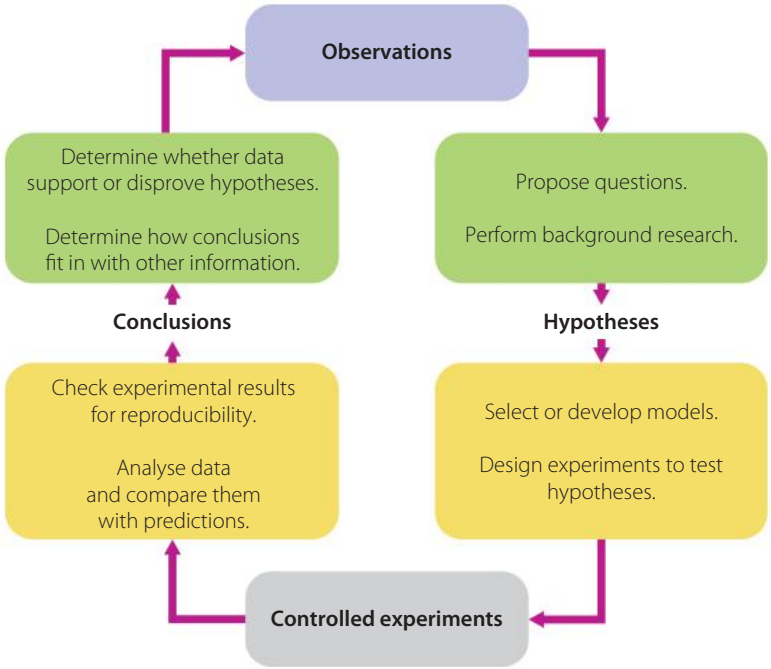
valid
extent to which a report or investigation contains accurate data, inferences and conclusions

reliable
extent to which an observation and/or measurement can be repeated under the same circumstances and produce similar results

The role of a scientist is to collect scientific data. When most people visualise scientists at work, they usually picture a clinical laboratory and a white coat. Although it is the most publicised form of scientific work, lab testing is only one of many methods of scientific data collection. Scientists can also be found collecting data in hospital settings, conducting surveys on the streets or over the telephone, building models or digital simulations, diving the depths of the ocean or climbing metres from smouldering volcanic lava.

Whether the data is being collected in a confined laboratory or the open ocean, the design of every investigation must adhere to a specific subset of rules to ensure the data collected is **valid**, **reliable** and accurate. The rules that underpin the scientific method are outlined in Figure 3.3.1.

FIGURE 3.3.1
Scientists must follow the steps of scientific method to ensure the data collected can be used for future research.



3.3.1 Observations as evidence research task

Developing a research question based on an observation

Observations are the platform of every scientific investigation. In order for an observation to be investigated, it must first be transformed into a specific research question. Making the question specific allows you to identify your exact intentions and will make for a much easier design process. For example, the classic question, 'Why is the sky blue?' is not a specific question. To make your question more specific, you must think of what it really is that you are wanting to investigate; in this case, a better question would be 'How do wavelengths of light interact in different environments?'

independent variable
factor deliberately changed during an investigation to obtain data

controlled variable
factor that is kept constant during the investigation

control
experimental set-up where the independent variable is not applied

Identifying variables

Once a specific research question has been developed, you must consider the variables of your scientific design.

In every primary scientific investigation, there should only be one **independent variable**; this is the one factor that is deliberately being changed to see whether it has an effect on the result of the investigation. Considering all other factors that may influence the result of the investigation is addressed through **controlled variables** which are the factors that must be kept the same between the **control** and the independent variable. By deliberately changing only one factor whilst keeping all others the same, the scientist can determine whether what is being changed is in fact the cause of an effect.

9780170411196

Every primary scientific investigation must have a focus or **dependent variable**; this is based upon the initial observation. The dependent variable is the factor that is being measured to determine whether or not what is being changed is producing the observed effect.

dependent variable
factor measured in the investigation

By clearly identifying and addressing the independent and controlled variables, you can determine the most appropriate form of data collection. A scientific investigation can only be deemed valid if the method of data collection is regulated, there is only one factor being changed, and all other factors are considered and kept the same.

Variables in context

Variables can be put in perspective through reference to the question, 'Does fertiliser increase root growth in *Gardenia jasminoides*?' Here, the independent variable is the addition of fertiliser to one experimental group and the control is the group with no fertiliser added. Variables that must be controlled include the environment both plants are left in, the amount of soil and water added, the type and age of the plant, the time each plant is left to grow, and the measuring equipment and technique used to measure root growth. Controlling all possible conditions will therefore allow for the dependent variable, the length of the roots, to be measured and a cause-and-effect relationship to be determined.

Shutterstock.com/somchai rakin

FIGURE 3.3.2 Reliable results must show the relationship between the independent and dependent variable in many specimens.

Forming a hypothesis

Identifying the variables in a primary scientific investigation allows for a hypothesis to be devised. A hypothesis is an educated guess based on the relationship between the independent variable and the dependent variable in your investigation. The hypothesis forms the context of the investigation and guides each step in your experiment. At the conclusion of your investigation, you analyse your data in terms of your hypothesis by either supporting or disproving it.

Constructing a method

Following the formation of a hypothesis, a method must be constructed to test the claim. The method must explicitly describe all aspects of the investigation. It must have only one independent variable with all other variables remaining controlled, clearly state the dependent variable, outline the manner in which the data is going to be collected and consider any potential risks.

Writing a valid method

The validity of a method is reliant on the way in which the variables are addressed. In order to investigate the cause of an effect, you must have an independent variable: the one factor believed to be the cause. For example, if you were investigating whether fertiliser improves root growth, then the fertiliser would be the independent variable. To ensure the independent variable is the cause of an effect, the only change in your experimental set-up is that the independent variable is applied to one group and the group without the independent variable receives the exact same treatment. To do this, you must control all other variables. In the example used above, a valid method must have two groups of the same plant, one treated with fertiliser and the other without fertiliser. Then, both groups must receive the same amount of water and sunlight, be kept in the same environment, be planted in the same amount and type of soil, and be measured at the same time.

Similar to reading a recipe, a method must not leave anything up to the imagination. Each step in the method must refer to the specific equipment being used and the action taking place. Just as you

Shutterstock.com / Africa Studio

FIGURE 3.3.3 When gathering data on plant growth, it is important to explicitly state how growth will be measured in your method. Root growth can be measured according to the number of roots, their width and their length.

wouldn't write 'bake in an oven' when describing how to cook a cake, a method cannot simply end with a statement along the lines of 'record results'. The method in which the results are being collected is equally important to the experimental set-up and should thus be explicitly stated in the method.

The way in which the results are collected relies upon the dependent variable, the variable that is being measured in the investigation. Before writing the method, you must determine which characteristics of your investigation will form the dependent variable. For example, if the specimen shown in Figure 3.3.3 is what you wish to examine, you must determine whether your dependent variable is the width of the roots, the mass of the roots, the number of roots or the length of the longest root.

Assessing risks

No matter the importance of the phenomena being investigated, the health and safety of the scientist remains the top priority. Unfortunately, the nature of scientific investigations often means there is an element of risk involved. In order to reduce the degree of risk, it is important that all possible hazards are considered and appropriate precautions are addressed in the method. As shown in Figure 3.3.4, there are four main categories of risk, each with their own set of hazards.

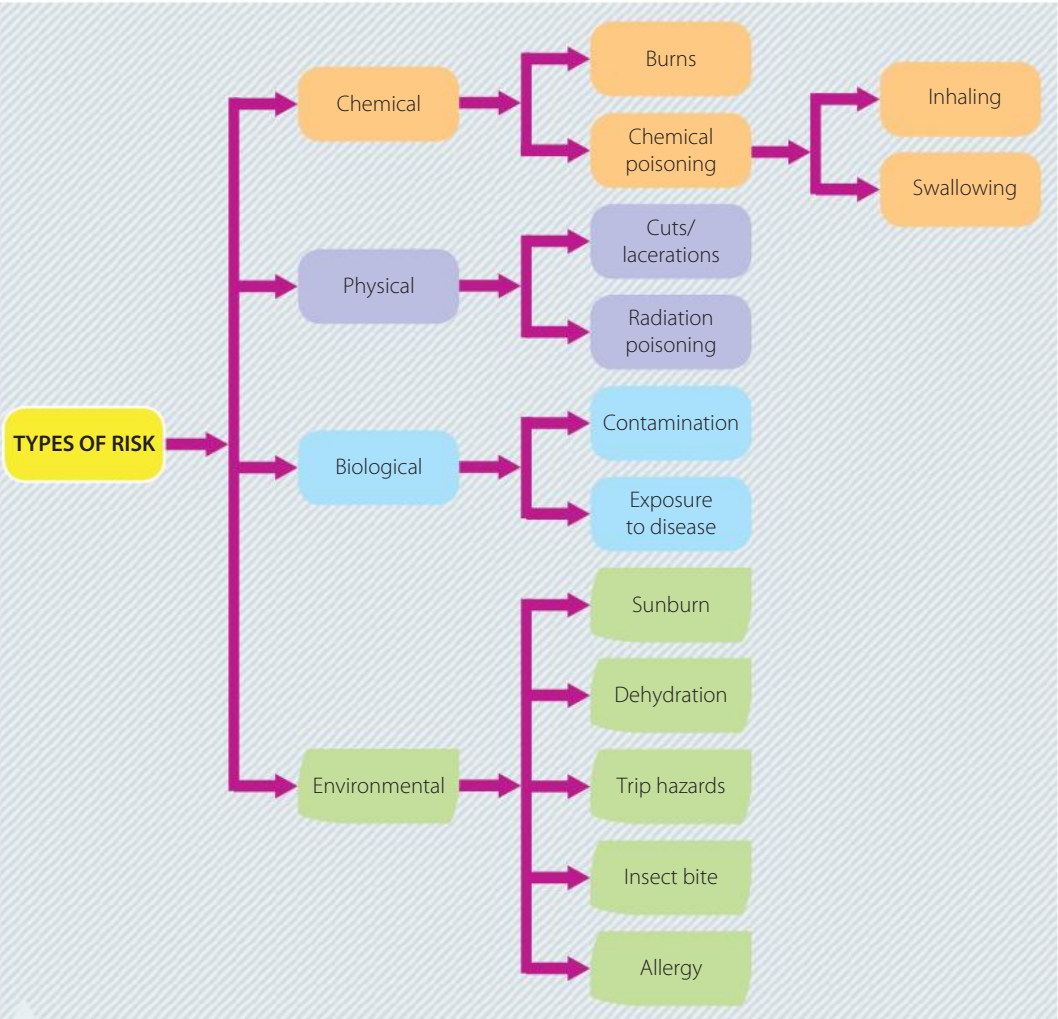


FIGURE 3.3.4 Categories of risk and their related hazards.

9780170411196

When planning primary scientific investigations, a risk assessment must be included at the beginning of the method. It must list the risks involved in the investigation and describe what precautions will be taken in order to reduce the likelihood of danger occurring. By doing so, scientists equip themselves with all the necessary equipment required to overcome a problem if something doesn't go to plan. The format in which the risk assessment should be constructed is shown in Table 3.3.1.

TABLE 3.3.1 Scaffold for risk assessment

RISK ASSESSMENT

RISK	MANAGEMENT
Burning eye from splashed acid	Wear safety goggles
Cut from broken glass	Place glassware in middle of table and stop work immediately if glass breaks

Limitations of observational tools

While scientists pride themselves on their ability to design investigations and collect data, they are limited by technology, physical space and time.

Analogue to digital technology

From watches to television, digital technology is no stranger in our daily lives. Even in the classroom, it is now common practice to learn from digital presentations such as PowerPoint rather than copy boards full of your teacher's handwriting. Of course, the science laboratory has not gone unscathed either. Digital thermometers and rulers, data loggers and scales are all instruments that have transitioned from analogue to digital over time.

One reason for the shift to digital technology in terms of scientific observations is the significant reduction in human error when measuring, such as parallax. Without digital technology, the accuracy of scientific observation is compromised and therefore the validity of the primary scientific investigation is weakened.

Science Photo Library/MARTYN F. CHILLMAID

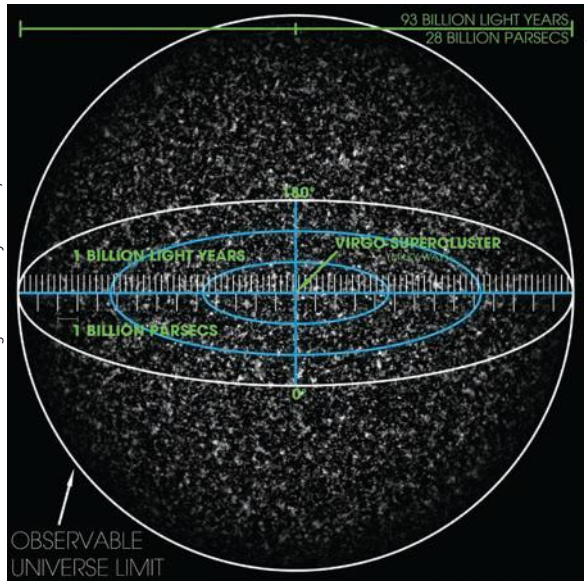
FIGURE 3.3.5 A digital data logger can provide accurate information on water pH, salinity, temperature, dissolved oxygen and turbidity.

parallax
scientific error caused by a change in line of sight by the observer

3.3 .1 CSIRO astrophysics for senior physics
3.3.2 CSIRO astronomy

Observing the universe

For many years, there has been contentious debate over whether life exists elsewhere in our own Solar System, not to mention the universe. As shown in Figure 3.3.6, the observable universe is just a tiny fraction of the entire universe. Limited by the inability to travel faster than the speed of light and the dilemma of the continuous expansion of the universe, scientists can only gather data on a small portion of the cosmological world.



By Andrew Z. Colvin (Own work) [CC BY-SA 3.0 (http://creativecommons.org/licenses/by-sa/3.0) via Wikimedia Commons

FIGURE 3.3.6 Our observable universe is just a fraction of the hypothesised universe.

INVESTIGATION 3.3.1

Designing your own primary scientific investigation

An important part of *Investigating Science* is being able to develop your own primary scientific investigation based on observations and given scenarios. Read the following information and answer the questions to produce a valid investigation.

OBSERVATION

After initially using goat milk soap for its organic properties, many people began to observe that the soap was effectively clearing their blemished skin.

HYPOTHETICAL SCENARIO

Executives from a particular goat milk soap company received feedback on the soap's effectiveness at clearing skin blemishes and proposed a new product design that featured the claim, 'Goat milk soap is more effective at removing skin blemishes than leading brands'. Your team of scientists have been asked to test this claim before the new product design can be confirmed.

Shutterstock.com/Vladimir Gjorgi

FIGURE 3.3.7 Skin blemishes are a common problem for many teenagers. This investigation evaluates the effectiveness of two methods to reduce the appearance of skin blemishes.

AIM

To determine whether goat milk soap is more effective at removing skin blemishes than leading skincare brands

VARIABLES

In this investigation, you must only change one factor and keep all other factors the same. You must decide on the dependent variable; there are many ways to collect data so you will need to ensure that your method of data collection is aligned with the equipment available to you.

Identify the independent, dependent and controlled variables.

HYPOTHESIS

Develop a hypothesis that states the relationship between the independent and dependent variables.

RISK ASSESSMENT

Copy and complete the table below to assess two risks involved in this primary scientific investigation.

RISK ASSESSMENT

RISK	MANAGEMENT

METHOD

The method must be valid and aim to collect reliable data in an accurate manner. It must explicitly describe the type of data collection, test your hypothesis and consider each of the variables.

1 What type of data collection will you be using to inform your results? Justify your answer.

2 Construct a valid and reliable method.

9780170411196

RESULTS

Usually, tables and graphs are used to depict experimental results.

1 Construct a table that identifies the independent and dependent variables and includes units of measurement shown in the title and subheadings.

DISCUSSION AND CONCLUSION

No primary scientific investigation is perfect. Of equal importance to the scientific design is the ability to reflect on any problems that may have been encountered and propose ways in which the investigation could be improved in the future.

1 Describe a problem with this investigation that may reduce the validity of your results.

2 Devise a way in which this problem could be overcome in future investigations.

SECTION REVIEW 3.3

REMEMBERING

1 Define:
   - **a** 'dependent variable'.
   - **b** 'independent variable'.
   - **c** 'controlled variable'.

2 State the purpose of a risk assessment.

3 Identify three environmental hazards.

UNDERSTANDING

4 Restate the four main steps in designing a primary investigation.

5 Explain how to write a hypothesis.

6 Use two examples to discuss the benefits and limitations of observational tools.

APPLYING

7 Demonstrate the importance of controlled variables in a primary investigation.

8 In order for data to be used in the future, it must be valid. Discuss how to collect valid data that can be used for further investigation.

9 Figure 3.3.8 shows an experimental set-up to test the hypothesis, 'Fertiliser increases flower growth'. Using the image only, justify why the results from this investigation will not be valid.

Shutterstock.com / Minaieva Antonina

FIGURE 3.3.8 Experimental set-up: Fertiliser increases flower growth.

3.4 Observing, collecting and recording

Presenting data

The purpose of a primary scientific investigation is to analyse the data collected and determine whether there is a possible cause-and-effect relationship present. However, when trying to interpret the results of an investigation, the sheer volume of text in many journal articles can be overwhelming and, at times, confusing. For this reason, data is represented in a number of different forms in order to clearly demonstrate the strength of the cause-and-effect relationship.

Tabulating data

Tabulating information is often the most efficient way to record data, particularly quantitative data. Tables provide an organised and systematic method of recording values that allow scientists to easily compare results between the experimental pressures.

While constructing a table may appear simple at first, it can be difficult to determine the appropriate format relating to your investigation. The purpose of a table is to allow peers to review the results of an investigation without having to decode scientific jargon or long, detailed sentences. The table must have a heading that summarises all the information contained within it. Figures 2.18.1 and 2.18.2 in Chapter 2 (page 33) illustrate useful scaffolds which can assist in formulating a table that presents qualitative and quantitative data, respectively.

Graphing data

Once information has been tabulated, it can then be used to generate a graph. Graphs are used by scientists to visually represent data from the primary scientific investigation and observe possible cause-and-effect relationships.

As shown in Table 3.4.1 and Figures 3.4.1–4, different types of graphs are used depending on the type of data collected in the primary scientific investigation. In most cases where the graph has axes, the independent variable is expressed along the horizontal *x* axis and the dependent variable on the vertical *y* axis.

TABLE 3.4.1 Types of graphs used to depict scientific data and their purpose

GRAPH TYPE	DATA TYPE	PURPOSE
Line graph	Numerical data on both axes	To show changes that occur over time or distance
Scatter plot	Same as above	To show how one variable is affected by the other
Column graph	Categorical data against a numerical value	To show values of categorical data
Pie graph	Percentages	To show proportional data such as responses from a survey

Line graph

Line graphs are constructed to show a relationship between two variables where one is usually time or distance.

Examining trends in line graphs

trend
general pattern

After constructing a line graph that depicts a relationship between the independent and dependent variables, scientists often note a **trend** in the data. A trend is a pattern or direction that shows how the dependent variable is affected as the independent variable is changed. Trends are used to inform further investigations by stimulating scientists to devise further hypotheses as to why the pattern exists.

9780170411196

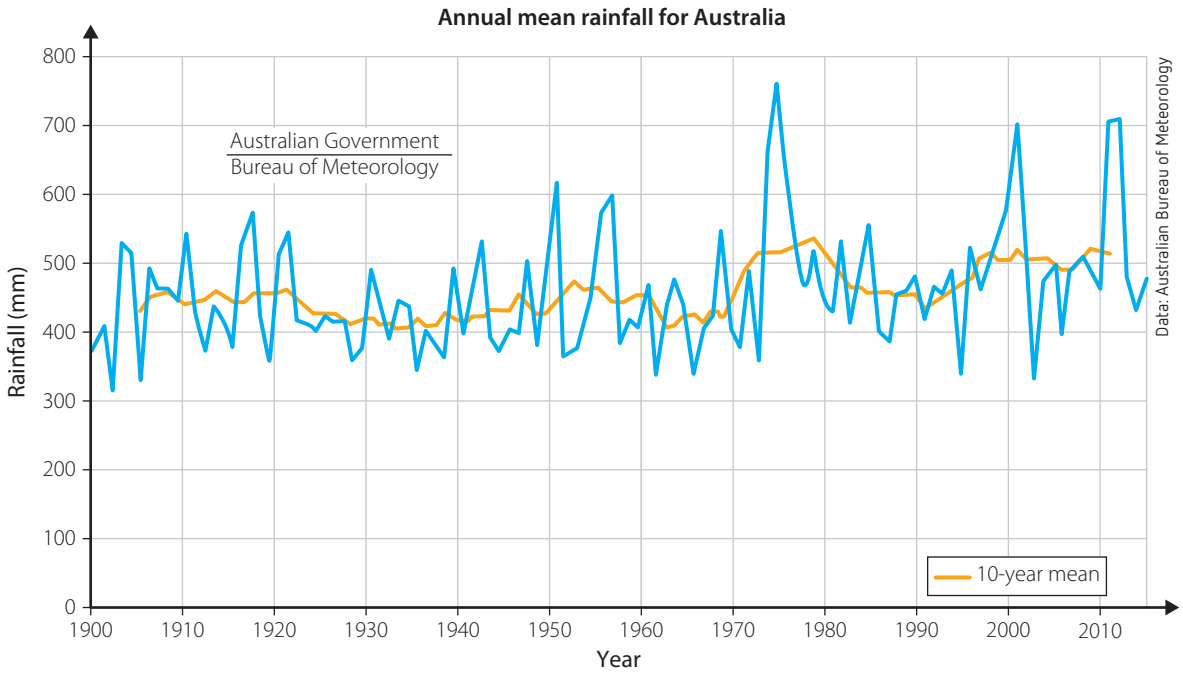


FIGURE 3.4.1 A line graph depicts a cause-and-effect relationship and is often used when the independent variable is time or distance.

Scatter plot

Scatter plots are used to determine whether there is a general cause-and-effect relationship between the independent and dependent variables.

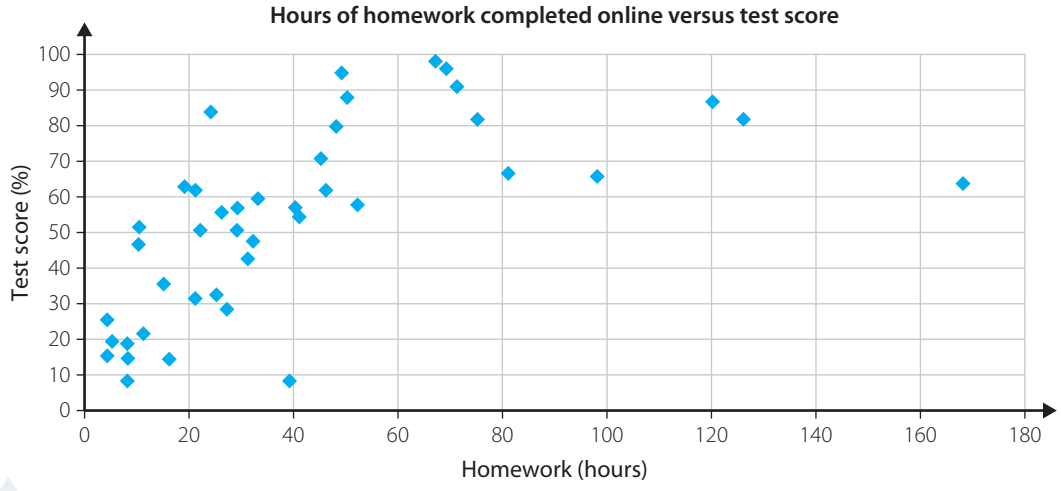


FIGURE 3.4.2 Scatter plots are used to show whether a relationship exists between the dependent and independent variable.

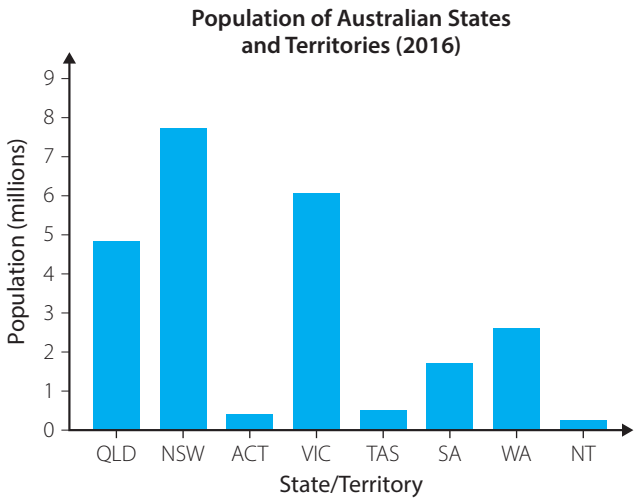
Line of best fit

If a relationship is found to exist in a scatter plot, a line of best fit may be drawn to make predictions. The line of best fit is a line drawn by the scientist to represent the general trend of the data on the scatter plot; it can be straight or curved.

Column graph

Column graphs depict changes in numerical data according to different categories. They are commonly used to show population numbers in different locations or differences in participant responses in surveys.

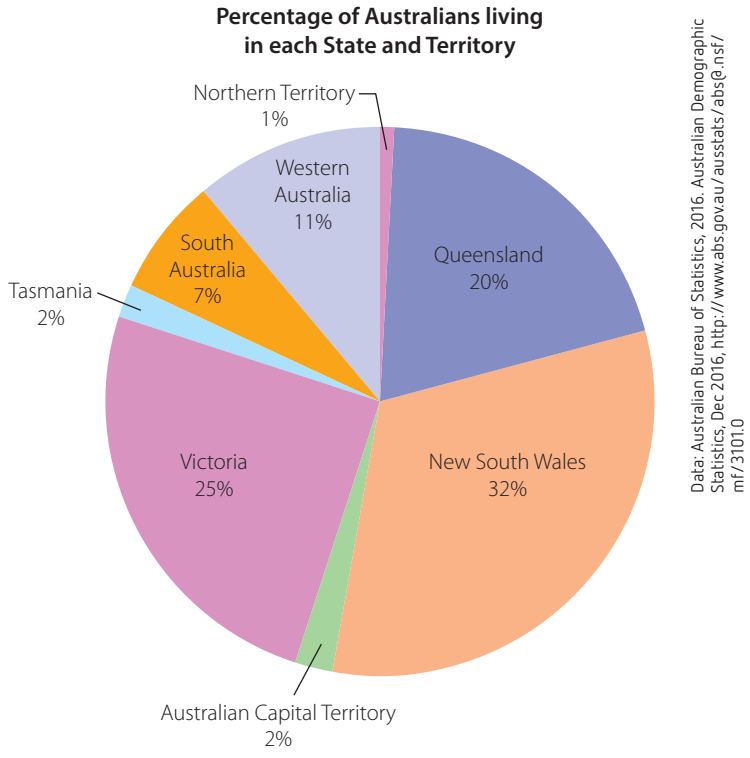
FIGURE 3.4.3 Column graphs plot numerical data against a category.



Pie graphs

Pie graphs are most commonly used to depict data that has been gathered through scientific investigations that include surveying, such as the *Census* and the *National Health Survey*.

FIGURE 3.4.4 Pie graphs often show percentage data.

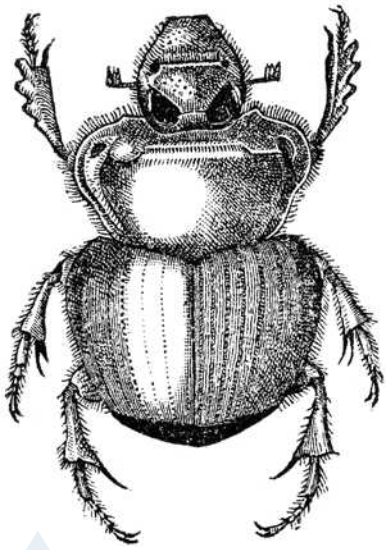


9780170411196

Visual representations

Visual representations refer to any stimulus that converts the data gathered into a diagrammatic form. Graphs are an example of a visual representation; however, digital images and drawings can also be used.

In the biological sciences, the results of an investigation are often related to observing specimens and are drawn straight from a microscope or in the field. The art of scientific drawing follows a unique set of rules. Figure 3.4.5 shows how the use of **stippling** highlights features of the specimen and allows scientists to illustrate the most intricate details. Visual representations of this nature are used to show comparisons between different species or to depict the results of an investigation where members of the same population have changed in response to a manipulated environment.



Alamy Stock Photo/bilwissedition Ltd. & Co. KG

FIGURE 3.4.5 Scientific drawing is used to visually represent results of an investigation.

3.4.1 Australian Museum: The Scott sisters

stippling
technique used in scientific drawing to show detail and shading using small dots

Digital representations

Similar to a visual representation, the purpose of a digital representation is to transform the data collected into an alternative source that summarises the findings and increases accessibility for a wider audience.

The most common sources of digital representations are simulations and models. Digital simulations and models can demonstrate complex scientific processes that are difficult to explain using text or verbal explanations alone. From gravity and orbits to isotopes and atomic mass, there are many websites dedicated to presenting digital explanations of scientific concepts across the disciplines of science.

SECTION REVIEW 3.4

REMEMBERING

1. Name four conventions used to analyse scientific data.
2. State the type of data represented in a:
   - **a** line graph.
   - **b** scatter plot.
   - **c** column graph.
   - **d** pie chart.
3. Identify an example of a digital representation.

UNDERSTANDING

4. Explain why data from primary investigations are presented diagrammatically.
5. Compare methods of tabulation when collecting quantitative and qualitative data.
6. Explain why it is important to have an average column when tabulating quantitative data.

Newspix/Craig Greenhill

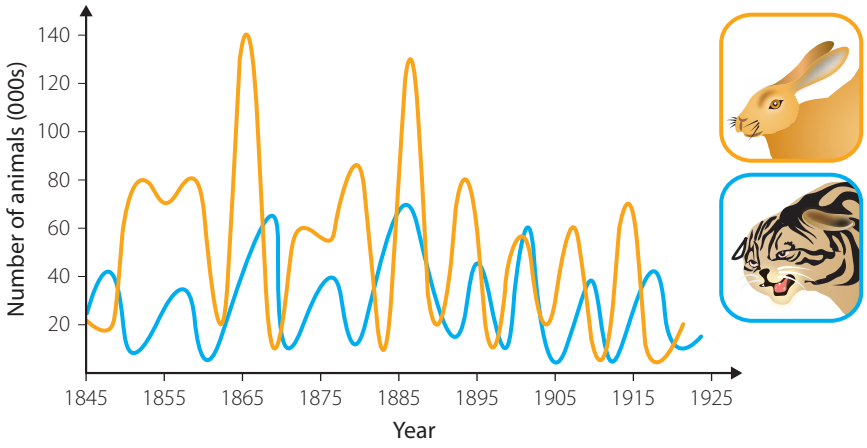
FIGURE 3.4.6 Surf lifesaving drone with flotation device.

APPLYING

7. A group of engineers are designing an upgraded drone to assist surf lifesavers patrol beaches and provide struggling swimmers with life-supporting flotation devices. The new drone is being designed to carry more than 3 kg (the carrying capacity of previous drones used on New South Wales beaches). They are planning an investigation to determine how much extra weight (to the nearest kilogram) their new drone design will be able to carry while flying at a height of 20 m. Draw a table designed to collect results for this investigation.

8 Examine the graph shown in Figure 3.4.7 depicting the population of a predator (blue) and prey (orange). Describe the trend in the line graph and propose reasons for the trend.

FIGURE 3.4.7
Line graph depicting a predator–prey relationship.



Data from Elton C, Nicholson M. 1942. The ten-year cycle in numbers of the lynx in Canada. Journal of Animal Ecology 11: 215–244.

9 Justify the use of stippling when drawing a visual representation of a biological specimen.

3.5 Conclusions promote further investigation

Drawing conclusions

The purpose of any scientific investigation is to gather data that either disproves or supports a hypothesis. From this, a scientist makes a conclusion as to how their investigation addressed a cause-and-effect relationship. A conclusion is usually two or more sentences that sums up the findings of the investigation and can be used by scientists in the future to conduct further research.

The collaborative nature of science

With thousands of new observations made by scientists across the world every day, the relevance of scientific thought constantly relies on the collaborative observations of many scientists over time. As hypotheses are tested and published, their acceptance may be challenged by societal norms or can lead to new observations from more advanced technologies, and, consequently, new conclusions.

Societal norms

The prevailing societal norms can influence whether new scientific research and developments will be accepted or not when they are first released. Following the publication of Darwin's *On the Origin of Species*, the Huxley-Wilberforce debate is an example of social norms conflicting with exceptional scientific observations. Known as 'Darwin's bulldog', Thomas Huxley famously fought the theory of evolution by natural selection with Oxford University's Bishop Samuel Wilberforce, in front of an audience of 700 at

9780170411196

the annual meeting of the British Association for the Advancement of Science. The debate took place in 1860, in the Victorian era; a time where scientific thought began to challenge traditional values.

© Look and Learn/C L Doughty

FIGURE 3.5.1 The Huxley-Wilberforce debate was a product of scientific observations challenging societal norms.

Technological innovations

Associated with almost every new scientific development is an advance in technology that allows a concept to be analysed at a more complex level.

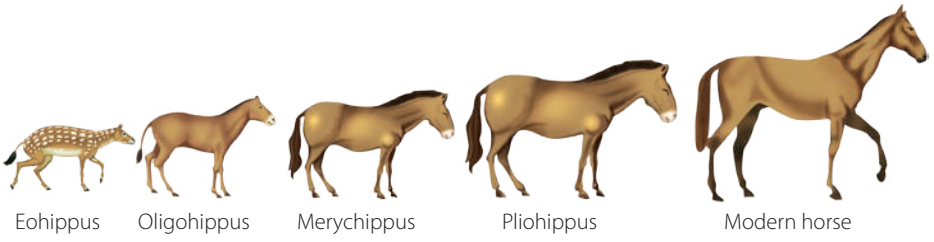
Although improvements in scientific equipment will progress the complexity of scientific understanding, there are less obvious advances in technology that have had a profound influence over the direction of scientific research. For example, the relatively recent introduction of the Internet has substantially increased the availability of journal articles and scientific research. Work that was previously only accessible by established members of the scientific community could now be accessed and scrutinised by the public.

Importance of collaboration in biological science

As environmental factors have changed and continue to change over hundreds of years, the scientific understanding of biological relationships and environmental interactions has depended on the collaborative study of scientists to draw final conclusions from the data.

With human life expectancy averaging around 70 years, it is impossible for one biologist to observe changes to species and populations over centuries. Biologists may also require the expertise of scientists in other areas of study to confirm their hypotheses. For example, a biologist may observe variations in the **phenotype** of a species and propose how they may have looked in past environments, and then rely on archaeologists and geologists to confirm the hypothesis.

phenotype observable characteristic that results from the interaction between genetics and the environment



Shutterstock.com/DummyAcksText

FIGURE 3.5.2 Our understanding of how species have changed over time has relied on the cumulative observations of scientists across many areas of study.

The theory of evolution by natural selection

Commonly referred to as 'Darwin's theory', the acceptance and publication of the theory of evolution by natural selection was actually the product of observations made by many individuals across the disciplines of science and other areas of study. It was only after Alfred Wallace, a fellow biologist, sent observations made in the Malay Archipelago to Darwin that the two realised they had devised theories very similar to one another. Both Darwin and Wallace drew upon the research of palaeontologists, geologists and embryologists whose observations helped in the formulation of the now widely accepted theory.

KEY THEORY

Theory of evolution by natural selection: the idea that individuals best suited to their environment will survive and pass on the favourable trait to their offspring.

As mentioned previously, even following decades of observations and research by many great scientists, the theory of evolution by natural selection was not well received due to the Christian belief of creation underpinning society at the time. It wasn't until many months after the publication that Huxley began rallying support for the controversial theory. Today, scientists continue to collect evidence for the theory and assess conclusions based on primary data collected in the field.

Getty Images/Time Life Pictures

FIGURE 3.5.3 Mendel formulated the principles of heredity genetics from observing pea plants in his monastery garden.

Heredity genetics

Observe the people around you. What is their hair colour? Is it curly or straight? Are their ear lobes attached? Can they roll their tongue into a U-shape? When they clasp their hands, is the left or right thumb on top? These are just some of the traits we now know as being heritable characteristics; that is, they are passed down from our parents. Our current knowledge of genes and heritability is the product of collaboration between many scientists. Perhaps the most meticulous scientific observer renowned for developing the field of genetics was the Austrian monk, Gregor Mendel.

trait
physical or chemical characteristic that is genetically determined

gene
sequence of DNA that is considered the unit of heredity, as it is transferred to the next generation

Alamy Stock Photo / Edward Parker

FIGURE 3.5.4 Mendel hand-pollinated every pea plant by taking the anther (male organ) of one pea plant and dusting it onto the stigma (female organ) of another plant that had its anthers removed.

Mendelian genetics

Often referred to as the 'father of genetics', Mendel developed the laws of genetic inheritance that would later explain the cause for variation in all living things.

Experimenting on thousands of pea plants over 8 years (1856–63), Gregor Mendel's aim was to study the inheritance of seven pairs of contrasting characteristics: plant height, pea colour, pea shape, position of flower, flower colour, pod shape and pod colour. He did this by painstakingly hand-pollinating two pea plants (Figure 3.5.4) with contrasting characteristics and observing the resultant offspring. From his recorded observations, Mendel formulated the basis of genetics as we know it. His simple observations provided evidence that there is a pair of characteristics for each trait: one from each parent. He also formulated the idea that some traits are dominant while others are recessive, providing an explanation to human heredity factors such as blood type, and hair and eye colour.

Our understanding of genetics today is not a product of Mendel's work alone but rather a collective effort made by many scientists of varying expertise who continue to theorise and design investigations based on Mendel's basic heredity principles.

3.5.1 How Mendel's pea plants helped us understand genetics
3.5.2 Gallery for genetics genius

Importance of collaboration in chemical science

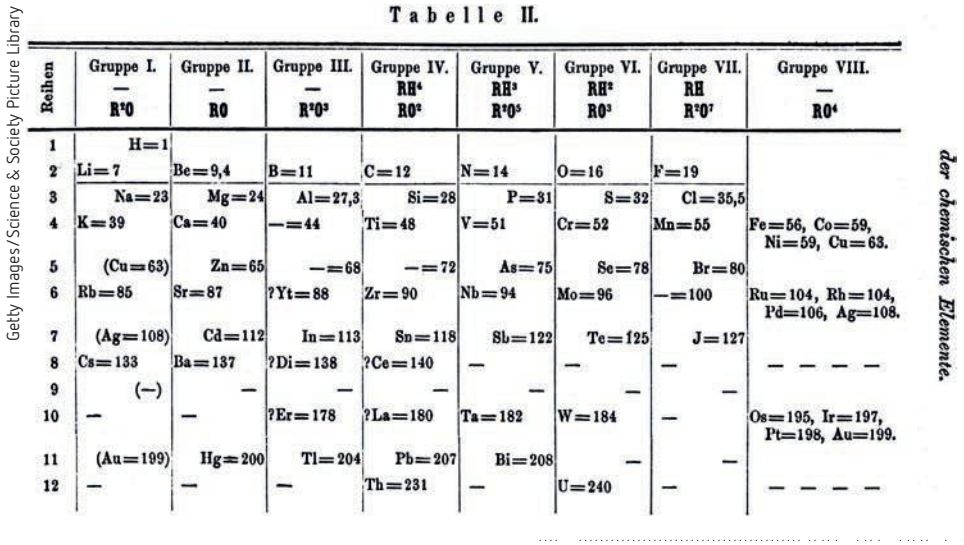
atom
from the Greek word 'atomos' meaning cannot be divided

Chemistry is the backbone of science. Without understanding atoms, their properties, and how they relate to one another, we would not have the knowledge required to make scientifically informed hypotheses about the phenomena we observe every day.

9780170411196

Periodic table of the elements

The scientist most commonly associated with the periodic table is Dmitri Mendeleev. Indeed, Mendeleev organised and published the first version of the periodic table, but he does not deserve all the credit for the modern table we refer to on a daily basis.



Getty Images/Science & Society Picture Library

Tabelle II.

Reihen	Gruppe I. — R^2O	Gruppe II. — RO	Gruppe III. — R^2O^3	Gruppe IV. RH^4 RO^2	Gruppe V. RH^3 R^2O^5	Gruppe VI. RH^2 RO^3	Gruppe VII. RH R^2O^7	Gruppe VIII. — RO^4
1	H=1							
2	Li=7	Be=9,4	B=11	C=12	N=14	O=16	F=19	
3	Na=23	Mg=24	Al=27,3	Si=28	P=31	S=32	Cl=35,5	
4	K=39	Ca=40	—=44	Ti=48	V=51	Cr=52	Mn=55	Fe=56, Co=59, Ni=59, Cu=63.
5	(Cu=63)	Zn=65	—=68	—=72	As=75	Se=78	Br=80	
6	Rb=85	Sr=87	?Yt=88	Zr=90	Nb=94	Mo=96	—=100	Ru=104, Rh=104, Pd=106, Ag=108.
7	(Ag=108)	Cd=112	In=113	Sn=118	Sb=122	Te=125	J=127	
8	Cs=133	Ba=137	?Di=138	?Ce=140	—	—	—	— — — —
9	(—)	—	—	—	—	—	—	
10	—	—	?Er=178	?La=180	Ta=182	W=184	—	Os=195, Ir=197, Pt=198, Au=199.
11	(Au=199)	Hg=200	Tl=204	Pb=207	Bi=208	—	—	
12	—	—	—	Th=231	—	U=240	—	— — — —

der chemischen Elemente.

FIGURE 3.5.5
The first periodic table: Mendeleev's organisation of elements according to atomic mass. This periodic table is different to the table you have most probably colour-coded and stuck into your science book some time within the last 5 years, but the general organisation is apparent.

The first attempt to group atoms according to their properties was completed by Antoine Lavoisier in 1789, who classified known atoms into gases, metals, non-metals and earths. Several other scientists also researched the atomic mass of the **elements**, which were then collated and presented at a scientific conference in Karlsruhe, Germany in 1860. Following the publication of this list, Mendeleev tabulated the information and devised the table that somewhat resembles the modern table we use today.

element
substance that cannot be separated into smaller substances by chemical means

The periodic table of elements is now a scientific staple used across many areas of study. It is used to predict chemical reactions, determine which elements can be used as a conductor or insulator of electricity and to compare DNA structures between organisms.

Importance of collaboration in the physical sciences

Physical science is a broad term used to describe the branches of science related to the inorganic world such as physics, astronomy, inorganic chemistry and earth science. As our knowledge in these areas continues to develop, we rely on observations made by scientists many centuries ago and compare them with modern observations and new conclusions.

Heliocentric model of the Solar System

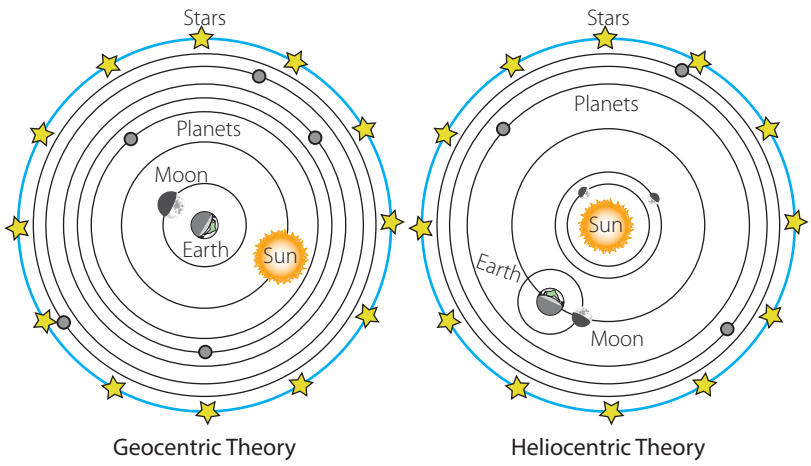
Our understanding of the Solar System and how the planets, moons and Sun interact is fundamental to our understanding of weather systems, tides, seasons and even the possibility of extraterrestrial life. Before the current model was confirmed, there was significant conflict as to how the planets and Sun were arranged.

The first recognised theory of how Earth interacted with other planets, stars and the Sun was devised more than 2000 years ago by a Greek mathematician. Ptolemy's model was known as the geocentric or 'Earth-centred' model, and was based on mathematical principles such as Pythagoras' theorem and 'spherical trigonometry'. At the time of this model there was a strong belief that Earth was superior to other planets which may have influenced his hypothesis that the Earth was at the centre of the entire

Solar System. Ptolemy's geocentric model of the Solar System was accepted and remained the dominant theory for over 1400 years. Remnants of his theory still pertain in our current vocabulary such as the phrases 'sunrise' and 'sunset' which suggest that the Sun is moving around the Earth; however, we now know that this is not the case.

During the 'scientific revolution' that occurred in the 16th and 17th centuries, many theories that attempted to explain everyday observations were put under scrutiny. Refuting Ptolemy's theory at this time was Polish mathematician and astronomer, Copernicus, who proposed the Sun as being a stationary body at the centre of the Solar System. Now referred to as the heliocentric or 'Sun-centred' model, Copernicus challenged the assumption that the Earth was the centre of the universe. Based on his observations of planetary movement over many years, Copernicus' theory attempted to resolve some mathematical inconsistencies that arose from Ptolemy's assumption that Earth was stationary and all planets moved on a spherical orbit around it.

FIGURE 3.5.6
Previous and current models of the Solar System



The current understanding of the Solar System is built upon the heliocentric model which, in turn, was based on elements of the geocentric model. The geocentric model would not have been devised had Aristotle not observed that the Earth is spherical rather than flat. Therefore, in order to build our scientific knowledge, it is imperative that theories continue to be reviewed, new observations made and new conclusions reached.

Importance of collaboration in earth and environmental science

Earth and environmental science is a field of study that examines changes to landforms and environmental conditions over time. The nature of this area of science relies on the collection of data over decades. While scientists in the past have been known to work on one theory over such a time period, current economic pressures and the availability of research grants rarely allow for such an occurrence now. Consequently, modern scientists rely on collaborative collection of data that builds upon the observations and hypotheses proposed by previous scientists.

Plate tectonics

In 1912, Alfred Wegener put forward his continental drift theory. Wegener's theory suggested that all of the continents were once joined together into one giant landmass called **Pangaea** and that the continents somehow separated and drifted across the oceans. Wegener's theory was based on two pieces of evidence: the observation that the continents fit together like a jigsaw, and the collection of similar prehistoric plant and animal fossils from continents a considerable distance apart.

Pangaea
from the Greek 'pan' meaning all and 'gaea' meaning Earth; therefore, 'all of the Earth'

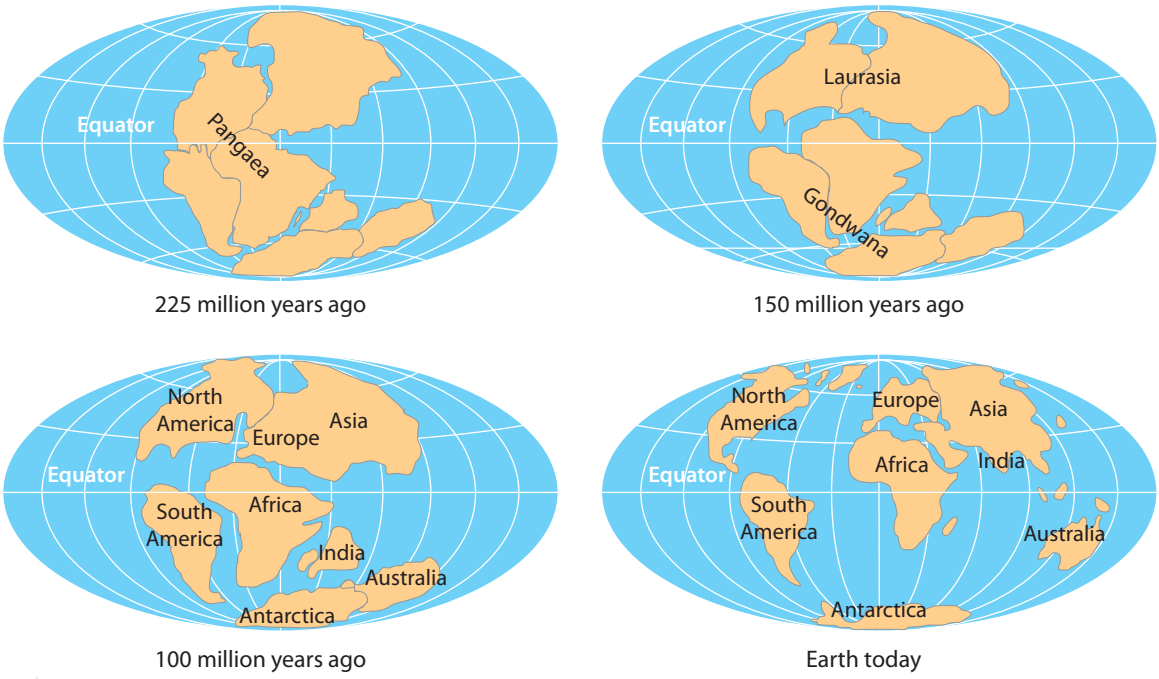


FIGURE 3.5.7 Wegener's theory of continental drift proposed that the continents moved away from each other over time but did not describe how this happened.

During Wegener's time, there was no way of measuring whether continents could move or not. In 1945, sonar technology was used to survey the depth of the ocean floor. Scientists found that there were many underwater 'mountain ranges' called mid-ocean ridges. Harry Hess proposed some 20 years later that the mid-ocean ridges were caused by hot magma rising from the mantle and forming a new rocky crust. As shown in Figure 3.5.8, this new rocky crust pushed the old crust outwards which caused the seafloor to spread. Hess' theory of seafloor spreading was the first model to explain Wegener's theory that continents could drift away from each other. Hess' explanation for continental drift was again supported with evidence gathered by successive scientists such as **sediment** thickness and rock age around mid-ocean ridges.

sediment
solid fragmented material that is transported and deposited by water, ice or wind, forming layers on the Earth's surface

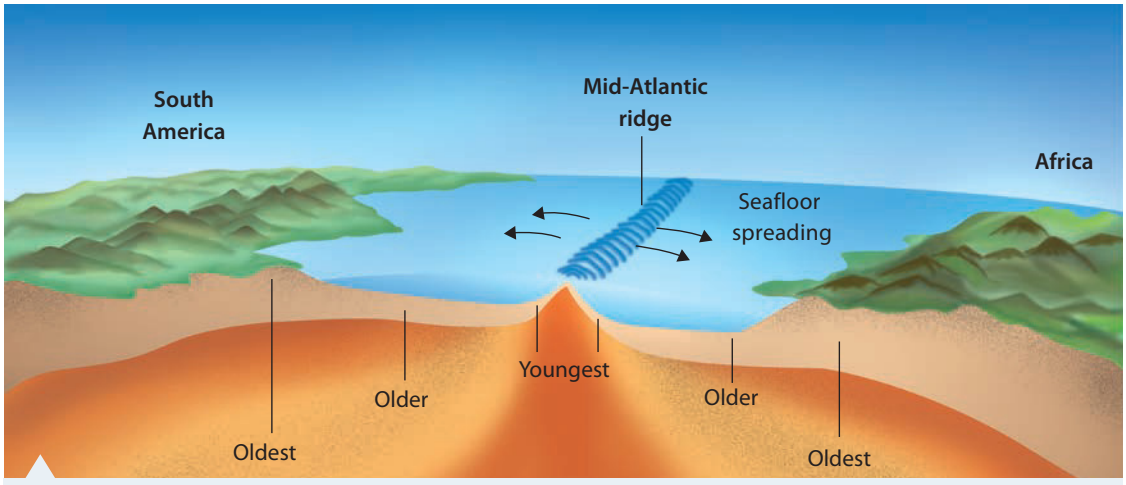


FIGURE 3.5.8 Hess proposed seafloor spreading as the cause of continental drift.

Without Wegener, Hess and other scientists involved in the collection of evidence to support plate tectonic theory, we could not have attained the comprehensive knowledge that explains the distribution of continents over the Earth's crust. This is a clear example of where previous conclusions, in this case from Wegener's work, prompted further observations, the collection of data and developed new understandings of the movement of plates over time.

INQUIRING FURTHER

Contemporary scientists rely on observation and collaboration as an important part of their research. Conduct a secondary source investigation into one of the following areas of research being conducted in Australia today and discuss the importance of observation and collaboration. Present your research as a three to five-minute audiovisual presentation.

- Professor Paulo De Sousa, University of Tasmania – The Mars exploration rovers project
- Professor Greg Woods – Devil facial tumour disease
- Dr Beth Fulton, CSIRO – Strategic modelling of Australia's fisheries
- Dr Brad Tucker, ANU – The skymapper supernova survey
- Professor Neal Menzies, University of Queensland – Soil fertility

SECTION REVIEW 3.5

REMEMBERING

1. Define 'conclusion'.
2. Name two factors that influence the acceptance of scientific conclusions.
3. Identify three examples of where the periodic table has been used in scientific research.

UNDERSTANDING

4. Explain how collaboration between scientists was influential in the development of the theory of evolution by natural selection.
5. Name three scientists who contributed to the development of heliocentricity and describe their input.
6. Describe how Hess used Wegener's conclusions to support the theory of plate tectonics.

APPLYING

7. Relate modern society to the acceptance of scientific thought.
8. Relate the primary data collected from your practical investigation to investigations conducted by other scientists.
9. With reference to two examples, assess the importance of using conclusions to support further investigation.

9780170411196

CHAPTER REVIEW QUESTIONS

REMEMBERING

1. Create a glossary of all of the terms listed in this chapter.
2. List the quantitative and qualitative observations that can be made when watching a candle burn.
3. Identify an example where combining qualitative and quantitative data can improve scientific accuracy.

UNDERSTANDING

4. Outline one way that Aboriginal and Torres Strait Islander peoples use observation to manage their natural environment.

APPLYING

5. Examine a slide of your choice under a light microscope. Draw a diagram of your observation that includes both qualitative and quantitative data.

ANALYSING

6. The Bernoulli effect describes the phenomenon where fluid can move at a faster speed when there is less pressure. Design a practical investigation that aims to collect quantitative and qualitative data on the Bernoulli effect.

EVALUATING

7. A student is overheard saying that quantitative data is more scientifically accurate than qualitative data. Is this an accurate statement? Justify your answer.
8. Evaluate the influence of Mendel's findings on our current understanding of genetics.

CREATING

9. Create a visual representation of a biological specimen viewed under a stereo (dissecting) microscope.

DEPTH STUDY
BIOLOGY

INVESTIGATING CORAL BLEACHING ON THE GREAT BARRIER REEF

Suggested length: 14 hours including research and generation of graphs and tables for presentation

Focus: Secondary-sourced investigation and presentation

3.6.1 Secondary investigation scaffold

SECONDARY-SOURCED INVESTIGATION SCAFFOLD

Syllabus outcome

Identify the syllabus outcome you will be investigating and write a summary of the outcome.

Syllabus statement: *Analysing primary data through tabulation, graphing and visual/digital representations*

Aim

Write the aim as a sentence. Start the sentence with 'To' followed by a verb; for example, 'investigate', 'measure' or 'test'.

Secondary sources

List all of the sources that you are using in your investigation and cite them using the correct citation protocols.

Suggested source:

- Australian Institute of Marine Science

Investigation design

Outline how you are designing the final presentation (refer to Chapter 2 for further information).

Method

The method is written as numbered steps. Each sentence must start with a verb.

Results

The results may be recorded in tables, graphs or diagrams, or written as observations in sentence form.

Validity and reliability

Remember that validity is related to ensuring that the sources come from educational, government, university or scientific web pages, journals and textbooks. Reliability is associated with finding similar explanations of the concepts across many sources.

Discussion and conclusion

In the discussion and conclusion, analyse your findings to answer your hypothesis, aim and inquiry question/s.

3.6.1 Australian Museum Lizard Island Research Station

3.6.2 Great Barrier Reef Foundation

3.6.3 Managing the reef

3.6.4 Science and the Great Barrier Reef

3.6.5 Coral bleaching risk indicators and Summer sea water temperatures for the Great Barrier Reef

9780170411196

DEPTH STUDY
CHEMISTRY

HOW CHEMICAL TESTING HAS HELPED SOLVE CRIMES

Suggested length: 12 hours including research and writing

Focus: Secondary-sourced investigation: Essay

SECONDARY-SOURCED INVESTIGATION SCAFFOLD

Syllabus outcome

Identify the syllabus outcome you will be investigating and write a summary of the outcome.

Syllabus statement: *Investigating how observation and experimentation explain cause and effect in historical examples*

Aim

Write the aim as a sentence. Start the sentence with 'To' followed by a verb; for example, 'investigate', 'measure' or 'test'.

Secondary sources

List all of the sources that you are using in your investigation and cite them using the correct citation protocols.

Suggested sources:

- National Institute of Justice
- Crime Scene Investigator Edu
- Explore Forensics

Investigation design

Outline how you are designing the final presentation (refer to Chapter 2 for further information). Make sure you include the following (if applicable):

- Variables (independent, dependent and controlled)
- Treatments / control

Method

The method is written as numbered steps. Each sentence must start with a verb.

Results

The results may be recorded in tables, graphs or diagrams, or written as observations in sentence form.

Validity and reliability

Remember that validity is related to ensuring that the sources come from educational, government, university or scientific web pages, journals and textbooks. Reliability is associated with finding similar explanations of the concepts across many sources.

Discussion and conclusion

In the discussion and conclusion, analyse your findings to answer your hypothesis, aim and inquiry question/s.

3.7.1 Secondary investigation scaffold

3.7.1 National Institute of Justice: Forensics

3.7.2 The Real CSI

3.7.3 Crime Scene Investigations and forensic laboratory science

3.7.4 Explore forensics

3.7.5 Solving cold cases with DNA: The Boston strangler case

3.7.6 Forensic cases: The murder of Leanne Tiernan

DEPTH STUDY
PHYSICS

HOW DOES THE MASS OF A PENDULUM AFFECT ITS ACCELERATION TO THE EQUILIBRIUM POSITION?

Suggested length: 10 hours

Focus: Primary scientific investigation

3.8.1 Primary investigation scaffold

PRIMARY SCIENTIFIC INVESTIGATION SCAFFOLD
In the discussion and conclusion, analyse your findings to answer your hypothesis, aim and inquiry question/s.
Syllabus outcome Identify the syllabus outcome you will be investigating and write a summary of the outcome. Syllabus statement: *Investigating the role of variables in a primary scientific investigation*
Aim Write the aim as a sentence. Start the sentence with 'To' followed by a verb; for example, 'investigate', 'measure' or 'test'.
Investigation design Outline how you are designing the final presentation (refer to Chapter 2 for further information). Make sure you include the following (if applicable): ▪ Variables (independent, dependent and controlled) ▪ Treatments / control
Hypothesis (if applicable) A hypothesis is an educated (informed) guess that is tested through investigation to explain and reach answers to scientific questions.
Secondary sources List all of the sources that you are using in your investigation and cite them using the correct citation protocols. Suggested sources: ▪ Teach Engineering ▪ The Physics Classroom
Method The method is written as numbered steps. Each sentence must start with a verb.
Results The results may be recorded in tables, graphs or diagrams, or written as observations in sentence form.
Validity and reliability Remember that validity is related to the method and equipment used to perform your experiments, whereas reliability is associated with the repetition of the experiment obtaining similar results with minimal error.
Discussion and conclusion In the discussion and conclusion, analyse your findings to answer your hypothesis, aim and inquiry question/s.

3.8.1 Swinging pendulum
3.8.2 Kinematics
3.8.3 Pendulums
3.8.4 Acceleration

9780170411196

DEPTH STUDY
INVESTIGATING SCIENCE

HOW ARE OBSERVATIONS USED BY ABORIGINAL AND TORRES STRAIT ISLANDER PEOPLES TO MANAGE THE LOCAL AREA SUSTAINABLY?

Suggested length: 12 hours

Focus: Secondary-sourced investigation

SECONDARY-SOURCED INVESTIGATION SCAFFOLD

Syllabus outcome

Identify the syllabus outcome you will be investigating and write a summary of the outcome.

Syllabus statement: *Investigating observations that informed land management by Aboriginal and Torres Strait Islander peoples*

Aim

Write the aim as a sentence. Start the sentence with 'To' followed by a verb; for example, 'investigate', 'measure' or 'test'.

Secondary sources

List all of the sources that you are using in your investigation and cite them using the correct citation protocols.

Suggested sources:

- CSIRO
- Creative Spirits
- Rosemary Hill, Petina Pert, Jocelyn Davies, Catherine Robinson, Fiona Walsh, Fay Falco-Mammone. (2016). *Indigenous land management in Australia: Extent, scope, diversity, barriers and success factors*. Cairns: CSIRO.

Investigation design

Outline how you are designing the final presentation (refer to Chapter 2 for further information).

Method

The method is written as numbered steps. Each sentence must start with a verb.

Results

The results may be recorded in tables, graphs or diagrams, or written as observations in sentence form.

Validity and reliability

Remember that validity is related to ensuring that the sources come from educational, government, university or scientific web pages, journals and textbooks. Reliability is associated with finding similar explanations of the concepts across many sources.

Discussion and conclusion

In the discussion and conclusion, analyse your findings to answer your hypothesis, aim and inquiry question/s.

3.9.1 Secondary investigation scaffold

3.9.1 Indigenous knowledge and environmental land management
3.9.2 Biological diversity
3.9.3 Indigenous perspective on sustainability
3.9.4 Aboriginal Heritage
3.9.5 Aboriginal land care

4

MODULE 2 CAUSE AND EFFECT – INFERENCES AND GENERALISATIONS

A scientific inquiry is commenced when a person makes an inference about an observation that is based on their current understanding. From this point scientists create hypotheses and conduct experiments to test the accuracy of their understanding. This process has led to generalisations that can be applied to the wider world, and has driven advances in scientific understanding and the development of new technologies.

Scientific inferences and generalisations do not operate in isolation. A scientist's personal experience and that of others can influence and advance knowledge in a wide range of disciplines.

INQUIRY QUESTIONS

- What can be inferred from observations?
- Can secondary sources be useful in scientific investigations?
- How do humans recognise patterns in data?
- What assumptions and generalisations can be made from data?
- Why should assumptions and generalisations made from data be tested?
- What part do peers have in a scientific investigation?

CONTENT

Students investigate:

- observations and inferences
- using secondary-sourced data
- observing patterns
- developing inquiry questions
- generalisations in science
- peer review

OUTCOMES

A student:

- develops and evaluates questions and hypotheses for scientific investigations INS11/12-1
- designs and evaluates investigations in order to obtain primary and secondary data and information INS11/12-2
- selects and processes appropriate qualitative and quantitative data and information using a range of appropriate media INS11/12-4
- examines the use of inferences and generalisations in scientific investigations INS11-9

9780170411196

Shutterstock.com/ChameleonsEye

9780170411196

4.1 Observations and inferences

Making inferences

Getty Images / Blend Images / John Lund

FIGURE 4.1.1 Past experience with objects that fall without support would lead most people to infer that there is a hidden means of supporting the woman in this illusion.

When people observe something happen that is novel or unique it often captures their interest; they become curious as to why it happened and begin to think about possible causes for the effect observed. For example, when an audience watches a magic show they respond to the illusions in a number of ways depending on their personal experiences. This is because each individual's past experiences leads them to make **assumptions** about how the world works. In the magic show example, nearly everyone would assume that objects fall when they have no support due to years of experience with objects doing just that, yet the magician's illusion causes the audience to become amazed because objects appear to do just the opposite. From this apparent contradiction the audience will begin to make a number of **inferences** about the trick they have observed. They can infer that there must be some kind of support or wires holding the woman up, which aligns with their past experience, or they can infer that the magician really can defy gravity.

The process of inferring possible explanations for observed phenomena is an integral part of the **scientific process**. Inferences are made based on past experiences, assumptions, available evidence and collective understanding about how the world works. An inference can be tested by developing hypotheses and the scientific process can be used to eliminate potential sources of error. Following these steps, a **generalisation** about the phenomena can be developed. In this way generalisations help people to negotiate and understand the world they live in.

assumption
idea in the form of an inference that was established in the past and is used to inform another inference

inference
conclusion that is rationally and logically made based on observations and available information

scientific process
systematic process whereby questions are answered and hypotheses tested to generate empirical evidence

generalisation
idea or conclusion that can be applied more broadly to related phenomena

Inferences and observations

An observation, in its purest form, is simply data that has no inherent meaning. However, all humans have a tendency to subconsciously view all new observations within the context of past experience, preconceived assumptions, available evidence and the collective understanding of those around us. This reasoning is used to make judgements about what is being observed. This in turn helps to make inferences about cause and effect, predict patterns, find trends in data and determine how things can be classified (Figure 4.1.2).

Past experience

All humans have past experiences that shape the way they interpret the world. For example, many people that experience arachnophobia have had a frightening experience with spiders in their youth, while other people that did not have the same frightening experience may react calmly to spiders. These differing past experiences can lead to people interpreting the presence of a spider in different ways.

Preconceived assumptions

We all have preconceived assumptions about what has happened and why. These assumptions often come in the form of inferences that have never been tested in the past and are used to inform another inference. A common preconceived assumption in young children is that lighter objects will fall more slowly than heavier objects. They often do not take into account air resistance as opposing gravitational force.

4.1.1 Preconceived assumptions: A time lapse of a forest during a growing season

It is not until this assumption is tested with objects of similar shape and size but with a different mass that this assumption is abandoned.

Available evidence

The observations people make don't always enable them to gather all the available evidence. This may be due to a number of reasons; however, it generally includes issues of time, scale and available technology. For example, a plant that is observed for an hour will not appear to move or respond to a stimulus. However, if the same plant is observed over a week using time lapse photography, the ability of the plant to move and respond becomes readily apparent.

INQUIRING FURTHER

People sometimes think that lighter objects fall more slowly than heavier objects. Can you think of a situation that would create the false assumption that lighter objects fall more slowly than heavy ones? Design an investigation to test the assumption that mass influences the velocity of a falling object.

mass
amount of matter in a solid, liquid or gas

Collective understanding

The stories, experiences and knowledge of other people have the ability to influence the way we think about the things we observe. Humans are social animals, and the opinions and thoughts of others have the capacity to influence our reasoning. When we go to school, we learn about the discoveries of scientists like Charles Darwin and use his theory of evolution via natural selection to explain how modern birds descended from dinosaurs.

4.1.2 A palaeontologist discusses the relationship between birds and dinosaurs
4.1.3 Bird-like dinosaur *Velociraptor*
4.1.4 Bird-like dinosaur *Chirostenostes*

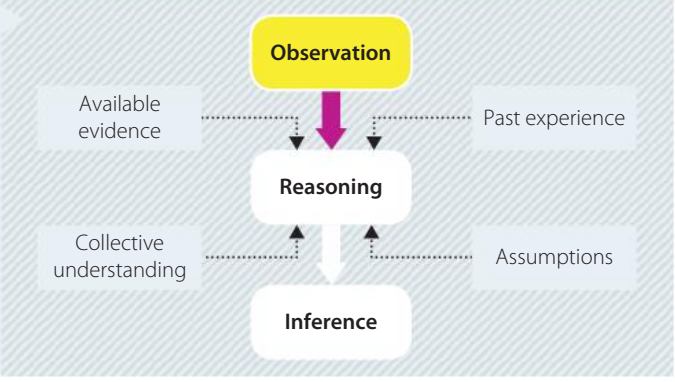


FIGURE 4.1.2 To make an informed inference scientists take into account their observations as well as logical reasoning.

Making inferences from quantitative and qualitative observations

The type of observations we make can be broadly classified into two types. Quantitative data refer to observations that can measured; they are typically represented numerically and have standard units (e.g. temperature or distance). Qualitative data describe something in its entirety and are observations that may use words or images to categorise observations (e.g. mammals that can be identified as dogs). Scientists use both types of observations to make inferences about the phenomena they observe.

quantitative data
numerical values collected as evidence during an investigation (e.g. calculations, measurements)

qualitative data
descriptive data collected as evidence during an investigation (e.g. images, observational sentences)

INQUIRING FURTHER

In the 1950s Solomon Asch developed a series of experiments to examine how others could influence the perceptions of his participants. One experiment involved a participant among a group of actors. He asked the group to compare and match the length of lines on a card. The actors all gave incorrect answers, and at first, the one 'real' participant gave the correct answer. As time went on, the participant elected to change their responses to match those of the actors.

Research other experiments on conformity. What ethical considerations would need to be met to conduct a conformity experiment today? What factor would influence the results? How can you check that the results are reliable?

4.1.5 Asch conformity experiment

INVESTIGATION 4.1.1

Collecting quantitative and qualitative data

Every experiment endeavours to collect data in one form or another. One of the major challenges for scientists is to decide what data needs to be collected to effectively answer their question. Collecting the right type of data will enable scientists to make and draw inferences with increasing validity.

AIM

To conduct a collaborative investigation that requires the collection of appropriate quantitative and/or qualitative data and analyse its validity

An investigation may be chosen from **one** of the following questions.

- How do different variables such as temperature, light and soil pH affect the growth rate of plants? (pick one variable)
- How do variables such as surface area, temperature, speed of flow (stirring), acid volume and concentration influence the reaction rate of calcium carbonate in acid? (pick one variable)
- What variables, such as temperature, and continuous and non-continuous use, affect the life of a battery? (pick one variable)
- How do different variables such as turbidity, pH, oxygen saturation levels and nutrient load impact the water quality of a local pond or stream? (pick one variable)

MATERIALS

- relevant equipment to perform and make quantitative and qualitative observations according to the selected investigation
- complete a risk assessment on any materials with an associated risk

METHOD

1. In a team select a question on which to base the investigation.
2. Create an aim for the investigation.
3. Design a method for the investigation, being sure to include equipment, the type of data that will be collected and how it will be recorded.
4. Conduct the investigation and record the data.
5. Record the quantitative and/or qualitative observations.

RESULTS

Analyse the data and propose a number of inferences that could be made to explain or describe the observations.

DISCUSSION

1. Quantitative and qualitative data have different characteristics. Identify the types of data collected in the investigation.
2. Justify why the investigation required the collection of the particular types of data identified in Question 1 in order to meet the aim.
3. Identify data that was not collected that could further increase the validity of the inferences.
4. Select the inference that is most likely to explain or describe the phenomena in the investigation and justify your reasoning.

Mark Fergus Photography

FIGURE 4.1.3 A vigorous reaction is produced when marble chips (calcium carbonate) are added to a high volume and concentration of hydrochloric acid.

Observations and inferences made by Aboriginal and Torres Strait Islander peoples

The traditional lifestyle of Aboriginal and Torres Strait Islander peoples requires that they make close observations of Country and Place in order to survive. From these observations, Aboriginal and Torres Strait Islander peoples are able to infer what plant foods are edible, when to collect and how to prepare them; how to find fresh drinking water; and when and where hunting and fishing will be most abundant. The inferences and generalisations about Country and Place are central to the culture of the Aboriginal and Torres Strait Islander peoples and are passed down from one generation to the next.

lore
tradition and knowledge held by a cultural group passed down through the generations

leaching
process in which water-soluble substances are dissolved into surrounding water, allowing the substances to be transported and removed from their source material

species
group of living organisms with similar characteristics that can interbreed

A toxic puzzle: Removing plant toxins

A number of edible Australian native plants **species** can pose a significant risk of poisoning if they are incorrectly prepared. Determining the correct techniques requires close observation and reasoning to make the appropriate inferences regarding their preparation. The correct way to prepare these plants is a part of Aboriginal **lore** and the knowledge is kept according to the male or female gender association of the plant. This means that either the men or the women are entrusted with the knowledge of how best to collect, prepare and cook particular plants, as well as their potential medicinal uses. Youth are often not entrusted with this knowledge until they have demonstrated responsible use and understanding of safer foods and materials.

Some of the plants that require safe preparation via **leaching** include the following.

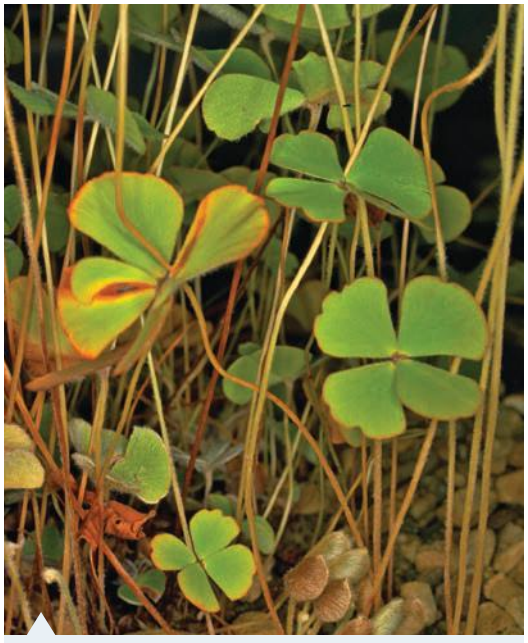
Cunjevoi or Spoon Lily (*Alocasia brisbanensis*) is a rainforest plant found along the east coast of Australia. The plant, including its large starch-rich rhizome, is poisonous, and even a small amount incorrectly prepared has been known to kill. Records indicate that Indigenous peoples removed the toxins by soaking the rhizomes for an extended period of time in water to leach out the toxins, before pounding the rhizome and making it into cakes for roasting. Due to its highly toxic nature, Cunjevoi is not utilised as a food source today.

Bracken (*Pteridium esculentum*) is a hardy fern that grows in forests, heaths and paddocks with a high to moderate rainfall. It is toxic to both humans and livestock due to its high tannin content and leucocyanidin. However, the new shoots and rhizome can be eaten if leached or boiled correctly.

Nardoo (*Marsilea mutica* and *Marsilea drummondii*) are ferns with clover shaped leaves that grow in river flats and on the edges of swamps and wetlands throughout inland Australia. The sporocarps are separated from their casings and leached in water to remove the toxins. They are then ground and baked as cakes. Famously, the

Getty Images / Photolibrary / Ted Mead

FIGURE 4.1.4 Cunjevoi (*Alocasia brisbanensis*) is a highly toxic plant.



© M. Fagg, Australian National Botanic Gardens

FIGURE 4.1.5 Nardoo (*Marsilea drummondii*) showing the sporocarps that are used to make cakes.

explorers Burke and Wills starved to death while eating nardoo cakes, possibly because they failed to prepare the sporocarps correctly to remove the enzyme thiaminase which depletes the body of vitamin B_1.

4.1.6 Aboriginal exploitation of toxic nuts as a late-Holocene subsistence strategy in Australia's forests

Wonky holes: Fresh water in the ocean

Wonky holes are submarine freshwater springs found along the Great Barrier Reef. They attract large numbers of fish and are thought to act as nurseries. They are of significant cultural importance for Indigenous peoples.

wonky hole submarine freshwater spring found along the Great Barrier Reef

4.1.7 Submarine groundwater discharge into the near-shore zone of the Great Barrier Reef

4.1.8 'Wonky holes' help coastal water planning

INQUIRING FURTHER

Contact your local Aboriginal or Torres Strait Islander community and arrange a field trip to explore the local environment. Investigate how Indigenous peoples in your local area used inferences and observations to know what foods were edible, when to collect them and how to prepare them. Prepare a report for the class based on what you discovered during your investigation.

4.1.1 Observations and inferences

SECTION REVIEW 4.1

REMEMBERING

1 Define and provide an example of an
   - **a** 'observation'.
   - **b** 'inference'.

UNDERSTANDING

2 Discuss the main idea behind making inferences in terms of scientific processes and developments.

3 Outline the relationship between observations, inferences and generalisations.

APPLYING

4 Show how you would test a hypothesis based on an observation, inference and generalisation. Support your answer with an example from your own experience.

5 A person makes the claim that you can catch the flu by being exposed to cold weather. Identify the reasoning you would apply to challenge this person's claim. Explain how you could support your reasoning.

6 Identify and discuss the types of observations and inferences Aboriginal and Torres Strait Islander peoples would traditionally have made to identify a poisonous plant.

7 Describe the observations and inferences that traditionally would have been made by Aboriginal and Torres Strait Islander peoples in order to recognise that leaching could remove the toxins from poisonous plants.

ANALYSING

8 Conduct a secondary-sourced investigation into the characteristics of wonky holes and explain how the characteristics of these phenomena would have indicated the presence of fresh water to Aboriginal and Torres Strait Islander peoples.

4.2 Using secondary sources

Informing your data with research

Humans have been making observations and inferences about the natural world since the birth of humankind. The ability to make accurate observations and sound inferences about the world around us is vital for survival. For much of human history the knowledge gained was transmitted by word of mouth which required direct contact between those with the knowledge and the learner. With the development of written language, direct contact between people was no longer needed, and it became possible for knowledge to be transmitted over large distances and time.

The Greeks, who were recording their observations prior to 600 BCE, are known as being one of the first civilisations to document their findings on the natural world. By documenting their observations and their inferences they formed the foundations of scientific knowledge. For example, the scientist John Dalton (also known as the father of modern chemistry), was influenced by the works of the ancient Greek philosopher Democritus in the development of his model of the atom. In turn, Dalton's model has been further developed by scientists such as Ernest Rutherford, Niels Bohr and Albert Einstein.

With permission of University of Delaware Library Special Collections

FIGURE 4.2.1 A 1573 edition of one of the two surviving works of Democritus. This work most likely influenced John Dalton, who is credited with being the father of modern chemistry.

Through consulting the writings and accumulated knowledge of those before them, scientists have been able to further develop an understanding and knowledge of the natural world. By utilising recorded works scientists today have no need to start from the very beginning and can instead focus on contributing to the continued evolution of scientific knowledge.

atom
from the Greek word 'atomos' meaning cannot be divided

Consulting the research

Consulting the research literature in the area of interest is vital before commencing a scientific investigation. By consulting secondary sources research scientists are able to capitalise on the accumulated knowledge and collective understanding of scientists before them and focus their efforts on areas that are not as well researched or understood. The advantages of consulting the research are outlined below and in Figure 4.2.2.

research literature
accumulated written knowledge based on investigations and thoughts of scientists that have been published

Making inferences from the research

All scientific investigations require evidence to support their findings. By reviewing the work of scientists working in the same or related fields a scientist can draw on the collective understanding and reasoning of the scientists that came before them. This means that scientists do not have to start at the very beginning but are instead able to further build on the research within the field and thus contribute to an ever expanding body of knowledge. For example, by consulting Democritus' work Dalton was able to build on the idea that atoms were indivisible. Alternatively, scientists can challenge the reasoning underpinning the inferences drawn from observations in previous studies and go on to test them. This has the potential to establish an alternative interpretation of the evidence and overturn flawed conclusions.

Develop inquiry questions

The vast majority of scientific investigations begin with a question the researcher wishes to answer. By consulting the research, a scientist is able to determine which questions have already been answered by other scientists and find gaps in the research where questions have not been fully answered or only partially answered. This can help a scientist focus on an area that is under researched and make a more substantial contribution to the body of scientific knowledge. For example, Democritus was unable to explain how atoms formed what is now known as molecules.

molecule
group of atoms bonded together, representing the smallest fundamental unit of a chemical compound that can take part in a chemical reaction

hypothesis
educated guess tested through experimentation to answer the inquiry question; states the relationship between the independent and dependent variables

independent variable
factor deliberately changed during an investigation to obtain data

dependent variable
factor measured in the investigation

inquiry question
driving force of the research and can be investigated scientifically

element
substance that cannot be separated into smaller substance by chemical means

This question was of great interest to Dalton and other scientists, and could only be addressed as the understanding of the atom developed.

Construct suitable hypotheses

A **hypothesis** is developed by making a proposition about how the **independent variable** and the **dependent variable** relate to one another. By reviewing the research, a scientist can determine which variables and their relationships to other variables have been tested in the past, how these variables may relate to a potential **inquiry question** and which variables may not have been tested. This helps a scientist develop a hypothesis relevant to their own inquiry question. For example, using Democritus' ideas and the discovery of other **elements** Dalton was able to propose a hypothesis that atoms combined to form molecules in whole number ratios.

Plan suitable investigations

There are many ways to conduct an investigation on an inquiry question, and the methods and technology used can influence the reliability and validity of the results they obtain. Scientists can learn how other investigations similar to their own were conducted previously, and the types of tools and technology that were used by consulting the research. This may be of great assistance in designing the method of their own investigation. For example, Dalton used or adapted many of the techniques employed by his fellow chemists to conduct his own investigations. Which techniques Dalton used often depended on the particular requirements of the investigation, and the equipment and technology he had available to him.

Avoid unnecessary investigation

There is a vast amount of research that has been done by scientists in the past and it is impossible for a single person to know of all the investigations that have been done before them. By consulting the research, scientists can determine which investigations have been conducted in the past and which have not. This reduces unnecessary repetition and will allow them to make a unique contribution to science. For example, Dalton did not use his time needlessly trying to discover elements that had already been discovered.

4.2.1 Using secondary sources

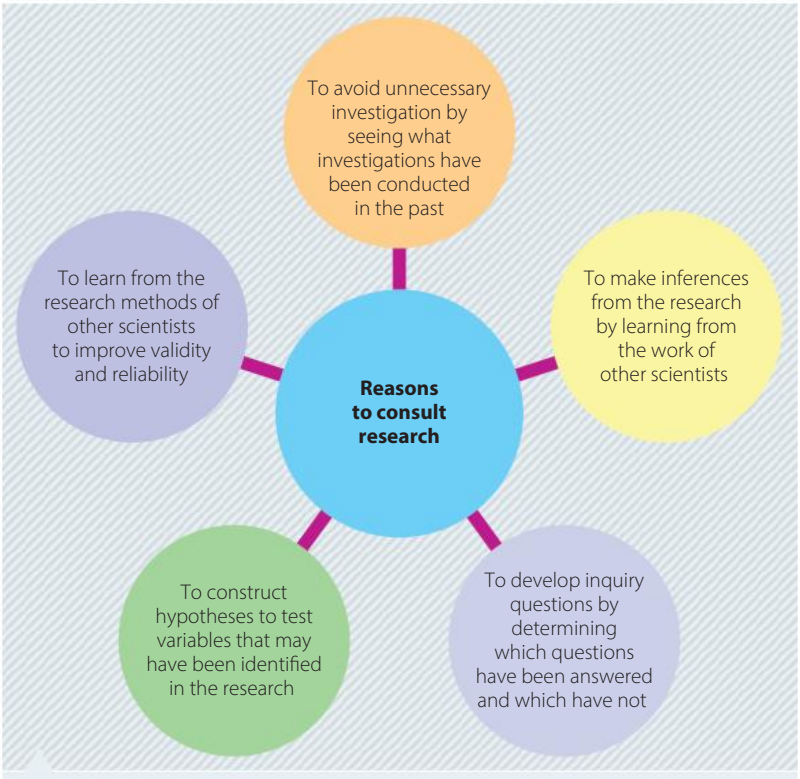


FIGURE 4.2.2 Five reasons to consult the research when commencing an investigation.

Repeating investigations

An important aspect of science is that the research that is published is verified and accurate. Many scientists want to make a unique contribution to science by addressing an inquiry question that has never been asked before. However, it can be argued on ethical grounds that repeating research that has previously been published is just as important as it confirms reliable research and challenges research that has flaws.

INVESTIGATION 4.2.1

Utilising secondary sources

Collecting and reviewing information from secondary sources is an important component of conducting a scientific investigation. By doing so, scientists can source the different perspectives of various researchers and critically analyse the similarities and differences in their findings.

AIM

To review the similarities and differences in secondary sources based on Investigation 4.1.1 and explain how the findings are applicable to related scientific fields

MATERIALS

- relevant secondary sources based on the chosen investigation

METHOD

1. Select a range of secondary sources that address the following investigation initially selected in Investigation 4.1.1. (Note: five sources should be a minimum.)
   - Secondary sources related to plant cell structures and size, and the development of measurement in microscopy
   - Secondary sources related to calcium carbonate in acid and chemical reactions in cave formations
   - Secondary sources related to factors affecting battery life and energy storage
   - Secondary sources related to the impact of humans in a local environment and methods of environmental measurement
2. Collate the secondary source details such as Author, Date of publication, Title, Journal or Publisher name, or internet URL with date of access using the bibliography style of your school.
3. Summarise the findings of each secondary source.
4. Identify and outline incidences where the secondary sources provide similar or different information.

RESULTS

1. Write a descriptive report on the theoretical findings of the various secondary sources and identify areas in which they are similar or different.
2. Create a glossary of specific concepts used in the secondary sources.

DISCUSSION

1. Explain why it is important for the information in secondary sources to correlate in order to draw an inference about the data from the experiment.
2. Not all secondary sources will support the same explanation or method for the experiment. Identify what factors or influences could lead to the differences of opinion between the authors of the secondary sources.
3. Identify what information would be needed on a secondary source to establish the reliability and validity of the information it contained.
4. Describe the information contained in the secondary sources that gives an indication of the reliability and validity of the source.
5. Explain why it is important to evaluate the reliability and validity of secondary sources.

SECTION REVIEW 4.2

REMEMBERING

1 Define and provide an example for:
   a 'secondary sources'.
   b 'inquiry question'.
   c 'hypothesis'.

UNDERSTANDING

2 Describe three reasons to consult secondary sources in order to improve the quality and relevance of an investigation.

3 Explain how science has been able to build upon the knowledge and understanding of previous generations by utilising secondary sources of research.

APPLYING

4 Explain how consulting the research may help you to develop a clear understanding of what you want to investigate and to identify a suitable inquiry question.

5 A student wished to investigate the inquiry question, 'How does air pressure in a soccer ball affect how far it travels when the same force is applied?' Referring to the inquiry question, create a list of terms to be searched to find relevant secondary sources and justify their inclusion on the list.

4.3 Observing patterns

Patterns in data

psychologically primed
effect where exposure to a particular stimulus unconsciously influences a person's response and understanding of the stimuli

Humans are **psychologically primed** to recognise patterns. Deep in humanity's evolutionary past, recognising patterns was essential to survival. Being able to recognise the patterns in animal tracks, the sudden flight of prey animals when they detect a predator and the seasons are all patterns that if unrecognised could have cost early humans their life.

Scientists also must be able to recognise patterns in data. Recognised patterns help to build a body of evidence needed to support scientific conclusions in experiments. The theories, models and laws that are developed are then utilised to advance technology and society, and to make predictions into the future.

For example, if an experiment was conducted to test the hypothesis, 'The type of paper used in a paper plane can influence how far a paper plane will fly', the results may show a pattern in which one type of paper causes the paper plane to fly further than another type under the same conditions. In this case, the pattern detected in the results confirms the hypothesis.

type II error
when a hypothesis is incorrectly rejected

valid
extent to which a report or investigation contains accurate data, inferences and conclusions

reliable
extent to which an observation and/or measurement can be repeated under the same circumstances and produce similar results

The failure to recognise a pattern when there is actually one present is called a **type II error**. Often this happens when a hypothesis is incorrectly rejected. For example, the above hypothesis may be rejected if the experimenter failed to notice that the wind had increased while conducting the experiment and skewed the results so that it looked like the type of paper didn't make a difference.

Consequently, scientists expend considerable time and effort to ensure their experiments are both **valid** and **reliable** so they can correctly interpret the patterns in the experimental data.

Observing natural and universal patterns through time and space

If a phenomenon happens right in front of a scientist as they observe it, it becomes relatively easy to detect patterns in the data and formulate a hypothesis which can then be used to explain what caused the phenomenon to happen. However, it is much more difficult for a scientist to collect the data they need to support a hypothesis if that data spans considerable amounts of time, space or scale. To collect the data

themselves, a scientist would often need to travel significant distances, wait for developments in technology or need vast amounts of time: something the average scientist cannot achieve alone.

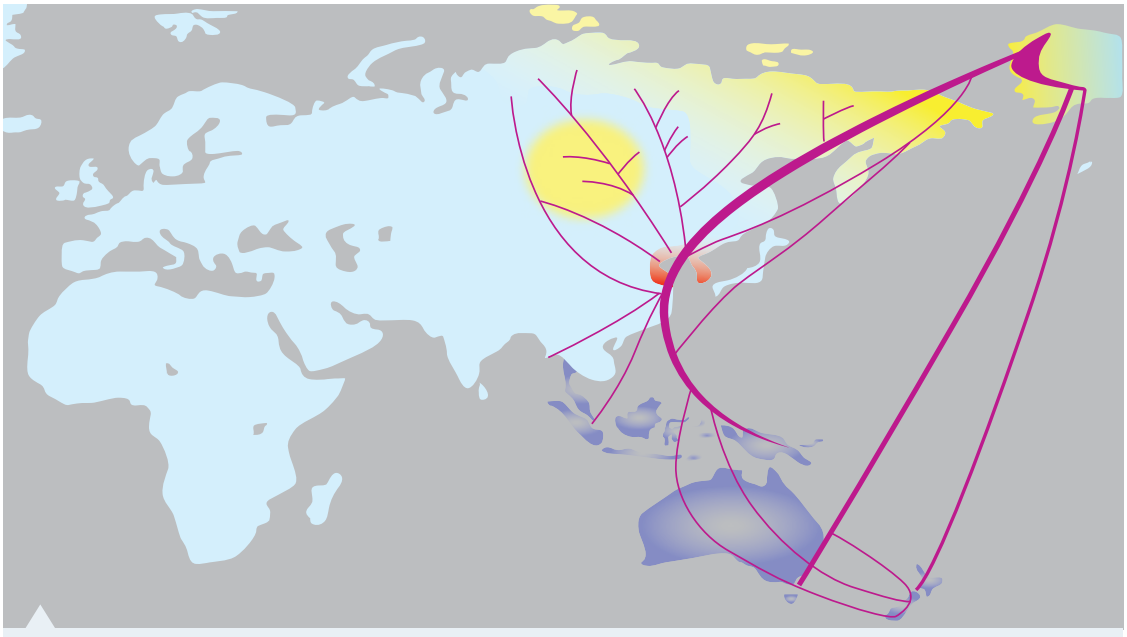
As communication, record keeping and technology has improved, so too has the ability of science to explain phenomena that otherwise would have remained a mystery. By networking with other scientists and enthusiasts across the globe, checking historical records and keeping up with advances in technology, scientists working in similar areas are able to gather the data that establishes the patterns needed to support their hypotheses.

Migrating Australian birds

The regular appearance, disappearance and reappearance of birds according to the season suggests that they are migrating to the casual observer. Where they go often can remain a mystery. But when the birds are caught and banded by a scientist a more complete picture of their migratory patterns can be built. Having a network of ornithologists around the globe ensures that migrating birds with bands attached can be tracked and their location recorded so that a pattern soon emerges. Some birds like the Grey Fantail (*Rhipidura albiscapa*) will spend winter in Queensland and summer as far south as Tasmania, while others like Bar-tailed godwits (*Limosa lapponica*) make the journey to the mangroves and mudflats of South Australia in September before returning to Alaska and Siberia to breed for the northern summer (i.e. June, July and August). By having a large network of colleagues tracking the birds over the globe, scientists can determine the birds' travel path and enable stopover points to be protected to ensure their survival.

migrating
process of moving from one region to another according to the seasons

4.3.1 Where do bush birds go?
4.3.2 Migratory birds make journey from Alaska to Adelaide for summer vacation



BirdLife Australia

FIGURE 4.3.1 The East Asian Australasian flyway.

Halley's Comet

While on a trip to Paris in 1680 Edmond Halley noted the position of a comet in the morning sky. At the time comets were thought to be unique one-off events, but then in 1682 another comet was seen in the skies over England. Halley's curiosity was sparked and he endeavoured to plot the path of the comet, with the help of Sir Isaac Newton's theory that the Sun's gravity affects the motion of planets and other celestial objects. Halley searched the historical records and was able to confirm three previous sightings of the comet, the most famous being on the Bayeux Tapestry which records the invasion of England by William the Conqueror in 1066. By taking previous observations of the comet and using Newton's gravitational theory, Halley was able to determine that this comet had an elliptical path and that it should complete its

comet
small celestial object composed primarily of dirt, gas and ice that travels on an elliptical (oval-shaped) path on its orbit around the Sun

4.3.3 A brief history of Halley's Comet

journey once every 75 years. Further historical research by other scientists has found records of Halley's Comet that date as far back as China in 239 BCE, and Babylonia in 164 BCE and 87 CE. Halley's Comet last made an appearance in 1985–6 and it is not expected to return until 2061.

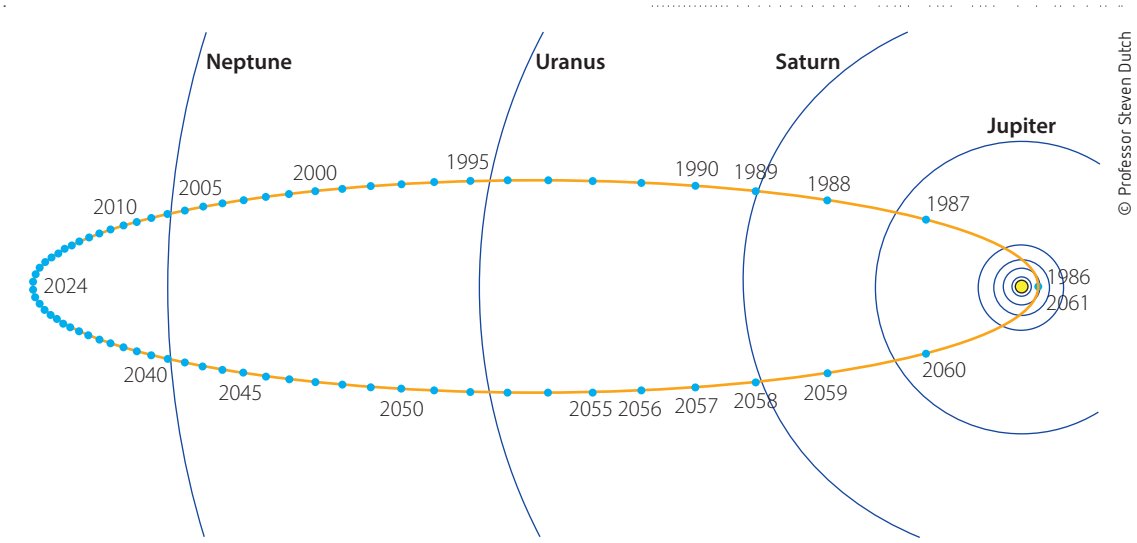


FIGURE 4.3.2 Halley's Comet on its current trajectory.

Snowflakes

The unique shape of snowflakes was a mystery that had long interested scientists; however, technological breakthroughs and developments in chemistry have helped to solve some of this mystery. Advances in microscopy enabled scientists to determine that there is a microscopic dust particle at the centre of every snowflake. Advances in weather monitoring technology found that if

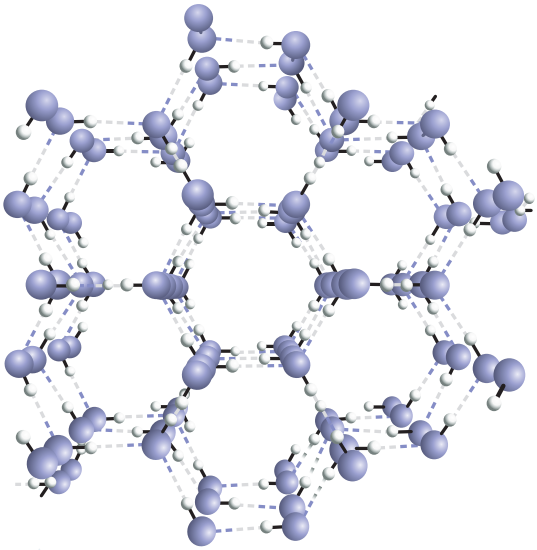


FIGURE 4.3.3 Hexagonal symmetry in a snowflake is formed when water forms hydrogen bonds.

Science Photo Library/KENNETH LIBBRECH

FIGURE 4.3.4 Snowflake showing hexagonal symmetry caused by the hydrogen bonds between the water molecules.

the dust particle is moving through air that is below 0° Celsius and has a water saturation between 1.4–0.1 g/m^3 a snowflake will form. The basic shape of the snowflake is dependent on the ratio of temperature to water saturation of the air. Finally, advances in the understanding of chemistry explained that the polar nature of water molecules is caused by the distribution of the oxygen and two hydrogen atoms which gives the molecule a positive and negative side that can form hydrogen bonds. The snowflake's fractal shape is the result of the hydrogen bonds that are formed when the water molecules build up around the dust particle. This bonding forms the regular repeating pattern of the crystal, typically with **hexagonal symmetry**, while the unique pattern of each snowflake is believed to be the result of variations in the original dust particle. In this way the beautiful **fractal** patterns of snowflakes form.

hexagonal symmetry
repeating pattern that forms a shape that can be cut into six identical wedges

fractal
mathematically related repeating pattern that exists at different scales

4.3.4 The science of snowflakes

INQUIRING FURTHER

In 1902, the *Monthly Weather Review* published several images of snowflakes. These images had been photographed by Wilson Bentley (1865–1931), a farmer whose hobby was photographing snowflakes under a microscope.

Research the process Bentley used to collect and photograph snowflakes. Use your research to design a primary investigation to replicate Bentley's.

Groups in the periodic table

In the early 19th century scientists were searching for a way to organise the elements that had been identified at the time. Then, in 1869, a Russian chemist named Dmitri Mendeleev (1834–1907) published the forerunner to the modern **periodic table**. He did it by creating groups of elements with like properties, and demonstrating the resultant pattern called **periodicity** that could be used to predict the properties of elements.

Mendeleev's periodic table was so successful that the spaces he left in his table for undiscovered elements were soon filled, with the newly discovered elements having many of the properties he predicted.

Today the periodic table uses atomic number rather than weight as its means of organisation, and the noble gases have been added, but the fundamental structure of Mendeleev's periodic table remains unchanged. A major feature of the periodic table is the groups Mendeleev identified which run down the columns of the table. Increased understanding of the atom demonstrated that these groups have elements of similar **electron** configurations. These configurations indicate that the elements in each group have similar properties and behave in a similar chemical manner. For example, the alkali metals in group 1 have the characteristics of metals and tend to be very reactive while the noble gases in group 18 exist primarily as gases and are unreactive. Scientists now use the periodic table to 'see' patterns in elements and predict the outcome of **chemical reactions**.

periodic table
organisational structure in which the atomic elements are arranged to highlight elements with similar properties

periodicity
tendency to repeat at regular intervals

electron
negatively charged particle in the atom spinning around the energy shells of the atomic nucleus

chemical reaction
chemical process that involves the rearrangement of the elements of the reactants into new products

4.3.5 Dimitri Medeleev: Chemistry's improbable saviour

4.3.6 The genius of men

INVESTIGATION 4.3.1

Looking for patterns

Not all observations and measurements allow a scientist to see an immediately obvious pattern. Sometimes it takes considerable time to gather enough data to be certain a pattern is there at all. However, once the data is collected it becomes possible to propose a hypothesis to explain the pattern that has been detected.

AIM

To examine data collected from observations and measurements on a given phenomenon, and determine if a pattern can be detected that can form the foundation of an explanatory hypothesis

MATERIALS

Select one of the following data sources.

- data collected from a phenomenon over time from an individual or personal investigation
- Internet sources providing data on the Aurora Australis or fractals in nature
- data of radioactive decay shown in Figure 4.3.5.

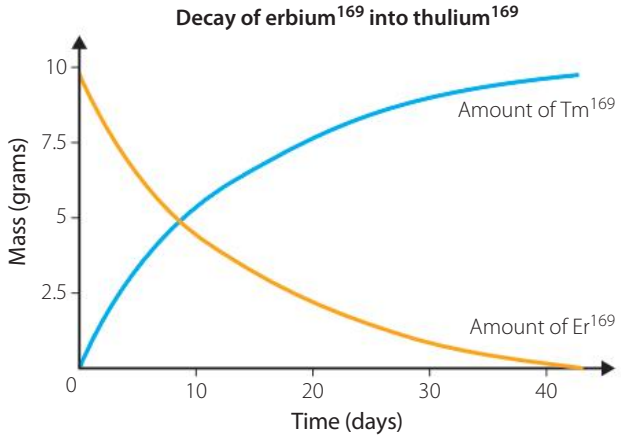


FIGURE 4.3.5 A graphical representation of the data obtained by a physics student who was monitoring the decay of the radioactive isotope erbium^{169} into the stable isotope thulium^{169}.

METHOD

1. Carefully analyse the available data from your chosen source and determine if a pattern can be detected in the available data.
2. Note the pattern you have observed.

RESULTS

Propose a hypothesis that can be used to explain the pattern detected in the selected phenomena.

DISCUSSION

1. Justify the reasoning for the hypothesis, with reference to the available data.
2. Describe the type of investigation that would need to be undertaken to confirm or reject the hypothesis that has been proposed. Include the dependent and independent variables, and any variables that would need to be controlled.
3. Predict what would happen to the pattern in the data if a variable in an experiment designed to test the hypothesis was not controlled.
4. Describe how failing to control the variable in question 3 would impact the decision to accept or reject the hypothesis.

Patterns that are not there

All humans are capable of recognising patterns; however, sometimes a person detects a pattern that isn't really there. Many common superstitions are examples of this, from the football star who always has to wear their lucky socks because they had a winning streak while wearing them in the past or the belief that people with cold hands have a warm heart. Yet in both of these cases there is no reliable and valid data to support the superstitious belief.

Statistically, humans are far more likely to think there is a pattern where no pattern actually exists in comparison to thinking there is no pattern where there actually is one. Evolutionary psychologists theorise that this is because there is less risk associated with assuming there is a pattern when there isn't one. For example, a person is not likely to lose their life if they cross their fingers for luck, but they may very well do so if they ignore the pattern that it is more likely a person will be hit by a car if they cross the road at a red pedestrian light. For this reason, seeing patterns that are not there tend to be far more common, 'just in case'.

In science these types of mistaken beliefs are known as **type I errors**. This can happen when a proposed hypothesis is incorrectly accepted when it should not be. Often this happens when chance causes patterns to emerge in random data and because the human brain is primed to see patterns we assume that there is a pattern. Scientists go to considerable lengths to overcome this tendency using statistical analysis, with the most common being the use of *p*-values.

type I error
when a hypothesis is incorrectly accepted

***p*-value**
statistical measure of the probability of making a type I error

***p*-values** give a statistical estimate of the likelihood that a scientist has made a type I error in the analysis of their results. Typically, *p*-values under 5% are considered significant , whereas a *p*-value above 5% is considered insignificant. In statistical analysis the *p*-value is typically written as a percentage of 1; for example, $p = 0.05$ means that there is only a 5% likelihood that a type I error has been made.

Pareidolia and optical illusions

Pareidolia is the tendency to see faces in otherwise random objects or things and is one example of how the human brain is evolutionarily hardwired to detect patterns. Evolutionary psychologists theorise that pareidolia is a particularly common occurrence because from the moment we are born, humans are dependent on other humans around them. Being able to recognise faces and read facial expressions quickly is believed to have been advantageous in helping early humans socialise, as the stronger the social bond in a group the more likely the group was to survive, as each depended on the others to aid in their survival. However, this predisposition can misfire and sometimes results in seeing faces that are not there.

iStock.com/fotolinchen

FIGURE 4.3.6 The face people can see in these clouds is an example of pareidolia. In reality, this picture represents an image of water vapour, and light and shadow, yet the human brain will rarely fail to see the 'face' this image invokes.

Similarly, **optical illusions** can invoke the sense of seeing something that is not really there. Optical illusions are the result of our brains taking 'shortcuts' in order to interpret information quickly. For example, Figures 4.3.7 and 4.3.8 show how the human brain can be tricked by **perspectives** that give the illusion of depth. Yet being able to judge depth quickly in a real life situation may mean the difference between life and death; for example, when determining how far away a deadly snake is. Take too long in those first few seconds to judge the distance and it may just result in a deadly bite. These shortcuts work because 99.9% of the time they judge distance accurately; it is only 0.1% of the time that they don't (e.g. when presented with an optical illusion).

pareidolia
psychological priming effect whereby a familiar pattern is perceived from random stimuli

optical illusion
image that deceives the visual system

perspective
way of seeing or interpreting something

Pareidolia and optical illusions are both examples of type I errors. Usually, they can be thought of as fun tricks of the brain; however, scientists need to be aware of how our brains are evolutionarily wired to ensure they are not making snap judgements about the phenomena they are studying. By being aware of these brain shortcuts, scientists can work to overcome the innate biases they may have.

4.3.7 Pareidolia, seeing faces in strange places

4.3.8 Pareidolia: Why we see faces in hills, the moon and toasties

4.3.9 Objects are people too. The quirky world of facial pareidolia in pictures

Alamy Stock Photo/David BERTHO

FIGURE 4.3.7 The viewing perspective of the image gives the illusion that the pyramid in front of the Louvre Museum has disappeared.

Alamy Stock Photo/David BERTHO

FIGURE 4.3.8 Viewed from another angle, the same image can be shown for what it is; an optical illusion that plays on the brain's tendency to take 'shortcuts' when judging depth.

INQUIRING FURTHER

Humans are exceptionally good at facial recognition. In just milliseconds a human can determine the age, gender and general features of a face in order to tell the difference between two or more faces. In contrast, computer software programmers have had to go to considerable length to 'teach' computers to recognise faces.

Research the characteristics of human faces that computer software uses to determine the difference between one face and another.

INQUIRING FURTHER

The anchoring effect is a well-known psychological phenomenon where people tend to associate one number or fact to another unrelated number or fact. For example, 14.4% of people in Australia are over the age of 65. What is the maximum age of the youngest 50% of the Australian population? Most people will guess a maximum age somewhere between 40 and 50 years of age when the actual age is 34. The number 65 has acted as a mental anchor and swayed people to predict higher than they should.

Other human psychological tendencies which result in misconception and errors are priming, the decoy effect, the illusion of scarcity, loss aversion and more. Which of these psychological tendencies are likely to create errors when analysing the results of an investigation?

Data outliers

Very rarely when conducting a scientific investigation will a scientist collect data that clearly shows a nice straight line relationship between the independent and dependent variables. It is more likely that the data points appear scattered across the graph. The scientist must then determine if the variables can be related to each other in what is called a **regression analysis**. Typically, a regression analysis of two variables that are related is known as a line of best fit.

regression analysis statistical process of establishing the relationship between variables

The closer the data points are to the line of best fit the greater the chances are that the variables are correlated; or in other words, there is a relationship between the variables. However, on occasion a **data outlier** can skew the line of best fit and reduce the confidence that the variables are correlated. In this instance it is common to remove data outliers as it is likely that they occurred as a chance error. As a result, a better **correlation** can be obtained.

data outlier data point distant from other observations and measurements that may indicate an error

The strength of a correlation in statistical analysis is typically represented by *r* and ranges from 0 to 1 (though negative values from 0 to –1 can be found if the regression is negative; i.e. the line of best fit goes downward rather than upward). The amount of confidence that can be placed in a correlation is shown in Table 4.3.1.

correlation relationship or connection between two or more variables

TABLE 4.3.1 Correlations values and the confidence that there is a relationship between the independent and dependent variables.

CORRELATION VALUE (r)	CONFIDENCE
$r = 0$ to 0.09	No confidence. No relationship exists between the variables.
$r = 0.1$ to 0.29	Small confidence. It is very unlikely there is a relationship between the variables; random chance is just as likely to be influencing the results.
$r = 0.3$ to 0.49	Medium confidence. A relationship between variable is suggested, though other unaccounted variables are likely to also be influencing the dependent variable.
$r = 0.5$ to 1.0	Large confidence. A relationship between the variables is statistically very likely.

Care must be taken when removing data outliers, as it can be tempting to remove data points that don't 'fit' the pattern you hypothesised. The consequence is that data points are removed to suit the internal biases of the person conducting the data analysis and the result is that they create the pattern they 'want' to see. If this analysis is then used to build a conclusion, its accuracy can be questioned. For this reason outliers that are removed are often noted in the report.

4.3.10 Outliers: to drop or not to drop

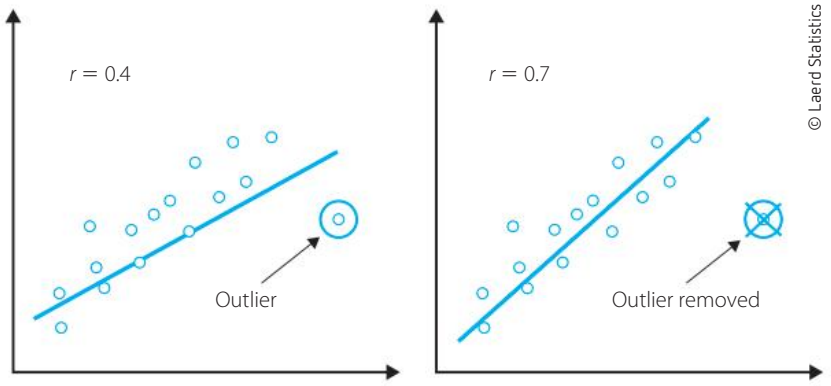


FIGURE 4.3.9 The closer the data points are to the line of best fit the better the correlation. Removing a data outlier can change the position of the line of best fit and in turn improve the confidence in the correlation.

4.3.1 Observing patterns

SECTION REVIEW 4.3

REMEMBERING

1 Define 'type I error' and 'type II error', and give an example of each.

2 Identify what the image in Figure 4.3.10 is an example of.

UNDERSTANDING

3 In 1912 Alfred Wegener proposed a hypothesis that the continents moved slowly over time due to changes in the Earth's mantle; a hypothesis which was eventually accepted 40 years later as plate tectonics theory. The data needed to support this theory spans the Earth's geological history. Explain why finding the data needed to establish the pattern that supports Wegener's hypothesis was so difficult to collect.

4 Two students in Mr Lloyd's Chemistry class were conducting an investigation on the rate of reaction. Vin proposed a hypothesis that increases in surface area of the reactants will increase the rate of reaction and conducted her investigation. The results gave a statistical p-value of 0.01. Bridgett proposed a hypothesis that increases in air pressure increased the rate of reaction and after conducting the investigation her statistical p-value was 0.2. Explain which investigation is likely to have the most reliable hypothesis.

FIGURE 4.3.10 What do you see in this image?

APPLYING

5 Table 4.3.2 represents a random data sample collected by a student testing the relationship between how tall a girl is and her age. She is trying to establish what the average height is for girls according to age. Plot the data points on a graph and determine a line of best fit using all data points. Repeat the graph, this time removing data points that can be considered outliers.

6 Explain how the removal of outlier data points in question 5 changes the line of best fit (regression line) and can lead to greater confidence in the correlation between the age and height.

TABLE 4.3.2 A random sample of girls by age and height in a high school.

AGE (TO NEAREST 6 MONTHS)	HEIGHT (CM)
11	136
11	146
11	148
11	151
11.5	151
11.5	155
12	150
12	155
12	159
12.5	154
12.5	160
12.5	164
13	150
13	162
13	168
13.5	164
13.5	168

AGE (TO NEAREST 6 MONTHS)	HEIGHT (CM)
13.5	170
14	166
14	170
14	161
14.5	172
14.5	175
15	170
15	172
15	173
15.5	172
15.5	174
16	174
16	176
16.5	172
16.5	182
17	173
17	176

4.4 Developing inquiry questions and making generalisations

Testing assumptions

As discussed in section 4.1, one of the influences on the reasoning used to make an inference are the assumptions about what has happened and why. Often these assumptions are made without critically analysing their origin and how they influence a person's thinking, yet they have the ability to bias the interpretation and analysis of the data in an investigation. The result can be a conclusion that is based on a **false premise**. For this reason, scientists must be willing to examine their assumptions and seek alternative explanations through careful use of the scientific method and by reviewing related research that other scientists have done previously in this area. By doing so scientists can gain new insight into the phenomena to be investigated and be more confident their research is applicable in the real world.

false premise
incorrect proposition or assumption that is used to form the basis of an argument or conclusion

INVESTIGATION 4.4.1

Overturning assumptions in history

Throughout history, scientific assumptions have been overturned and rejected due to careful examination of the evidence. By challenging assumptions, scientists have been able to free the various scientific fields from flawed ideas that were holding them back from a more complete understanding of phenomena.

AIM

To examine long-standing false assumptions in a given scientific field and the investigations that overturned them through the use of secondary sources

Fields to investigate include, but are not limited to:

- spontaneous generation and the investigations that led to the proposal of the germ theory
- Dalton's proposition that atoms are indivisible and unchangeable, and the discovery of radioactivity (including the work of Henri Becquerel and Marie Curie)
- phlogiston theory and Lavoisier
- human influences on atmospheric pollution.

MATERIALS

Secondary sources reviewing historical examples of overturned assumptions, such as the internet sources listed below and associated weblinks.

- Pasteur brewing: Pasteur, beer and more
- What is John Dalton's atomic model?
- Benchmarks: Henri Becquerel discovers radioactivity on 26 February 1896
- Marie Curie: Unlikely revolutionary
- Phlogiston theory
- How do we know that humans are the major cause of global warming?

METHOD

Carefully analyse the available data for each overturned assumption from secondary sources and identify the following:

- the initial assumption and its origin
- the scientist/s that debunked the assumption and the supporting evidence used to do so
- the implications this change in assumptions has had on the related field of study and any subsequent advances that have been made.

RESULTS

Report on the findings of each of the named examples from the research conducted.

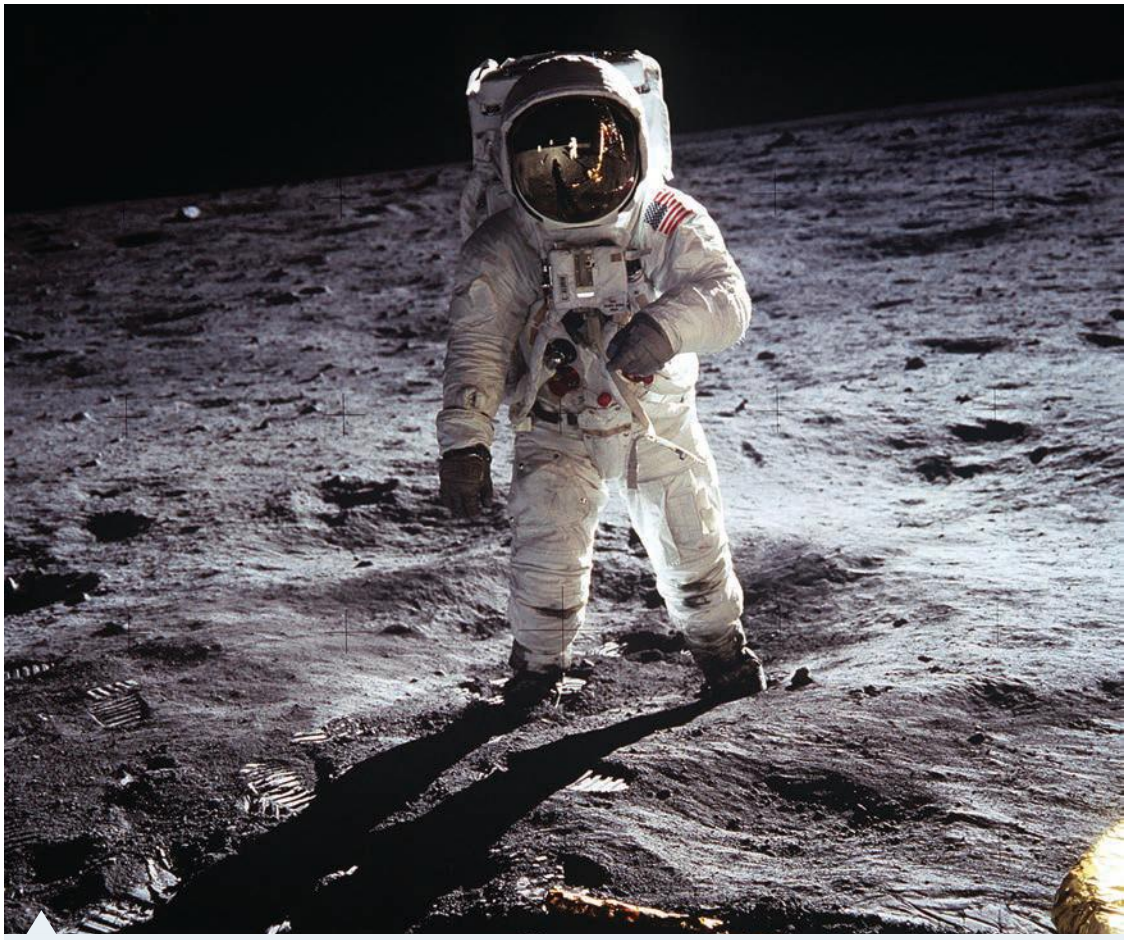
DISCUSSION

1. With reference to the examples studied explain the statement: 'Gathering or generating the appropriate data is often necessary to overturn a false assumption'.
2. Describe the circumstances that lead to a scientist either using or generating a false assumption with reference to how an inference is formed.

4.4.1 Experiments
4.4.2 What is John Dalton's model?
4.4.3 Benchmarks: Henri Becquerel discovers radioactivity
4.4.4 Marie Curie: unlikely revolutionary
4.4.5 Phlogiston theory
4.4.6 How do we know humans are the major cause of global warming?

Generalisations

A generalisation is a statement or concept that is drawn from experience with a specific case or example. For example, a student was interested in observing the rates at which different objects fall. After conducting an experiment on six objects of various shapes she concluded the objects followed a pattern whereby they initially accelerated due to gravity and then reached terminal velocity before striking the ground. From this conclusion she made the generalisation that all objects accelerate to terminal velocity as they fall. However, though she drew the correct conclusion from the investigation she conducted, she failed to recognise that this may not be a universal principle. For example, objects falling in an environment without air, such as on the moon, will continue to accelerate until they hit the ground and do not adhere to the generalisation she described.



Imagefolk/Mary Evans Picture Library

FIGURE 4.4.1 When Buzz Aldrin landed on the moon in 1969 he dropped a hammer and a feather at the same time to demonstrate the effect that air resistance has on a falling object. This challenged the assumptions and generalisations many people held about what influenced how objects fall.

Scientists must also be aware of how they make generalisations. Even though they have done the best they can in their analysis and interpretation of the findings from their investigation, the conclusion they draw may or may not be generalisable across different but related examples. To overcome this problem, scientists rely on their colleagues to peer review their research, offering alternative perspectives and doing related research that tests the inquiry question in a different way. For this reason, the more culturally and socially diverse the scientists are who conduct the peer review the better, as there is more chance of offering an alternative perspective. This is why it is strongly encouraged for women and people from indigenous and minority backgrounds to enter science. In this way alternative explanations can be sought and collectively science can come closer to 'truth'.

peer review
process in which experts review and critique the work and research of others in the same field

INVESTIGATION 4.4.2

Testing common assumptions and making generalisations

AIM

To generate an inquiry question and hypothesis, design and conduct an investigation to test a common assumption, and to draw a conclusion based on the trends in the data

Common assumptions that may be investigated include, but are not limited to:

- washing with antibacterial soap kills more germs than washing with normal soap
- the Sun rises in the east and sets in the west
- what goes up must come down.

MATERIALS

- relevant equipment to test a common assumption
- be sure to do a risk assessment on any materials that have an associated risk

METHOD

1. In a team, or individually, select a common assumption to investigate.
2. Make some preliminary observations of the assumption and research the origin of the assumption selected.
3. Use the preliminary observations and research of the selected assumption to generate an inquiry question and a hypothesis to be tested.
4. Design an investigation to test the hypothesis.
5. Conduct the investigation and collect appropriate data.
6. Analyse the data for any trends or patterns.

RESULTS

1. Record data using appropriate formats (see Chapter 2).

DISCUSSION

1. Draw a conclusion based on the trends and patterns that were found in the data.
2. Predict possible implications of the conclusion drawn by making a generalisation to the wider world.
3. Discuss the reliability and validity of the generalisations made from this investigation.
4. Recommend further inquiry questions that could be investigated to generate further evidence for the generalisation made in this study.

iStock.com/Talaj

FIGURE 4.4.2 There is considerable controversy regarding the effectiveness and safety of antibacterial soaps. In 2016 the US Food and Drug Administration banned 19 ingredients that were found in antibacterial soaps, some of which were found to interfere with hormone cycles in women.

WS 4.4.1 Developing inquiry questions and making generalisations 1

WS 4.4.2 Developing inquiry questions and making generalisations 2

SECTION REVIEW 4.4

REMEMBERING

1 Define and provide an example for:
   a 'assumption'.
   b 'conclusion'.
   c 'generalisation'.

UNDERSTANDING

2 Describe the ways in which scientists ensure that they do not base their investigation on a false assumption and consequently draw an incorrect conclusion.

APPLYING

3 Use an example to describe how longstanding assumptions can be overturned by the application of the scientific process.

4.5 Peer review

Collaborative teams

Collaboration has a number of benefits over competition or working alone when trying to find the answers to inquiry questions that otherwise would have been next to impossible to answer. For this reason, collaborative teams are often formed as a result of the shared goals of the scientists involved. The benefits of cooperative teams include the following.

- Increased efficiency: resources, talent and ideas can be pooled to save on cost, time and effort, particularly important factors at a time when the world is facing multiple crises in the form of environmental degradation and climate change.
- Cross-discipline research: some of the most important questions that need to be answered in science today do not 'sit' within one particular branch or discipline of science, but instead cross over many subject areas. Collaborative scientific teams are capable of bringing in experts from the various related fields to work on an investigation, allowing for the exchange of ideas and opinions as well as the development of new technology and scientific methods.
- International research: some scientific issues, like climate change, span the entire globe and have the potential to affect all life on Earth. By working in international collaborative teams it is possible to formulate a more complete picture of the issues and work toward a global solution.
- Developed capacity of young scientist: every scientist has to start somewhere and having the support and mentoring of older more experienced scientists in a collaborative team can help a young scientist develop skills and confidence. In this way science can ensure the next generation of scientists have the capacity to answer the big questions into the future.
- Crosschecking and alternative perspectives: when a scientist works alone they can be susceptible to their own internal biases and assumptions. In contrast, a collaborative team of people, especially if they come from diverse backgrounds, will often have one or two people that will raise questions and see problems that otherwise may not have been seen. As a result, a team is often more effective at crosschecking their assumptions and seeing alternative perspectives.

Alternative perspectives

Everyone has different experiences over their lifetime, they learn different things and they interact with different people. These different experiences mean that people can have anything from a slightly to a vastly different viewpoint and understanding of the things and events that science studies. Although it may at first seem hard to work with people or manage ideas that come from a different perspective it actually has its advantages.

The first advantage is that people and ideas that come from alternative perspectives help others to 'see through their eyes' and in many cases people from diverse backgrounds are capable of offering a different explanation for the phenomena that is of interest. Secondly, by offering alternative explanations, people from diverse backgrounds challenge their colleagues to evaluate their own perspectives and assumptions, forcing them to either defend their position with evidence or to reject or modify their stance in favour of the new perspective offered.

Getty Images/TORSTEN BLACKWOOD

FIGURE 4.5.1 A scientific team returning from Antarctica after collecting research data vital to understanding the implications of climate change. By working together the team can collect more data, crosscheck each other's findings and investigate climate issues that would be too hard to tackle on their own.

One way science seeks these alternative perspectives is through the process of peer review in which other scientists question the assumptions, theories and perspectives of their peers. Consequently, science benefits from the differences between people with the general rule of the greater the diversity the better. Scientists can then get closer to an explanation or concept that reflects the phenomena and when it is applied in the real world it is much more likely to be successful at solving problems or predicting outcomes.

4.5.1 Meet the scientists confronting climate change as a team

Scientists also seek alternative perspectives prior to conducting an investigation by consulting the published research that other scientists have done in the past. This can be used to inform a scientist on what assumptions, theories and perspectives already exist on the subject. However, it is very possible that when a scientist reviews the published research they find a range of alternative perspectives, assumptions and theories. This is particularly common in fields where a **scientific consensus** has not yet been reached and a clear understanding is still being debated in the scientific community. Unfortunately, this can make it confusing when trying to work out which assumption, theory or perspective is the 'right' one to use to inform a scientist's own investigation. The good thing is it is not expected that a scientist use the 'right' perspective, theory or assumption; only that they identify which one they are subscribing to in their investigation and that they use evidence to support this stance. It then becomes the responsibility of the scientific community to judge the strength of the theory or perspective based on the evidence that is presented.

Prof. Veena Sahajwalla, SMaRT@UNSW, Science

FIGURE 4.5.2 Australian Research Council (ARC) Laureate Professor Veena Sahajwalla is revolutionising recycling science to unlock the wealth of resources embedded in the many complex wastes currently destined for landfill. In addition, she also received Georgia Sweet Award to initiate her Science 50:50 Program in 2015 to inspire young women to pursue careers in science and technology for an innovation-driven future.

scientific consensus collective judgement of a community of scientists in a particular scientific field

4.5.2 The women of science who never got the credit they deserved

INVESTIGATION 4.5.1

The benefits of collaborative teams and alternative views in science

Collaborative teams and the alternative views that they offer have been integral to advances in various fields of science both throughout history and in the current practice of science. Today all scientists consult the alternative viewpoints of other scientists both in person and by reviewing past research. It is increasingly rare that scientists work in isolation in their chosen fields.

AIM

To assess how scientists work in teams, and how alternative perspectives are able to develop inquiry questions and hypotheses that are used to build a body of evidence

Select one of the following scientific issues that have been investigated by collaborative teams.

- Large Hadron Collider
- The development of the periodic table
- The study of bio-astronomy, including the search for life on Mars
- Building the case for geological uniformitarianism
- A scientific endeavour involving a team of scientists of your choice

MATERIALS

Possible secondary sources describing the work of collaborative teams are listed below (see weblinks).

- Explainer: How does an experiment at the Large Hadron Collider work?
- Sydney University scientists work on the Large Hadron Collider
- Development of the periodic table
- Are we alone? Scientists discuss the search for life and odds of E.T.
- Mission to find another Earth: Project Blue hopes to inspire
- Charles Lyell and the development of uniformitarianism
- Uniformitarianism overview
- Secondary sources on a collabarative scientific team of your choice

METHOD

Carefully analyse the secondary sources of your selected scientific endeavour and identify the following:

- the inquiry question and hypothesis that was being investigated
- the benefits that using collaborative teams and alternative perspectives have in addressing the objectives of the scientific endeavour
- the evidence found to address the inquiry question and hypothesis.

RESULTS

Report on the findings from the collaborative teams and/or alternative perspectives from your selected example.

DISCUSSION

1. Explain why alternative perspectives can help build a body of evidence to support or refute a hypothesis, with reference to the example studied.
2. Describe two benefits of working in a collaborative scientific team, with reference to the example studied.
3. Predict the likely outcomes of the example investigation if the scientists involved had not chosen to seek alternative viewpoints and/or work collaboratively.

4.5.3 How does the Large Hadron Collider work?

4.5.4 Sydney University scientists work on the Large Hadron Collider

4.5.5 Development of the periodic table

4.5.6 Are we alone? Scientists discuss the search for life and the odds of E.T.

4.5.7 Mission to find another Earth: Project Blue hopes to inspire

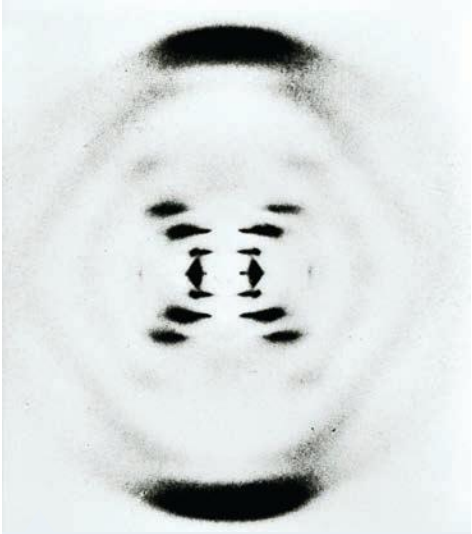
4.5.8 Uniformitarianism: Charles Lyell

4.5.9 Uniformitarianism

Collaboration or competition? The story behind DNA

The early 1900s saw major breakthroughs in biological science, in particular the mechanisms of inheritance; however, the chemical structure of the molecule responsible for transmitting information through the generations was unknown. By the 1950s the hunt was on to finally uncover this elusive molecule. Deoxyribonucleic acid (DNA) was the prime candidate for genetic inheritance and numerous scientists were competing to become the first to discover its molecular structure. Scientists working on the structure of DNA included Linus Pauling, Maurice Wilkins, James Watson, Francis Crick and Rosalind Franklin. However, they worked in three different universities that were in direct competition with each other and each scientist brought a different skill set and approach to the problem. Controversially Maurice Wilkins is believed to have given James Watson and Francis Crick an X-ray diffraction image produced by Rosalind Franklin without her consent, an image that was crucial to unlocking the structure of DNA. The result was that Maurice Wilkins, James Watson and Francis Crick were credited with the discovery of DNA's molecular structure and awarded a Noble prize while Rosalind Franklin's contribution was largely ignored due to her unfortunate death prior to the nomination.

4.5.10 The structure of DNA: Cooperation and competition



Alamy Stock Photo / Science History Images

FIGURE 4.5.3 Rosalind Franklin's X-ray diffraction image that was acquired by Maurice Wilkins and was key in determining that DNA had a double helix structure.

Scientific mysteries

Science doesn't have all the answers. Science is a way of finding out the answers to questions about the natural world. What many people think of as science, such as the theory of evolution, Newton's laws and the atomic model, are actually the best answers science has come up with to answer specific questions. Questions such as: has life on Earth always existed in the form it has now? Is there a consistent way to explain how objects move? What is matter made of? These are questions that the scientific community has come to a consensus on, at least at some fundamental level.

However, there are number of questions that still remain unanswered. Scientists are searching for the answers, but the evidence gathered so far can be interpreted in different ways and more evidence is needed before the questions can be settled to the agreement of the majority of scientists. In this way science and scientists are constantly pushing at the boundaries of knowledge and understanding of the natural world. The process of peer review, where fellow scientists check and question the work of their peers, is essential to increasing our understanding.

The origins of life on Earth

How life first came to be on Earth is a question that has plagued science for all of recorded history and perhaps beyond. The major difficulties in answering this question have been twofold. The first difficulty is the timescale involved, as life on Earth first arose billions of years ago. The second difficulty is the technology needed to gather and analyse the data to support or discount the various hypotheses proposed. Some of the hypotheses are described below.

- Panspermia: early life forms were transported to Earth through space, perhaps via comets, meteorites or space dust.
- Abiogenesis: conditions of the early Earth were sufficient to first allow the accumulation of an organic compound and then the formation of life.
- Clay theory: inorganic clays were used as a scaffold for the replication of primitive chemical structures in the precursor to RNA.

4.5.11 Seven theories on the origin of life

4.5.12 Top five problems with current origin-of-life theories

iStock.com/BirdofPrey

FIGURE 4.5.4 The thermal hot pools at Yellowstone National Park contain Archaea (single-celled prokaryotes), which are one of the earliest life forms to have existed on Earth. The Archaea create the bright iridescent colours of the pools.

Is feynmanium the last element?

The number of elements that can physically exist currently stands at 118 with ununoctium, which leads many to ask just how many elements can be found to physically exist. Theoretical physicist Richard Feynman, who worked on the Manhattan atomic bomb project and was a professor at the California Institute of Technology, is credited with proposing that the last possible element of the periodic table would be 137, and therefore feynmanium is named in his honour. This theoretical limit to the periodic table is based on Bohr's model of the atom and the supposition that an outer electron in element 138 would need to travel faster than the speed of light, which is not possible according to the model.

Further advances in the atomic model incorporate quantum physics, where the effects of exceptionally small particles travelling at extreme speeds are not predictable by Bohr's non-relativistic atomic model. When using quantum models of the atom the predicted number of elements of the periodic table can be extended to 173. However, it remains to be seen if atoms of that size can actually be discovered.

feynmanium
possible last element of the periodic table as proposed by Richard Feynman

An expanding universe?

In the 1910s Vesto Slipher and Carl Wirtz made observations that spiral galaxies had redshift in their spectra. A possible explanation for this shift was not theorised until Albert Einstein's general theory of relativity suggested that the universe was expanding. Then in the 1920s Edwin Hubble and Milton Humason investigated the relationship between redshift and the distance from the Earth; from their findings they theorised that galaxies are moving away from each other and that the universe was expanding at a constant rate. This finding supported the then hypothesis proposed by Georges Lemaître, that the universe originated from a central point now known as the Big Bang. The Big Bang theory has since been widely accepted by astronomical physicists.

4.5.13 The search for the final element

However, in science the answer to any question cannot be said to be 100% proven. Different perspectives and apparent inconsistencies can lead some scientists to question an accepted theory and seek alternative evidence-based answers. In recent years this has happened in relation to our understanding of the universe. A small number of significant research papers have been published that analyse the light given off from distant galaxies, such as spectral analysis and luminosity, using different approaches. These studies suggest that the universe is not expanding and that concepts such as dark matter and dark energy are not required to explain the apparent expansion of the universe as proposed by the Big Bang theory. More research is needed, but it is possible that if further supporting evidence emerges then the Big Bang theory might be modified or overturned completely.

4.5.14 The universe is not expanding

4.5.15 First test of Einstein's gravity kills off dark matter

Cultural bias

All people have a culture that they identify with and feel most comfortable in. This is often because it is the culture in which they were raised. However, every culture has differences in the way they perceive and do things as well as how they understand the natural world. In science it is the western European culture that tends to have the most scientists and for this reason a cultural bias has been created. This is primarily because the philosophy of science, upon which much of modern science is based, was first developed during the Enlightenment of western Europe (1685–1815). The consequence is that other cultural perspectives and methods to understand the natural world can be overlooked or even ignored. Unfortunately, this can and often does leave gaps in scientific knowledge and emphasises one cultural 'truth' over others.

Enlightenment
European intellectual movement of the 17th and 18th century emphasising reason as a means to advance science and society

cultural bias
interpreting and judging phenomena from a particular cultural viewpoint

The growing awareness of cultural bias means that many scientists are attempting to correct or adapt the biases created by the dominance of western European culture. By doing so science will bring a more

socially just, balanced and holistic interpretation of the natural world that acknowledges and learns from all cultures.

Cultural bias in Australia

When the British colonised Australia, numerous descriptions in journals, diaries, property titles and paintings depicted the country to be lightly wooded meadows and grasslands with rich, deep **friable** soils interspersed with banks of timber which gave a very pleasing appearance reminiscent of the parklands and gardens of their homelands. Little thought or consideration was given as to why the Australian landscape appeared this way. The influence of Aboriginal and Torres Strait Islander peoples on the landscape was systematically dismissed and the country was attributed to being in its 'natural' state by the British settlers.

A primary reason for this is the biases and assumptions of the European settlers that saw Indigenous societies as inferior due to an apparent lack of science, economy and organised religion, or at least one that they could easily recognise. The result was that Aboriginal and Torres Strait Islander peoples were dismissed as nomadic hunter-gatherers and considered a part of the flora and fauna, rather than humans with a rich culture that practised advanced **agriculture** and land management techniques over tens of thousands of years.

Evidence gathered by archaeologists Bruce Pascoe and Bill Gammage, including the stories of Aboriginal and Torres Strait Islander peoples as well as early colonial records, provide scientists with a very different picture of how Indigenous peoples lived on and managed Country. This evidence includes stories, colonial journals and diaries, and landscape paintings which indicate that Aboriginal and Torres Strait Islander peoples practised agriculture and aquaculture in a highly organised and sustainable way.

friable
easily crumbled

agriculture
cultivation of the soil for growing crops, and the rearing and management of animals for food and other useful products

4.5.16 Bruce Pascoe on the complex question of Aboriginal agriculture

4.5.17 Let the land speak: How has the landscape shaped our family history

18000 years of agriculture

Close analysis of recorded practices of Aboriginal and Torres Strait Islander peoples indicates that they controlled the growth of forests and woodlands through the use of fire in such a way that open meadows and grasslands were created which were suitable for the growing of grasses such as kangaroo grass (*Themeda australis*), and for the harvesting of grain and yams (*Microseris lanceolata*). The use of fire prevented the encroachment of trees onto the most fertile soils and the build-up of fuels in woodlands that had the potential to erupt into uncontrolled bushfires that could wipe out an entire season's crop. This practice along with the return of harvest waste to the soil resulted in the rich deep soils noted by European settlers, who stated that 'the ground [was] soft and spongy and very absorbent' and that 'horses sank to the fetlock into the soil'.

Other traditional Indigenous agricultural practices that have been noted by archaeologists include aquaculture and animal husbandry. Records and stories indicate that Aboriginal and Torres Strait Islander peoples constructed dams, weirs and traps for the collection and harvesting of fish, while examples of using battues to drive and draft kangaroos and emus suggest that Indigenous peoples were actively managing livestock populations in contrast to what was assumed by the European settlers.

Subsequent to the arrival of the British colonial settlers, Aboriginal and Torres Strait Islander peoples were exposed to diseases such as measles and chicken pox which killed an estimated 50–75% of people. Additionally, Indigenous peoples were removed from Country and dispossessed of their land, which was taken by the British colonialists to be used for traditional agricultural practices such as grazing for sheep, cattle and horses, as well as for growing crops such as wheat. The change in agricultural practices meant that the soil became compacted by animal hooves, the top soil became impervious to rain, causing erosion and infertility, and the elimination of controlled fires created a significant risk of wildfire.

Glass plate negative, full plate, 'Aboriginal fisheries, Darling River', unattributed studio, Sydney, New South Wales, Australia, 1880–1923 2017, Museum of Applied Arts & Sciences, accessed 5 June 2017, <https://ma.as/324833>

FIGURE 4.5.5 The Brewarrina or Ngunnhu fish traps along the Barwon River in north-west NSW allowed the easy harvesting of fish such as Murray cod, perch, catfish and black bream by the local Indigenous peoples. It is still possible to visit the Brewarrina fish traps, though a weir built upstream in the 1960s has reduced the number of fish caught in the traps.

4.5.18 40 000-year-old fish trap in outback NSW

4.5.19 Dark Emu and Aboriginal culture

4.5.20 Aboriginal people - how to misunderstand their science

Joseph Lycett, National Library of Australia, nla.obj-134636220

FIGURE 4.5.6 A 1820 painting by Joseph Lycett depicting the 'parklands' of Lake George, or Weereewa as it is known by the Ngunnawal people, north of Canberra just after settlement by Europeans.

To Aboriginal and Torres Strait Islander peoples the scientific knowledge and understanding that they have of the natural world, how the natural world works and how the natural world got to be the way it is, is not simply a collection of facts, rather it is a path to understanding. This is embedded in stories to explain the physical, earth and life sciences. Stories of the natural and supernatural world explain the connections and relationships between the human, physical and sacred worlds.

Today, a growing body of evidence suggests that the initial assumptions about Aboriginal and Torres Strait Islander peoples by European settlers was influenced by their prejudice and bias for European culture. As this evidence grows it becomes clearer that modern Australians have much to learn from the traditional agricultural practices and connection to Country of Aboriginal and Torres Strait Islander peoples. Ray Norris, a chief research scientist at CSIRO Astronomy & Space Science, said in 2014, 'We must overcome the intellectual inertia that keeps us in that old paradigm, stopping us from recognising the enormous contribution that Aboriginal culture can make to our understanding of the world, and to our attempts to manage it.'

'Ngangaana-gu karrai billa's, dya karrai billa's durai, ngangaana ngingu – Look after the land and rivers, and the land and rivers will look after you,' is an old Wiradjuri saying that promotes sustainability.

INQUIRING FURTHER

Contact your local Aboriginal and/or Torres Strait Islander community and ask if a community member would be willing to share their stories of local Indigenous agricultural practices and how this changed after British settlement. Prepare a report for the class based on what you have discovered during your investigation.

SECTION REVIEW 4.5

REMEMBERING

1 Describe two benefits of scientists working in collaborative teams.

UNDERSTANDING

2 Explain how having people who come from diverse backgrounds is a benefit to science.

3 Describe the reasons why a named problem or question could remain unresolved in science, and outline the evidence that would be needed to resolve it.

APPLYING

4 Aboriginal and Torres Strait Islander peoples are known to have traditionally grown harvested grains and yams, built waterways and fish traps, and managed livestock. Research one of these forms of agriculture and address the following questions.

- Describe one form of agriculture that Aboriginal and Torres Strait Islander peoples practised.
- Estimate how many people this form of agriculture was capable of supplying food for.
- Describe the impact of British colonisation on Indigenous agriculture.
- Explain how the cultural bias of British colonialists resulted in their failure to recognise or acknowledge the forms of agriculture practised by Aboriginal and Torres Strait Islander peoples.

CHAPTER REVIEW QUESTIONS

REMEMBERING

1. List five reasons why a scientist would consult published research when commencing a scientific investigation.
2. Define 'data outlier' and 'correlation'.
3. Identify one example of a scientific pattern that has been observed over time.
4. Identify how Aboriginal and Torres Strait Islander peoples were able to leach the toxins from otherwise toxic plant foods.
5. Identify the term used in science to describe a situation when a hypothesis is accepted when it should not be.

UNDERSTANDING

6. Describe a longstanding historical assumption that has been updated by scientific investigation.
7. Describe, using an example, how generalisations are used in science to build an understanding of phenomena.
8. Compare the similarities and differences between optical illusions and pareidolia using examples.
9. Use an example to explain how false assumptions can result in a scientist making a flawed conclusion when conducting an investigation.
10. Explain why the mystery of how the origins of life on Earth arose still remains unsolved.

APPLYING

11. Explain the impact that the data outlier in Figure 4.6.1 is likely to have on the correlation of the independent and dependent variables if it was:
    - **a** left in the data set.
    - **b** removed from the data set.

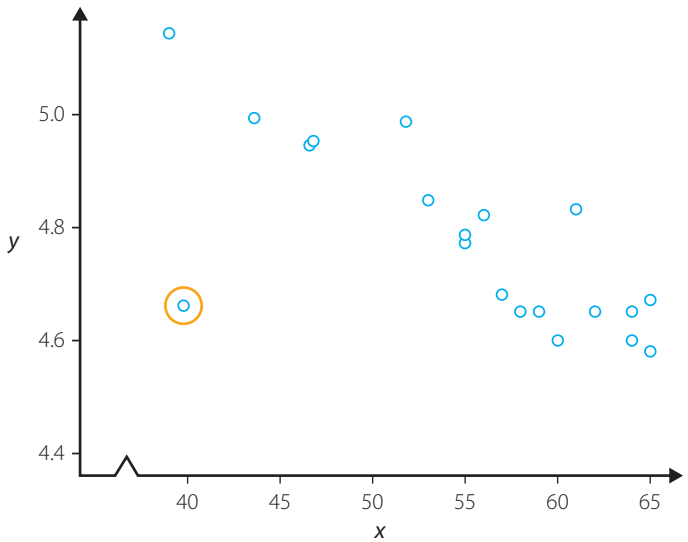


FIGURE 4.6.1
Data set showing an identified outlier (circled).

12 A student went into their garden and noticed the burdock leaf shown in Figure 4.6.2. From the image describe the following:

- **a** an observation they may have made when looking at this leaf
- **b** an inference they may have made based on observations and reasoning
- **c** a generalisation they may have made regarding the risk to the burdock plant.

13 A scientist has the following inquiry question they wish to answer:

Why do great white sharks migrate along the southern coast of Australia, travelling from the west coast of Australia to the mid-eastern coast of Tasmania?

- **a** Describe the problems the scientist is likely to encounter when trying to gather the data needed to answer the inquiry question if they were working alone.
- **b** Explain what benefits there would be in using a collaborative team to answer this inquiry question.

14 From the time of ancient Greeks to the Middle Ages, it was assumed that matter was made up of four elements: air, earth, water and fire.

- **a** Propose an inquiry question and hypothesis that could be used to test this assumption.
- **b** Describe the type of results you would expect to see if this assumption was correct.

iStock.com/rdonar

FIGURE 4.6.2 A burdock leaf.

ANALYSIS

15 The following are two excerpts taken from the writings of George Worgan, the naval surgeon who accompanied the First Fleet and made a number of expeditions north of the British settlement at Sydney Cove.

'…in our excursions inland…we have met with a great extent of park-like country and the trees of a moderate size and at a moderate distance from each other, the soil, apparently fitted to produce any kind of grain and clothed with extraordinarily luxuriant grass… '

'... it is something singular, that all, of this kind of trees, and many others appear to have been partly burnt, the bark of them being like charcoal.'

- **a** Using Worgan's description of the area, identify the features of the landscape that you could infer had been influenced or changed by Aboriginal and Torres Strait Islander peoples.
- **b** Make a judgement about how Worgan's cultural bias impacted his understanding of the Australian landscape he encountered in 1788.

16 Edmond Halley hypothesised that the comet he had observed was on an elliptical path that took approximately 75 years to complete. He then consulted secondary sources in the form of historical texts. Explain how the use of secondary sources helped to support his conclusion and the generalisation that comets orbit the Sun.

17 The animal in Figure 4.6.3 has evolved a means of self-defence that exploits a visual weakness in humans and other predators.

- **a** Identify the effect that causes people to misinterpret the information in the image.
- **b** Explain how this defence mechanism could cause an ecologist to make a type II error if they were conducting a fauna count in the area.

Alamy Stock Photo/Marc Anderson

FIGURE 4.6.3 Tawny frogmouth (*Podargus strigoides*) and hatchling in eucalypt tree.

SYNTHESIS

18 A scientific investigation involves the following stages (not in order):

Inference, Consultation of research, Conclusion, Reasoning, Hypothesis, Analysis of results, Initial observation, Data collection, Generalisation, Inquiry question

- **a** Draw a concept map that illustrates how these stages relate to each other.
- **b** Emma has conducted research and found that the inquiry question she wished to study has already been addressed. Describe her options for proceeding, with reference to the concept map.

19 Type I and type II errors can occur for a number of reasons. Use a firsthand investigation studied in this module to answer the following.

- **a** Describe the possible sources of type I and type II errors that may have impacted the results and their interpretation.
- **b** Explain the steps that were, or that could have been, taken to reduce the likelihood of making a type I or type II error.

EVALUATION

20 Two ecologists, one male and one female, observed the following behaviour in kangaroos.

When two adult male kangaroos are in a mob, no females are mated. Only after a fight ensues between the two males does mating occur. The defeated male leaves the mob and the male that won then mates with all the female kangaroos.

The ecologists then made the following inferences from their observation.

Male ecologist: The male kangaroos fight to see who is the strongest; the male that wins then has control over all of the females and can mate with them as he likes.

Female ecologist: The female kangaroos refuse to mate with a male until he has proven himself to be the strongest; only after he has done so will the female willingly mate with the winning male.

- **a** Explain how two people who saw the same behaviours came up with a different inferences as to what caused what they saw.
- **b** Justify why having a diversity of scientists is important, using the situation and information given in this example.

21 According to the 2009 paper published by Doran and Zimmerman, *Examining the Scientific consensus on Climate Change*, there is a 97.5% consensus among climatologists that human activities have caused the observed increase in global average temperatures since the mid-20th century. Evaluate this statement and explain the following.

- **a** Why is a 97.5% consensus among climatologists significant?
- **b** Why might it be expected that 2.5% of scientists do not share the certainty that human activities have resulted in increases in global average temperatures?
- **c** Why is diversity in viewpoints a good thing for science?

DEPTH STUDY
BIOLOGY

IMPLICATIONS OF USING ANTIBACTERIAL SOAPS

Suggested length: 8 hours including research and presentation

Focus: Secondary-sourced investigation and report

4.6.1 Secondary investigation scaffold

SECONDARY-SOURCED INVESTIGATION SCAFFOLD

Syllabus outcome

Identify the syllabus content you will be investigating and write a summary of the outcome.

Syllabus statement: *Investigating the implications and make a generalisation regarding the use of antibacterial products in the environment*

Hypothesis (if applicable)

A hypothesis is an educated (informed) guess that is tested through investigation to explain and reach answers to scientific questions.

Aim

Write the aim as a sentence. Start the sentence with 'To' followed by a verb; for example, 'investigate', 'measure' or 'test'.

To make an informed generalisation on the impact that antibacterial products can have in the environment and societal health

Secondary sources

List all of the sources that you are using in your investigation and cite them using the correct citation protocols.

Suggested sources:

- ABC News
- SBS News
- World Health Organization
- JETACAR
- Department of Agriculture and Water Resources

Investigation design

Outline how you are designing the final presentation (refer to Chapter 2 for further information).

Method

The method is written as numbered steps. Each sentence must start with a verb.

Suggested steps:

1. Identify environments and industries where antibacterial products are used.
2. Investigate the justifications for using antibacterial products within these environments and industries.
3. Investigate possible alternatives to using antibacterial products.
4. Draw a generalisation to support your position on the use of antibacterial products.

Results

The results may be recorded in tables, graphs or diagrams, or written as observations in sentence form.

Validity and reliability

Remember that validity is related to ensuring that the sources come from educational, government, university or scientific web pages, journals and textbooks. Reliability is associated with finding similar explanations of the concepts across many sources.

Discussion and conclusion

In the discussion and conclusion, analyse your findings to answer your hypothesis, aim and inquiry question/s.

4.6.1 Antibacterial soap in spotlight as companies clamber to remove ineffective chemicals after US ban

4.6.2 Antibacterial soaps to be reformulated in Australia

4.6.3 The use of antibiotics in food-producing animals: Antibiotic-resistant bacteria in animals and humans

4.6.4 Antimicrobial resistance

9780170411196

LEACHING TOXINS

DEPTH STUDY
CHEMISTRY

Suggested length: 8 hours including research, primary investigation and presentation

Focus: Primary investigation and presentation

PRIMARY INVESTIGATION SCAFFOLD

Syllabus outcome

Identify the syllabus content you will be investigating and write a summary of the outcome.

Syllabus statement: *Inferring the effectiveness of leaching toxins from plants*

Introduction

This is the background information about the topic. In a primary investigation, identify the experiment you will be conducting. In a secondary investigation, make sure your sources are valid.

Hypothesis (if applicable)

A hypothesis is an educated (informed) guess that is tested through investigation to explain and reach answers to scientific questions.

The caffeine in coffee beans can be leached using a number of different techniques, the most effective of which is …

Aim

Write the aim as a sentence. Start the sentence with 'To' followed by a verb; for example, 'investigate', 'measure' or 'test'.

To investigate the different techniques used to leach caffeine from coffee beans and determine the most effective technique

Secondary sources

List all of the sources that you are using in your investigation and cite them using the correct citation protocols.

Suggested sources:

- Coffee confidential
- Science news for kids
- Serious Eats
- Chemistry textbooks

Investigation design

Outline how you are designing the final presentation (refer to Chapter 2 for further information). Make sure you include the following (if applicable):

- Variables (independent, dependent, controlled)
- Treatments / control

Method

The method is written as numbered steps. Each sentence must start with a verb.

The investigation method

Students to research and test the various techniques that can be used to leach caffeine from coffee beans and discuss how they could infer which technique was the most effective if they did not have a means of testing the level of caffeine quantitatively.

Students can test their inferences by measuring the levels of caffeine extracted.

Results

The results may be recorded in tables, graphs or diagrams, or written as observations in sentence form.

Validity and reliability

Remember that validity is related to the method and equipment used to perform your experiments, whereas reliability is associated with the repetition of the experiment obtaining similar results with minimal error.

Discussion and conclusion

In the discussion and conclusion, analyse your findings to answer your hypothesis, aim and inquiry question/s.

WS

4.7.1 Primary investigation scaffold

4.7.1 Decaffeination 101: four ways to decaffeinate coffee

4.7.2 Making caffeine content crystal clear

4.7.3 How coffee gets decaffeinated: Water process

DEPTH STUDY
PHYSICS

THE AURORA AUSTRALIS

Suggested length: 8 hours including research and submission of report

Focus: Data analysis from primary and secondary sources, report

4.8.1 Secondary investigation scaffold

SECONDARY-SOURCED INVESTIGATION SCAFFOLD

Syllabus content

Identify the syllabus content you will be investigating and write a summary of the outcome.

Syllabus statement: *Detecting the patterns in the variables over time of the Aurora Australis*

Hypothesis (if applicable)

A hypothesis is an educated (informed) guess that is tested through investigation to explain and reach answers to scientific questions.

Aim

Write the aim as a sentence. Start the sentence with 'To' followed by a verb; for example, 'investigate', 'measure' or 'test'.

To investigate the conditions that lead to the Aurora Australis being clearly visible in the sky and relate them to features of the Earth's atmosphere and the Sun

Secondary sources

List all of the sources that you are using in your investigation and cite them using the correct citation protocols.

Suggested sources:

- Aurora Service
- ABC News, Science News
- Optics & Photonics News
- Earth Moon Planet

4.8.1 Aurora Forecast

4.8.2 Auroras: What are they and how do you spot one in Australia?

4.8.3 What we see in the Aurora

4.8.4 A Terrella device for stimulating Aurora-like phenomena in a box

Investigation design

Outline how you are designing the final presentation (refer to Chapter 2 for further information).

Method

The method is written as numbered steps. Each sentence must start with a verb.

Suggested steps:

1. Identify the different variables that contribute to making the Aurora Australis visible; for example, atmospheric conditions and composition, latitude and solar activity.
2. Research the theory or theories that explain how and why the Aurora forms.
3. Investigate ways in which you could create a model of the Aurora to test the theories.
4. Discuss how variations in different contributing variables can cause the Aurora to be more or less visible based on these conditions.

You may wish to find out if a Terrella device is on display in your area so you can see a working model of an Aurora.

Results

The results may be recorded in tables, graphs or diagrams, or written as observations in sentence form.

Validity and reliability

Remember that validity is related to ensuring that the sources come from educational, government, university or scientific web pages, journals and textbooks. Reliability is associated with finding similar explanations of the concepts across many sources.

Discussion and conclusion

In the discussion and conclusion, analyse your findings to answer your hypothesis, aim and inquiry question/s.

9780170411196

MANAGING THE AUSTRALIAN LANDSCAPE

DEPTH STUDY
INVESTIGATING SCIENCE

Suggested length: 10 hours including research and submission of video production (mock film documentary festival)

Focus: Analysis of secondary sources, video production

SECONDARY-SOURCED INVESTIGATION SCAFFOLD

Syllabus outcome

Identify the syllabus content you will be investigating and write a summary of the outcome.

Syllabus statement: *Investigating how Aboriginal and Torres Strait Islander peoples managed Country prior to British settlement and how this knowledge can be used to manage the land today*

Hypothesis (if applicable)

A hypothesis is an educated (informed) guess that is tested through investigation to explain and reach answers to scientific questions.

Aim

Write the aim as a sentence. Start the sentence with 'To' followed by a verb; for example, 'investigate', 'measure' or 'test'.

To investigate how Aboriginal and Torres Strait Islander peoples managed Country and Place, and how this knowledge can be used to create a more sustainable future

Secondary Sources

List all of the sources that you are using in your investigation and cite them using the correct citation protocols.

Suggested sources:

- 702 ABC Sydney
- National Library of Australia
- ABC Conversations with Richard Fidler
- NSW Local Land Services
- NSW Aboriginal Land Council
- contact your local Aboriginal Land Council to learn from the Indigenous community firsthand

Investigation design

Outline how you are designing the final presentation (refer to Chapter 2 for further information).

Method

The method is written as numbered steps. Each sentence must start with a verb.

Suggested steps:

1. Research the history of Aboriginal and Torres Strait Islander agriculture and land management practices.
2. Find out how land management practices introduced by Europeans have changed the Australian landscape.
3. Contact your local Indigenous community to gain an understanding of these changes in your local area.
4. Assess the role Indigenous knowledge could have in developing sustainable land practices.
5. Make recommendations to further improve current land management practices in your area.

Results

The results may be recorded in tables, graphs or diagrams, or written as observations in sentence form.

Validity and reliability

Remember that validity is related to ensuring that the sources come from educational, government, university or scientific web pages, journals and textbooks. Reliability is associated with finding similar explanations of the concepts across many sources.

Discussion and conclusion

In the discussion and conclusion, analyse your findings to answer your hypothesis, aim and inquiry question/s.

4.9.1 Secondary investigation scaffold

4.9.1 Bill Gammage on how Australia was the biggest estate on Earth

4.9.2 Bill Gammage: The biggest estate on Earth

4.9.3 Bruce Pascoe on pre-colonial Aboriginal agriculture

4.9.4 Sustain. Invest. Protect.

4.9.5 Land councils

5 MODULE 3 SCIENTIFIC MODELS

There are many concepts in science that are hard to understand. This is often due to the fact that scientists study objects and concepts that are outside the range of everyday senses and knowledge. Some phenomena in science are incredibly small, while others are incredibly large, and some can appear to be incredibly unusual. Scientists make models of concepts to make these complex scientific ideas simpler. Models also help to illustrate the basic ideas behind a scientific idea. Once this basic idea is understood, more detail can be introduced, and a more complex model can be developed.

INQUIRY QUESTIONS

- How do scientists show relationships in and between phenomena?
- How do scientists show the complexity of the natural world?
- How can scientists demonstrate concepts that are as grand in scale as the universe or as small as the arrangement of atoms?
- What makes a scientific model useful?

CONTENT

Students investigate:

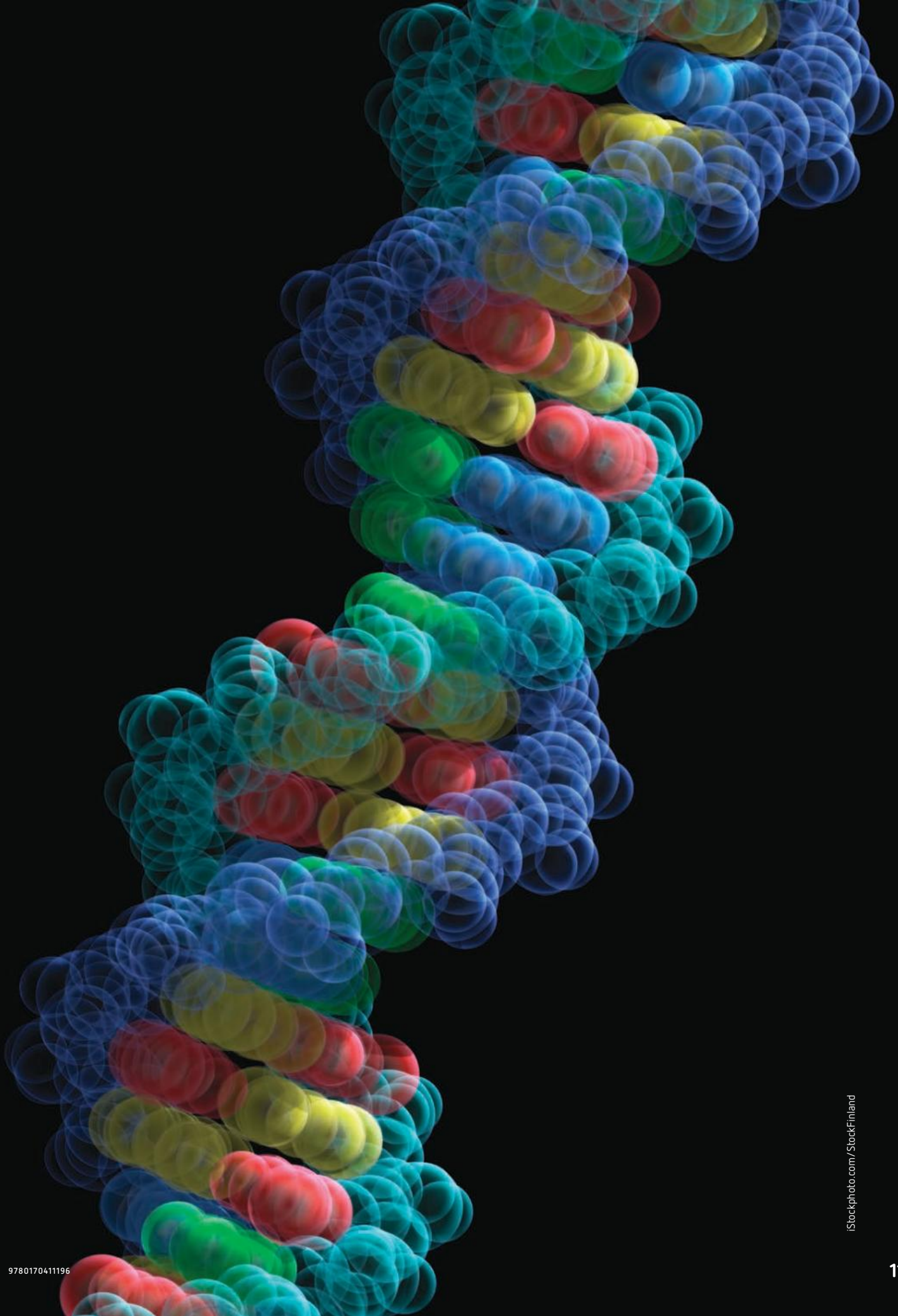
- models to inform understanding
- types of models
- constructing a model

OUTCOMES

A student:

- designs and evaluates investigations in order to obtain primary and secondary data and information INS11/12-2
- conducts investigations to collect valid and reliable primary and secondary data and information INIS11/12-3
- selects and processes appropriate qualitative and quantitative data and information using a range of appropriate media INS11/12-4
- develops, and engages with, modelling as an aid in predicting and simplifying scientific objects and processes INS11-10

9780170411196



iStockphoto.com/StockFinland

9780170411196

5.1 Scientific models to inform understanding

What is a scientific model?

At its heart, science is a way of understanding the world around us. Scientific concepts are often built on simple ideas which are then refined and changed to match newly discovered knowledge.

A scientific model is simply something that can be used to explain a concept. This is an important tool for scientists to explain their ideas, particularly when it comes to explaining concepts from the infinitesimal world of sub-atomic particles, to the near-infinite expanse of the universe. A good model allows someone to easily understand a difficult concept, or one directly outside our range of senses.

For example, what is the wind made of? We know something is there. To begin to understand this you should understand the particle theory of matter. All matter is made of small particles. These particles exist in three states of matter: solids, liquids and gases. The air is made of mostly gases, which generally move from areas of higher gas pressure to areas of low gas pressure. Wind is the movement of gases from the high to low pressure areas. This is a simple way of explaining what can be a very large and complex system.

A scientific model is not considered a final representation of the concept it is showing, rather it can allow understanding of a concept to be improved. Models can be modified or replaced, based on new research and ideas. The history of science is littered with old models being replaced by new ones. Most of the time this is a small improvement, but occasionally, it might be replaced by a completely new model, which might radically change people's understanding of the world.

Types of models

The role of a model is to clearly articulate a scientific concept. How this is achieved will depend on the scientific phenomenon being shown and the meaning that is being conveyed. For example, the **atom** can be represented in a number of different ways, including diagrams, physical models, analogies or computer models.

atom
from the Greek word 'atomos' meaning cannot be divided

Diagrams

Diagrams are the most basic of scientific models. Quite simply, they are a drawing or visual representation of a concept. This is often done to highlight a specific idea. Depending on the concept, the diagram can be simple or complex.

The model of the sodium atom in Figure 5.1.1 is a basic representation of the **electron** structure in the atom. It isn't realistic, as the actual structure is quite complex, being governed by the laws of **quantum** mechanics; however, it is useful in helping people to visualise some of the concepts relating to electron structure, which is important in understanding how **chemical reactions** occur. It is also a helpful tool in first introducing the concept of atoms and electrons, helping to build an understanding of their structure.

Part of its simplicity comes from the fact that it is easy to draw. A few concentric circles demonstrate the complexity of the interacting electrons.

electron
negatively charged particle in the atom spinning around the energy shells of the atomic nucleus

quantum
discrete amount of energy

chemical reaction
chemical process that involves the rearrangement of the elements of the reactants into new products

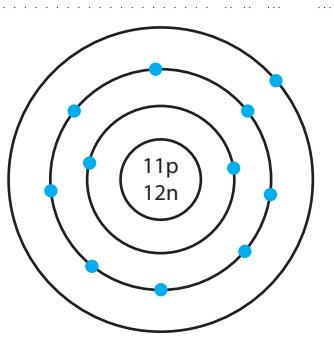


FIGURE 5.1.1 This diagram is a model of the sodium atom. It helps to simplify and visually represent a complex scientific concept.

9780170411196

Figure 5.1.2 shows an animal cell. Both parts of the diagram offer different insights. The left-hand side is more realistic, with a great deal of detail, and gives the reader an idea of where the parts of the cell fit within three-dimensional space. In contrast, it is easier to identify the individual parts of the cell in the image on the right. Both diagrams work well to increase the understanding of the reader. The sketch helps a student learn the basic ideas of cell structure, while the three-dimensional diagram builds upon, and expands, this basic knowledge.

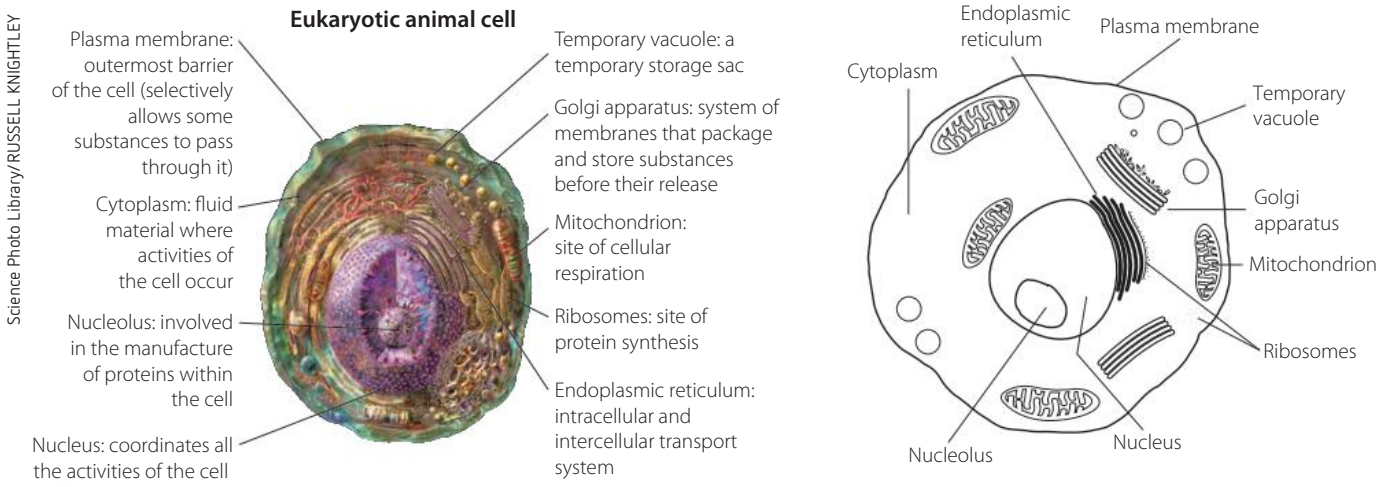


FIGURE 5.1.2 The two diagrams work together to help scientists understand the complexities of a eukaryotic animal cell.

Physical replicas

A physical replica often takes something that is very big, such as the Solar System, or something very small, such as atoms, and makes them a size that is relatively easy to handle or manipulate. Visualising the atomic world is often difficult, as the atoms themselves are incredibly small. For example, the radius of a hydrogen atom is 5.2×10^{-11} metres, or 0.000000000052 metres.

Among the most common physical replicas are models of parts of the human body. It is understandably hard for students to look inside a human body or to imagine how the complex systems work. A model that shows the major organs inside the body allows students to see how they fit within the torso, and also to remove each organ and inspect it easily.

5.1.1 Types of models

5.1.1 What is the shape of a molecule?

Molecular model kits

In these models, the balls represent the atoms while the sticks represent the chemical bonds (Figure 5.1.3). One of the great advantages of these physical models is that it is possible to manipulate them. You can see and feel how the atoms are found relative to each other.

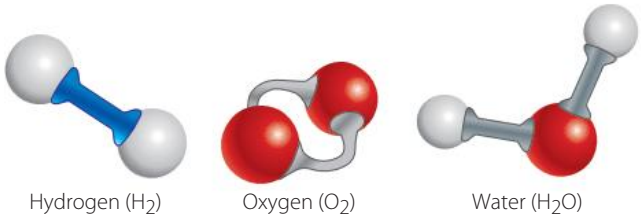


FIGURE 5.1.3 Molecular model kits are examples of physical replicas that are often used to demonstrate the structure of chemical compounds.

Molecular model kits allow a scientist to easily understand the shape and structure of molecules such as water. For example, the model oxygen atom has two holes, representing the two covalent bonds it can form, while hydrogen only has one. In this concept one atom of oxygen must bond with two hydrogen atoms for all the

chemical bond
electrical attraction between the atoms of elements that enables the formation of molecules and compounds

molecule
group of atoms bonded together, representing the smallest fundamental unit of a chemical compound that can take part in a chemical reaction

INQUIRING FURTHER

The Bohr model (also referred to as the Rutherford-Bohr model) attempted to model the hydrogen atom.

Research the development of the hydrogen atom and explain how the development of atomic models has enabled scientists to understand why the radius of hydrogen can change. Present your research as an academic research paper.

INQUIRING FURTHER

Look at and manipulate some biological models found in your school. Assess how useful they are in helping you to understand the workings of the body. Make a judgement on why biological models are often a good alternative to looking at the actual parts. Share your ideas with a partner and then combine these with the rest of the class.

holes to be filled, demonstrating covalent bonding and clearly showing the molecular structure of H_2O.

Mathematical representations

Many concepts in science have a mathematical basis. An example in physics is Newton's laws of motion. Newton's second law describes the relationship between force, mass and acceleration, and can be expressed mathematically, as shown in the key formula below.

mass
amount of matter in a solid, liquid or gas

KEY FORMULA

Newton's second law

$F = ma$

where

F = force, measured in Newtons (N)

m = mass, measured in grams (g)

a = acceleration, measured in ms^{-2}

A mathematical model is useful in that it is possible to quantify what happens in the physical world. For example, the formula given in Newton's second law tells us that by increasing the force on a mass, you increase the amount of acceleration it experiences.

WORKED EXAMPLE 5.1.1

QUESTION

If a person can exert a force of 25 N on a broken-down car weighing 1 000 kg, how much acceleration will this car experience?

FIGURE 5.1.4
Applying force of 25N to a car.

ANSWER

$F = 25\,N$
$m = 1000\,kg$
$a = ?\ ms^{-2}$
If, $F = ma$
$a = F/m$
$a = 25/1000 = 0.025\,ms^{-2}$
This mathematical model shows that a force of 25 N is not much when trying to move a car. Use the same formula to work out the acceleration if the force applied was 100 N.

INQUIRING FURTHER

Research the ideas behind Albert Einstein's special theory of relativity. Describe how his mathematical models influenced modern technology such as global positioning systems. Present your ideas as a five minute presentation.

Mathematical models are extremely important in many branches of science as they easily allow predictions, if certain conditions are known. Most of the mathematical models in science look at one aspect of the phenomenon in isolation. For example, the formula given in Newton's second law only examines the relationship between force, mass and acceleration. It ignores other factors such as friction in order to make the formula easy to apply.

9780170411196

Mathematical models are a common tool used in science, particularly in physics and chemistry, to understand and predict what will happen in certain situations.

Analogies

An analogy describes one phenomenon by comparing it to something different, usually an everyday concept that most people would be more familiar with. This allows a person to use their understanding of one concept to build their understanding of another concept.

A common analogy used in physics describes the flow of electrons around a circuit. In circuit theory, there are three main variables: **voltage**, **current**, and **resistance**. The flow of electricity involves the movement of incredibly small electrons around wires and is a hard concept to visualise.

voltage
force pushing electrons around the circuit

current
flow of electrons around a circuit

resistance
amount by which a circuit tries to stop the flow of electrons

However, for most people who have little knowledge of electricity, it may be easier to imagine water flowing through pipes. For water to flow, a water pump needs to push the water. This is like the voltage in the circuit. The moving water is like the electrical current. The size of the pipes is like the resistance through the wires. If the pipe is wide, then more water can flow. If the pipe is thin, then not much water is able to flow. While it is not a direct comparison, as the flow of electrons through a circuit is much more complex, the water analogy allows people to visualise how electricity might flow through different circuits.

Another example is in biology, where the structure and function of an eye can be compared to the structure and function of a camera (Figure 5.1.5). The analogy works well because both the eye and camera are essentially doing the same thing: focusing light onto cells in the retina or pixels on a charge-coupled device, a device used to measure the amount of light coming into the camera. The aperture and pupil both change size depending on either the diaphragm or the iris moving. This light is focused by a lens, in both cases, and excess light is prevented from entering by either the camera case or choroid. An analogy like this works well as it is possible for you to take apart an old camera and identify the different features and their function.

5.1.2 DNA: The book of you – an analogy

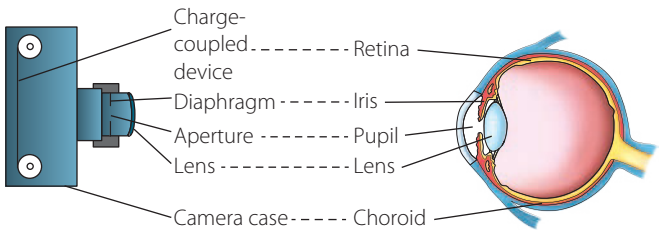


FIGURE 5.1.5
A biological analogy which compares the function of the human eye with a camera.

Computer simulations

The invention and development of microprocessors has seen rapid development in the use of computer modelling. Computers can solve complex mathematical problems in a fraction of the time it takes a person to do them, and therefore have allowed scientists to develop more complex models.

Many models previously discussed have been simple, often taking one or two factors of a concept and examining them in isolation. However, the real world is not that simple. To build the computer model, these interactions need to be turned into algorithms, a set of rules, or a formula that describes a relationship. The formula representing Newton's second law is an example of a simple algorithm, involving only a few factors.

For example, in ecology any ecosystem will have numerous interactions. There are interactions between the biotic (living) and the abiotic (non-living) parts. There are interactions involving predators and their prey. Increasingly there are also interactions with parts of the environment affected by urban growth.

The ecosystem might have a simple relationship between kangaroos and the amount of grass growth. For example, if the amount of grass increases, there will be more food available for the kangaroos to eat. This abundance of food means that the kangaroos will breed more, increasing their population. However, this relationship is not the only one in the ecosystem, as the amount of grass is dependent on the amount of rainfall, and this rainfall can be affected by other climatic factors. There are also other animals in the ecosystem that will be competing for the grass. The main point is that if you are going to build a complex computer model, it takes a lot of planning to get the model right.

Sometimes these algorithms will need to be refined as the model is tested. Once all the algorithms are set up, the computer model can run a simulation. This simulation can then be used to make predictions about some of the factors that might be an influence.

Computer modelling is used extensively to model the climate, which is described in more detail on page 123.

FIGURE 5.1.6 A kangaroo is a part of the Australian ecosystem.

Scientific models are useful for more than just showing a scientific concept; they are also useful in predicting phenomena.

INQUIRING FURTHER

Research the development of computers. As part of your research describe how the speed of computers has increased, and what limitations there might be in the future to further increases in speed. Present your research as a PowerPoint presentation.

Epidemic models

INQUIRING FURTHER

Research one major epidemic that has occurred in the last 1000 years; for example, Black Death, polio, the Spanish Flu, HIV/AIDS, SARS, bird flu, or Ebola. As part of your research look at the ways that scientists and researchers at the time used models or other systems to prevent the spread of the epidemic. Present your research as a short PowerPoint presentation with the following headings: Cause, Effect on ecosystem and population and How the outbreak was solved.

An epidemic is when a disease quickly spreads throughout a population. It comes from the ancient Greek words 'epi', meaning from above and 'demic', which means people.

Throughout history there have been many cases of epidemics spreading quickly through a population. Two of the most common causes of epidemics have been plague and smallpox. The Black Death, an outbreak of plague in the 14th century, is thought to have killed half of the world's population at the time.

Germ theory

The accepted model that explains the spread of disease is called **germ theory**. In germ theory, infectious diseases are spread by germs. A germ is anything that can pass from one organism to another. The term **pathogen** is the scientific term referring to disease-causing organisms or particles.

germ theory theory that infectious diseases are caused by the presence and actions of specific micro-organisms (germs)

pathogen organism or particle that disrupts the normal function of another organism (i.e. causes disease)

Most people are familiar with the idea of diseases being spread by bacteria or viruses; however, there are a range of pathogens, some of which are so small that many scientists are unsure if they can actually be classified as living organisms.

Bacteria are single cell organisms. They do not have a nucleus and their genetic material is spread throughout the cytoplasm of the cell. Bacteria are thought to be one of the earliest forms of life that evolved. An example of a disease caused by bacteria is Salmonella, a type of food poisoning which is caused by meat, often chicken, being infected and not cooked properly before it is consumed. Properly cooking the meat will destroy the bacteria.

9780170411196

Fungi are a group of organisms that are either single-celled, or found in colonies. Mushrooms are an example of fungi. While people might associate them with plants, they do not have **chloroplasts** like plants, so can't make their own food. They mostly feed off decaying living matter.

chloroplast cell found in green plants, containing the green pigment chlorophyll, which is crucial in converting sunlight into sugar through photosynthesis

A common fungal infection is tinea which is also known as athlete's foot. It is spread by fungal spores in places such as communal showers, where an infected person leaves spores which then make direct contact with the new host. It then thrives in warm and moist environments on the body, such as between toes and armpits, and in the groin region.

Protozoa are small, single-cell animals that are responsible for many dangerous diseases. For example, malaria is caused by a parasitic protozoan that first infects mosquitoes, and then spreads to humans and other animals.

Viruses are extremely small vectors made of genetic material that invade a host cell and then use the cell to make copies of themselves. As viruses are unable to reproduce without the aid of the cell they are invading, there is debate about whether they should be classified as living organisms. Examples of viruses include the human papilloma virus (HPV) which is the cause of many types of cervical cancer, and human immunodeficiency virus (HIV) which is spread by sexual contact or blood infection.

Prions are small parcels of protein material that can affect the brains of mammals. Unlike other disease-causing pathogens, prions are not made of either DNA or RNA. Mad cow disease, or bovine spongiform encephalopathy (BSE), is an example of a disease caused by a prion. Cows infected with the pathogen start exhibiting strange behaviour due to the prion causing degeneration in the brain. As the prion also infects the meat of the cows, the disease then spreads to the human population. There is no cure for the brain degeneration.

Viroids are the smallest agents known to cause disease. They are small pieces of RNA that cause diseases such as potato tumours.

INQUIRING FURTHER

In 1998 the water supply to Sydney became infected with *Cryptosporidium and Giardia*. *Giardia* is an example of a protozoan. Research the government response to the outbreak. Present your research as a one-page fact sheet aimed at informing the public of ways to prevent the spread of infection.

INQUIRING FURTHER

Research the work of Ian Frazer in developing the vaccine Gardasil against the spread of HPV. As part of your research, outline how he worked collaboratively with other scientists.

INQUIRING FURTHER

Creutzfeldt–Jakob disease (vCJD) is the human form of BSE. People who lived in the United Kingdom for more than six months between 1980 and 1996 are prevented from donating blood. Research the reasons for this in a one-page report. Include an assessment of the risk of a person developing vCJD if they lived in the UK during this time.

Assessing the effectiveness of the model of germ theory

As a model explaining the cause and spread of epidemics, germ theory has been very successful. After all, it is possible with microscope technology to directly observe different pathogens and their interactions. Bacteria and viruses are easily able to grow in laboratory conditions, while computer simulations have effectively predicted the spread of infectious diseases.

5.1.3 The pandemic game
5.1.4 Modelling an epidemic
5.1.5 Modelling and public health decision making
5.1.6 Principles of epidemiology

Areas of science

Modern germ theory utilises a wide range of disciplines. The roots of germ theory are in biology, particularly in the way cells interact and reproduce, as well as having a thorough knowledge of immune responses.

Development and knowledge of physics, especially the nature of lenses, led to higher powered microscopes which then allowed scientists to research and make discoveries in the microscopic world. Other advances in physics, particularly in regards to the nature of electrons, led to the development of the electron microscope, which allowed scientists to look even deeper into matter and into the world inhabited by prions and viroids.

5.1.2 Models are useful in science

To examine the spread of diseases, we need to understand the way in which objects move through water and the atmosphere, as many disease vectors travel through water or the air. This requires knowledge in physics and earth sciences. This can also be enhanced by computer science, which has allowed scientists to test many of their ideas using simulations. These simulations have been used to predict ways of stopping disease outbreaks spreading further.

Chemistry is used to examine the shape of pathogenic molecules and predict how they will react with, and in, cells. This has meant that medicines can be created to target the specific molecules that can cause disease.

Models of the universe

The movement of stars in the night sky has been studied for as long as humans have existed. Cave paintings discovered in Lascaux in central France are thought to be nearly 17 000 years old. These paintings show a map of the Pleiades star system. It is clear that having some knowledge of the star systems was important to our ancestors and would have had an impact on their lives. Most likely when they saw this star system, they knew it was soon going to be spring and therefore time to prepare for the hunting season.

There have been many ideas put forward to explain how the stars, the Sun and the moon move in relation to the Earth. This historical development will be studied in detail later in this chapter.

INQUIRING FURTHER

Compare the Big Bang model with the steady state model. Research evidence for both models and make a judgement on each model. Present your research as a poster.

The steady state model and Big Bang model

It was thought for some time that the universe had always existed, and that it would continue to exist for all time. Nothing significant would change over time, it would stay steady. Thus, this model was known as the steady state model.

In contrast to the steady state model, the current model of the structure of the universe comes from the Big Bang theory. In the Big Bang theory, the entire universe existed in one tiny region of space smaller than an electron. This point then rapidly expanded, eventually forming the universe as we see it approximately 14 billion years later. What caused the Big Bang is not currently known.

5.1.7 The Big Bang theory and the origin of the Earth
5.1.8 Evidence for the Big Bang
5.1.9 Cosmic mystery tour
5.1.10 The hot Big Bang model

The effectiveness of the Big Bang theory

The Big Bang theory was first proposed by Monseigneur Georges Lemaître, a Belgian Catholic priest studying the redshift of distant celestial objects.

Redshift is a phenomenon where spectral lines, small bands of light energy either emitted or absorbed, are observed in the light coming from distant celestial objects (Figure 5.1.7). These spectra give an indication of the elements found in distant objects in the cosmos. However, it was noted that the further away an object appeared, the further towards the red end of the spectrum it seemed to move.

element
substance that cannot be separated into smaller substances by chemical means

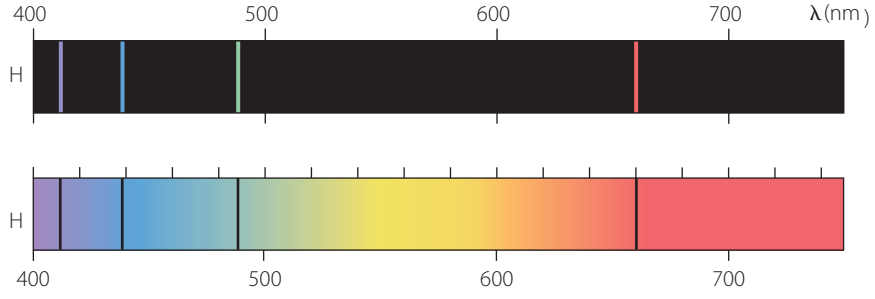


FIGURE 5.1.7 The emission and absorption spectra of hydrogen.

The theory was confirmed by Edwin Hubble, who was observing distant nebulae. He was studying the furthest objects known in the universe at the time, and found that the further away they were, the further the redshift of the light coming from them. This redshift indicated that these objects were travelling faster. Hence, at some stage in the past all objects in the universe were travelling faster than they appear to be now. These same objects also appeared to be moving away from each other. This meant that they were

9780170411196

much closer previously, and, if you keep going back in time, all matter and energy in the universe was at one point a singularity (at one point in space). The development of the Big Bang theory is an example of a new scientific model arising from an observation that didn't fit with the previously accepted explanation.

Areas of science

While astronomy is often regarded as a science in its own right, it uses aspects of many different sciences. Many of the big discoveries have come from utilising knowledge of light and optics. This is true when telescopes were invented and then refined. Galileo and Newton were scientists who made big contributions across optics and astronomy.

As shown by the work of Lemaître and Hubble, knowledge of chemistry allowed astronomers to use spectroscopes to determine the chemical composition of stars. It is this knowledge that has allowed astronomers to determine the chemical composition of distant stars and nebulae in the universe.

Modern astronomers also view the universe in a wide range of electromagnetic waves, from gamma observatories to radio telescopes. These studies rely on powerful computers to do much of the mathematical work.

There is also research being developed in the field of exobiology, looking for chemical and biological evidence of life on other worlds. Astronomers in the field of exobiology examine the spectra coming from planets to look for the building blocks of biological compounds such as water and methane.

INVESTIGATION 5.1.1

Examining atomic spectra

AIM

To show that different chemicals emit different spectra

MATERIALS

- Bunsen burner
- deflagrating spoon
- spectroscope
- metallic compounds: calcium carbonate, potassium carbonate, copper carbonate, lithium carbonate and sodium carbonate

HAZARD	MANAGEMENT
Metallic compounds are harmful if swallowed	Handle chemicals safely
Chemicals may irritate eyes	Wear safety goggles
Bunsen flame may burn your hair	Tie long hair back

METHOD

1. Use a deflagrating spoon to obtain an amount of one of the metallic compounds, and place it at the tip of the light blue flame of your Bunsen burner.
2. Note the colour of the flame produced.
3. Observe the flame colour through the spectroscope. Sketch approximate places where spectral lines are observed.
4. Repeat your observations with each of the metallic compounds.

RESULTS

Copy and complete the following table. Make sure you leave enough space to draw a sketch of the spectral lines for each compound.

METALLIC COMPOUND	FLAME COLOUR	SKETCH OF SPECTRAL LINES
Calcium carbonate		red _____ blue
Potassium carbonate		red _____ blue
Copper carbonate		red _____ blue
Lithium carbonate		red _____ blue
Sodium carbonate		red _____ blue

DISCUSSION

Explain how knowledge of spectra could be used to determine the chemical composition of stars.

Atomic models

5.1.11 Build an atom

5.1.12 The development of the atomic model

All matter in the universe is made of atoms. The current atomic model is known as the quantum mechanical model (Figure 5.1.8). In this model, the atom has a dense nucleus made of protons and neutrons, with electrons orbiting the nucleus and a great deal of space between the two regions. However, in quantum mechanics particles do not occupy a definite region of space. At the sub-atomic level, particles can exist as waves, and therefore, electrons also exist as waves.

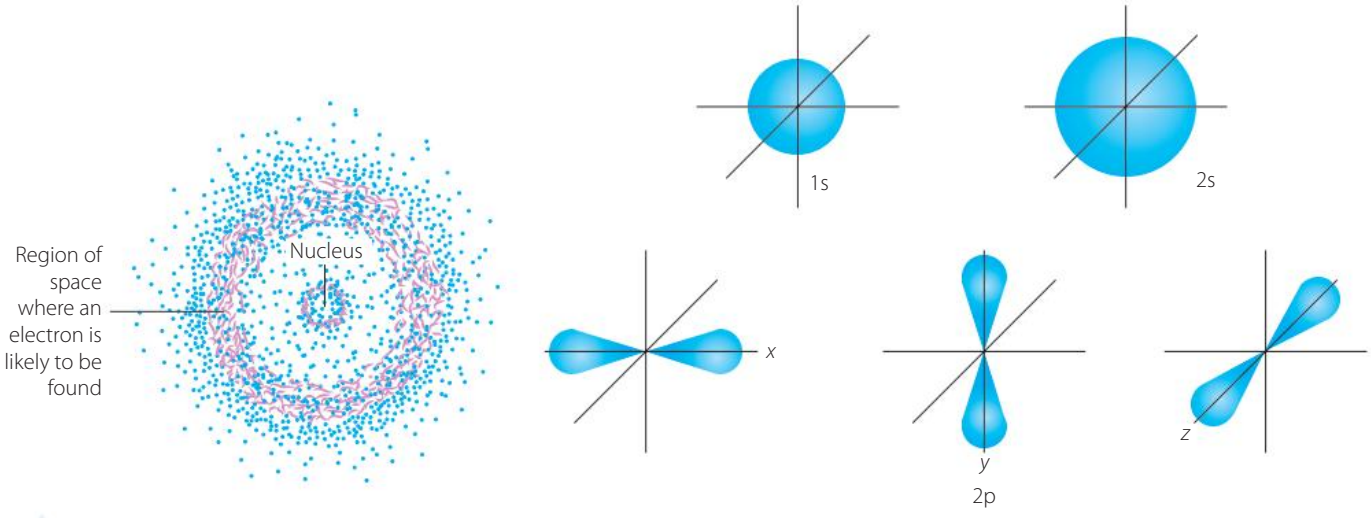


FIGURE 5.1.8 Electron shells in the quantum atom

9780170411196

The effectiveness of quantum mechanics

Quantum mechanics was developed as a way for 20th century physicists to explain issues they had with theories such as blackbody radiation and electron energy shell levels. For example, electron energy shells are composed of negative electrons orbiting a positive nucleus; therefore, when an atom loses kinetic energy the electrons would quickly spiral into the nucleus and obliterate the atom. The wave-particle duality of quantum mechanics solved that issue, enabling an explanation for stable atoms.

Areas of science

The models of the atom, and the energy shells of the electrons, use very complex mathematical ideas and computer simulations. It is also an example of an idea that is used in both physics and chemistry.

There is also work being undertaken in biology on the quantum influence on processes such as photosynthesis, vision in eyes and some enzyme chemical reactions.

Climate models

Climate science has become a topic of much research and debate in the last decade. The reasons for this are numerous, including the influence of politics and economics on the science being discussed. In addition, the climate system itself is by its very nature, a large and complex topic to fully understand.

INQUIRING FURTHER

Assess how the ideas in quantum mechanics are used in modern technology. Present your research as a five-minute presentation.

Illustrate the concept

In the 1890s scientists, such as Svante Arrhenius, predicted that changing the levels of carbon dioxide in the atmosphere would have an influence on the climate. From the 1950s, the use of computer modelling allowed scientists to predict what might happen if increasing amounts of greenhouse gases, including carbon dioxide, were emitted into the atmosphere.

The current climate model involves the concept of the greenhouse effect. A greenhouse is a special building usually constructed of clear glass walls. Its purpose is to provide a warm environment for plants that are suited for warmer environments, such as tropical plants. The clear glass walls let all the radiant heat from the Sun enter the greenhouse. This then heats up the air in the greenhouse, which is trapped, keeping the air inside the greenhouse much warmer than the air outside.

There are many gases in the Earth's atmosphere; however, some of these gases are better at trapping heat than others. The most abundant greenhouse gases are water vapour (H_2O), carbon dioxide (CO_2) and methane (CH_4). As light from the Sun enters the atmosphere it passes through and strikes the Earth. It is absorbed and then emitted again as heat. This heat radiates outward toward the upper reaches of the atmosphere trying to escape. However, the greenhouse gases present in the atmosphere absorb the heat or reflect it back down to the Earth.

INQUIRING FURTHER

Use an A4 page to draw a diagram demonstrating the basic idea of the greenhouse effect.

In some ways, this is good. It keeps the air temperature relatively stable at night when the Sun isn't shining on that part of the Earth. As a reasonably regular temperature is needed for complex forms of life to evolve, there are clearly benefits to having an atmosphere that traps in some heat.

In the mid-1700s the Industrial Revolution started, which saw the development of large machines and the invention of the internal combustion engine. This in turn led to an increase in the burning of fossil fuels, which then led to an increase of carbon dioxide, methane and water vapour in the air resulting in an increase in global temperatures.

Evaluating the effectiveness of the model

There has been a steady increase in average global temperatures since the 1700s, so in that respect the greenhouse gas model has been an effective one, as the prediction mimics the measured data (Figure 5.1.9).

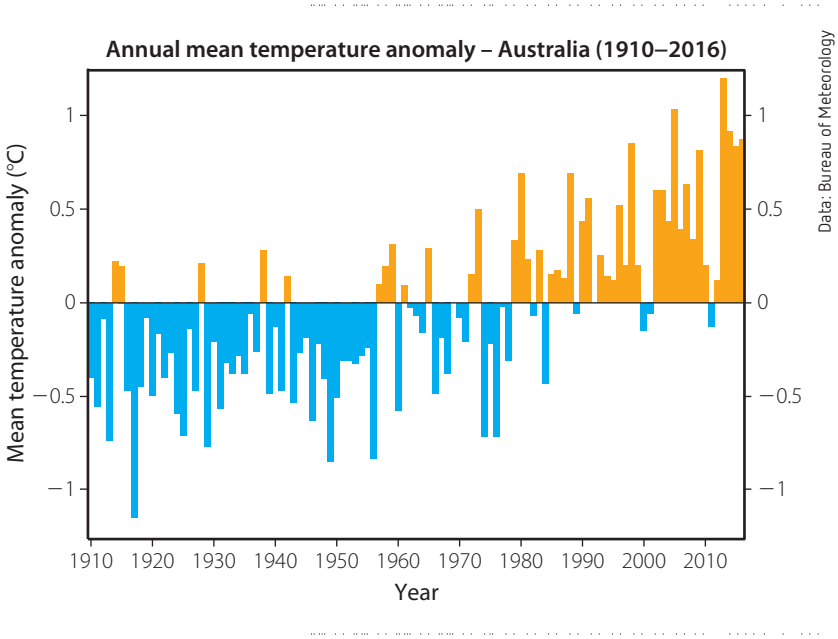


FIGURE 5.1.9 Data from the Bureau of Meteorology showing mean temperature anomalies in Australia since 1910.

Analysing the data in the graph shows that 14 out of the last 15 years have had a higher than normal average temperature. A higher than average temperature can increase ocean temperatures, particularly in tropical regions, and lead to the formation of larger tropical cyclones. In this example, the water evaporates, rising into the atmosphere and increasing the amount of moisture in the air. If this happens quickly the storm cells formed are generally stronger, leading to storms that potentially cause greater damage.

Most scientists agree that climate change will significantly impact the Earth, with devastating effects on environments around the world. Some of the main impacts predicted are rising sea levels, melting polar ice and increasing serious storm events. Many small islands in the Pacific Ocean, such as Kiribati, are already suffering damage due to sea level changes.

species
group of living organisms with similar characteristics that can interbreed

Impacts on ocean **species** have also been observed due to the warming of the world's oceans. Many species living in the ocean survive in narrow temperature ranges. Increasing ocean temperatures allows more carbon dioxide to dissolve into the ocean which causes the oceans to become more acidic. This is particularly problematic for species such as coral, which cannot form their structure in high acid conditions. This is discussed in more detail in the next section.

However, when dealing with a system as large and complex as the climate of the Earth, the computer algorithms will also be complex, and while the predictions may be accurate in the short term, they may prove less accurate over longer time periods. It is also the case that long-term trends such as average temperatures rising may be ignored by some people observing short-term periods of cold days. It is often these complexities that those who argue against the concept of climate change focus on.

INQUIRING FURTHER

Research some of the reasons why weather forecasting is only accurate over a short period of time. Communicate your findings as a short presentation.

9780170411196

Areas of science

Climate science encompasses a broad range of scientific disciplines. Earth science studies many of the interactions that occur within the non-living parts of the Earth, such as the movement of tectonic plates, and the complex interactions between the **hydrosphere** and the **atmosphere**. These interactions form the basis of many of the climate models that have been developed. An example in Australia is the impact of rising sea temperatures on coral in the Great Barrier Reef. Most corals are forms of primitive invertebrate animals. Many live in symbiotic relationships with a variety of algae species, which give some coral their vibrant colours. Most corals need clear, shallow water, within relatively narrow temperature and acid ranges. If the coral is under stress, it ejects its symbiotic algae and loses its colour, hence the term algal bleaching. If this occurs only occasionally, the reef will usually recover within a few years. However, when a bleaching happens over successive years, such as in 2016 and 2017, then it may be very hard for the reef to recover. Biology, and more specifically, ecology, examines many of the interactions within **ecosystems**. Physics, and particularly the study of thermodynamics, is crucial in understanding the movements of heat around the Earth. Thermodynamics studies the way that heat and other forms of energy interact with each other. In climate models, the interactions between energy coming from the Sun, absorption in the atmosphere and heat transfer in the oceans are all very important issues to consider. Chemistry is important in understanding many of the reactions that influence the climate. In climate science, a warmer ocean is able to absorb more gases from the atmosphere. When this occurs with a gas such as carbon dioxide, it forms carbonic acid, leading to increased acid levels in oceans.

hydrosphere
water layer of Earth, including oceans, seas, lakes and rivers

atmosphere
layer of gases surrounding the Earth

ecosystem
area where living things interact with non-living things

INVESTIGATION 5.1.2

Modelling the greenhouse effect

AIM

To model possible mechanisms for global warming

MATERIALS

- two beakers
- two thermometers
- microscope lamp
- cling wrap

METHOD

1. Cover the top of one of the beakers with cling wrap.
2. Place a thermometer in each of the beakers, carefully piercing the cling wrap of the first beaker to ensure there is not a gap around the thermometer.
3. Position both of the beakers in the Sun, or turn on the microscope lamp.
4. Measure the temperature every minute for 10 minutes.

RESULTS

Copy and complete the following table to record your results. Construct a line graph of your results.

»

TIME (MIN)	TEMP (°C) UNCOVERED	TEMP (°C) COVERED
0		
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		

DISCUSSION

1. Assess how effectively this experiment modelled global warming.
2. Outline ways of improving this experiment.
3. Implement these improvements and repeat the experiment.
4. Outline how the line graph makes it easier to explain some of the trends shown in an experiment.

SECTION REVIEW 5.1

REMEMBERING

1. Provide a description of a scientific model.
2. Briefly describe the basic epidemic model.
3. Briefly describe the main ideas in the Big Bang theory.
4. Briefly describe the ideas in the quantum mechanical model of the atom.
5. Briefly describe the main ideas used to describe climate modelling.

UNDERSTANDING

6. Compare some of the ways that pathogens can spread.
7. Compare the ideas of the steady state model with the Big Bang theory.
8. Outline ways in which the quantum mechanical model of the atom might be hard to explain to a primary school student.
9. Discuss how climate change might effect the environment and society, giving two examples.

APPLYING

10. Why is an understanding of the epidemic model important in modern society?
11. Describe ways in which biological models are useful for students studying medicine.
12. Assess why many of the developments in astronomy, particularly the development of the telescope, have been influenced by several branches of science.
13. Why is an understanding of quantum mechanics important in modern society?
14. Outline reasons why climate models are so complex.

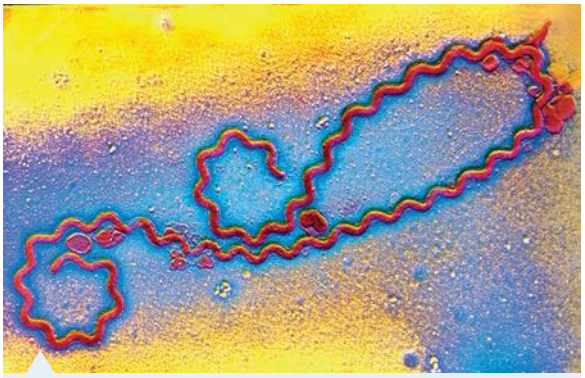
9780170411196

5.2 Types of models

Epidemic models

The human body is a complex machine. Billions of cells work with each other to ensure your body functions every day. In such a complex machine, parts will sometimes not work as they should. When this happens, a person may feel sick.

Hundreds of years ago, people thought that diseases were caused by demons entering your body and destroying it from the inside. The current model to explain disease is that pathogens enter the body and cause the symptoms we experience. An example of a pathogen is the virus that causes the common cold or the bacteria *Leptospira* which causes Leptospirosis (Figure 5.2.1).



Science Photo Library/CNRI

FIGURE 5.2.1 Transmission electron micrograph of the spirally shaped bacterium *Leptospira*, magnified × 400.

The Hippocratic Corpus

One of the first attempts to understand the cause of sickness came from the ancient Greeks. The physician Hippocrates (460 BCE–360 BCE) developed the Hippocratic Corpus, which explained sickness as an imbalance of the humours of the body. The humours were four fluids: melancholy, phlegm, bile and blood. An imbalance in any of the four humours would lead to disease. An excess of melancholy was the cause of depression, an oversupply of phlegm would cause pus to form and fever was caused by an excess of blood. In the example of fever, it was thought that draining blood from the body would help alleviate symptoms by getting rid of the excess of hot blood.

In ancient China it was believed that diseases were caused by an imbalance in the yin and yang forces. An imbalance of these forces caused your life force, Qi, to go out of balance, thus leading to disease symptoms.

INQUIRING FURTHER

Compare and contrast the ideas on the causes of disease between ancient Greece and ancient China. Present the research as a table of information.

Miasma theory

According to the miasma theory, sickness was spread by bad, or foul, air. The name comes from the ancient Greek word for pollution, but was an idea that was also used in ancient India and China.

In some ways, this idea had some credence in that the lack of sanitary conditions would have helped in the incubation and spread of diseases, as well as causing a bad smell. Many of the great plagues that infected large populations, such as the Black Plague and the bubonic plague, were worsened by the poor sanitary conditions in large cities without sewerage systems. In poorer parts of the world some of these old world diseases still occasionally reappear. In 2014 Madagascar suffered outbreaks of bubonic plague.

Alamy Stock Photo/Niday Picture Library

FIGURE 5.2.2 The plague as depicted in the Taggenburg Bible of 1411.

Too small to see

In the mid-1500s an Italian scientist, Girolamo Fracastoro, first proposed that sickness was spread by tiny particles, or spores in the air. These spores could be spread by direct or indirect contact, even over long distances. The sexually transmitted disease syphilis is named after a poem written by Girolamo.

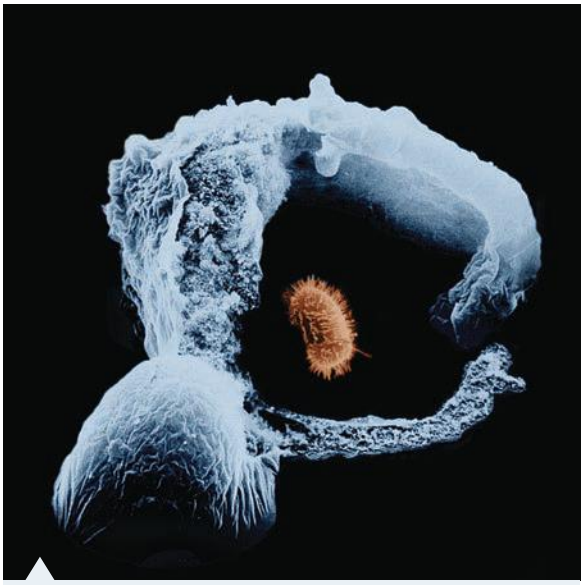
Old theories to explain illness, such as the one proposed by Girolamo, were based on intuition as it wasn't possible to actually observe carriers of disease because they were too small to see. It wasn't until the 1600s that it was possible to observe disease-causing organisms. It is most likely that the Dutch inventor Cornelis Drebbel made the first microscopes, with another Dutch scientist, Antonie van Leeuwenhoek, being the first person to observe single-celled organisms using a microscope.

Getty Images / Fine Art / Contributor

FIGURE 5.2.3 Examples of early compound microscopes from Italy. Like many scientific instruments in the past, the ornate look was almost as important as the function.

The use of microscopes opened up a new world of scientific discovery. As microscope technology improved it was possible to observe that the world was full of organisms beyond what humans had first thought. Disease-carrying agents such as Protista and fungal spores could be seen from these simple microscopes, such as the one shown in Figure 5.2.3. Although 'simple', it was possible for scientists to use these early microscopes to observe large bacteria at a magnification of 200 times their size. Antonie van Leeuwenhoek is credited with observing the first bacteria, although at that magnification, he could only just make them out.

Modern light microscopes can magnify objects up to 1000 times. That is, the image observed through the microscope is one thousand times bigger than the actual object. At this point, the wavelength of light is almost bigger than the object being observed. However, this is still not the largest magnification we have available today. It took the work of many scientists conducting further research before the development of electron microscopes in the 20th century.



Visuals Unlimited, Inc. / Dr. Kwang Jeon

FIGURE 5.2.4 An electron micrograph of an amoeba surrounding its prey (*Tetrahymena*).

As the name suggests, electron microscopes use electrons instead of light to magnify objects. Electrons have a much smaller wavelength than light, and as a result can get a much better resolution. Figure 5.2.4 shows an amoeba surrounding and ingesting a *Tetrahymena*. The development of the electron microscope continued scientific discoveries in the microscopic world, and allowed new pathogenic agents to be found and investigated.

INQUIRING FURTHER

Research the development of electron microscopes and some of the discoveries made by them. Present your findings as a timeline on an A4 page.

9780170411196

Models of the Solar System

The Solar System is a good example of a scientific model as it demonstrates the link between observation, technology and the development of knowledge. Astronomy and models of the Solar System are arguably the first branches of science to be developed.

In developing an understanding of the Solar System, ancient civilisations could plan for the seasons. For example, knowing when different constellations were in certain parts of the sky would signal when it was time to plant seeds, gather food for the upcoming winter, collect medicinal plants or get weapons ready for hunting in the upcoming spring. Knowledge of the stars and seasons led to the development of calendars by many ancient civilisations.

The earliest models of the Solar System were geocentric models. 'Geo' means Earth and 'centric' means in the middle. When you put these two words together you get the basic concept of the geocentric model: that the Earth is the centre of everything.

Logically, this would make sense as the Sun can be observed to 'rise' in the east each morning and 'set' in the west every evening. Day after day it looked as though the Sun was moving around the Earth, and the stars appeared to slowly move across the night sky. In comparison, to an ancient observer, Earth appeared to be in a steady state. It made sense, based on the information they had, for people to believe that the Earth was the centre of the universe and that the Sun moved around the Earth.

INQUIRING FURTHER

Research an ancient archaeological site thought to have been used for astronomy. For example: Wurdi Youang in Victoria, Australia; Stonehenge in England; Chichen Itza in Mexico or Angkor Wat in Cambodia. Identify and describe the evidence used to determine the astronomical significance of the site.

Ancient Greek philosophers and Ptolemy

Around 400 BCE the geocentric model was favoured by the ancient Greeks. In fact, one of the great Greek philosophers Plato, and his student Aristotle, wrote about the Earth being the centre of the universe. Everything else in the universe revolved around the Earth in fixed, crystalline, transparent spheres (Figure 5.2.5).

Five hundred years later Ptolemy, another Greek philosopher, modified the original geocentric model to better explain some interesting observations of the planets, namely their retrograde motion. This is the motion whereby some of the planets appear to be moving backwards. Ptolemy explained this observation by concluding that the planets moved in epicycles, small circular orbits, while travelling in a larger orbit around the Earth called a deferent.

Ptolemy's model tried to balance the observations of retrograde motion into the prevailing idea of a geocentric universe at the time (Figure 5.2.6).

Science Photo Library/Royal Astronomical Society

FIGURE 5.2.5 Plato's model of the universe consisted of crystalline spheres upon which all the objects in the night sky sat.

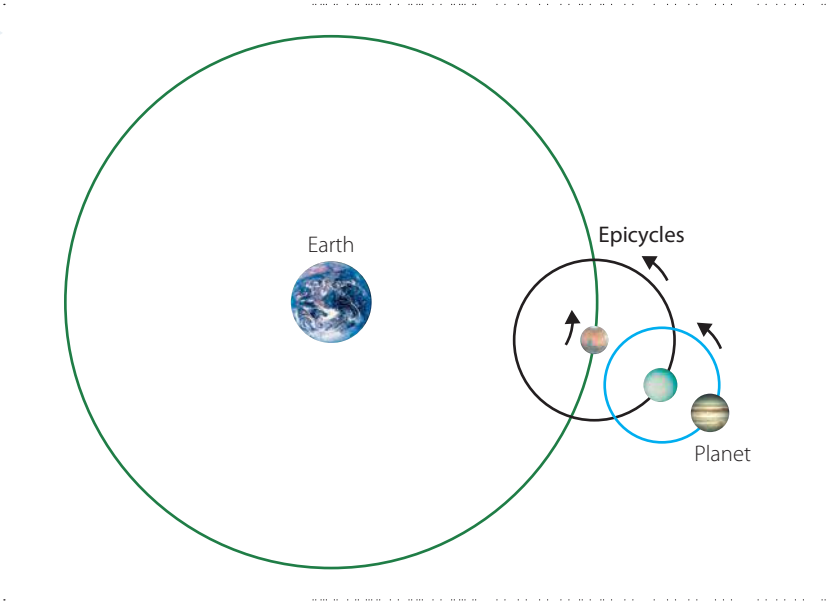


FIGURE 5.2.6 The model proposed by Ptolemy in which the 'wandering' stars were thought to make circles within circles.

Around the time of Plato, another Greek philosopher, Aristarchus, proposed a heliocentric model in which the Sun was placed at the centre of the universe. Using precise calculations utilising the parallax of celestial objects, he concluded that the Sun must be many times more massive than the Earth, and with this conclusion it made more sense for the Sun to be the centre of the universe. However, as the teachings and ideas of Plato were held in such high regard at the time, and there was no technology to support Aristarchus's idea, the geocentric model remained. For nearly 2000 years the geocentric model was the accepted theory of the universe; it took a leap in technology for this model to finally be challenged and changed.

INQUIRING FURTHER

The telescope was originally developed by Hans Lippershey as a toy for his children. However, it was only able to magnify images by a relatively small magnification. Galileo Galilei quickly realised its potential for looking at the night sky.

Research the original telescope made by Hans Lippershey and the modifications made by Galilleo. Compare this with telescopes made by Newton and modern light telescopes.

As part of your research include a graphic organiser such as a Venn diagram or a PMI chart to compare the features of the telescopes.

INQUIRING FURTHER

Research the relationship that science and religion have had throughout history. As part of your answer describe the interactions between Galileo and the Roman Catholic Church.

The Renaissance

Prior to the Renaissance, astronomers used devices such as hour glasses and water clocks to measure time, and had to make direct observations (using only their eyes) of the motion of stars and planets. When accurate clocks and telescopes were developed, scientists were able to make much more precise measurements.

Nicolaus Copernicus was a European astronomer and mathematician who proposed a heliocentric model of the universe in the early 1500s. His work was based on observations of the night sky and detailed mathematics.

The Italian scientist Galileo Galilei used the telescope to build upon and develop previously held astronomical theories. One of his many achievements involved his observations of Jupiter. The telescope allowed him to observe the planet in some detail, and he noted that Jupiter was orbited by its own satellites (moons). This observation confirmed that not every object in the universe orbited the Earth. Galileo proposed a new model in which the Sun was the centre of the universe. This new model proposed by Galileo was a complete change from the prevailing thinking, and also went against the teachings of the Roman Catholic Church which ruled Europe at the time.

9780170411196

Newton

Many regard Isaac Newton as the greatest scientist to have ever lived. Many of his ideas laid the foundation of classical physics. Some of his achievements are described below.

- Theories on the nature of light and optics: Newton discovered that white light was a combination of the colours of the rainbow. By using prisms, white light could be split into many colours. He also developed the reflecting telescope.
- Laws of motion: His laws of motion, covering the idea of inertia (the relationship between force and acceleration) and reactive forces, provided the basis for the study of kinematics.
- Differential calculus: Newton developed this branch of mathematics which was useful in developing his laws of motion.

These are all useful in the study of astronomy; however, in terms of models of the universe, his most important idea was a new way of thinking about gravity: the universal law of gravitation. Gravity is a force that exerts a small influence over a very large distance. Gravity is the main force that influences astronomical objects. Universal gravitation can be used to explain motion in the Solar System. Most of the mass in the Solar System is found in the Sun; therefore, it is the central body around which all other objects in the Solar System orbit.

Hubble

As astronomy developed, it was possible to take the light from distant objects, and pass it through a spectroscope, in order to reveal spectral patterns. An astronomer by the name of Edwin Hubble was observing these spectral patterns and noticed the lines changed depending on the distance of the object from the Earth. The objects that were further away had their spectral lines moved toward the red end of the spectrum. This so-called 'Doppler shift' indicated that the further away the galaxies were, the faster they were travelling.

When light from distant objects in the universe is passed through a prism, it spreads out like a rainbow. Scientists looking closely at this spectrum found faint lines. The lines are an indication of the types of atoms found in the objects that emitted the light. As a result, astronomers were able to determine the composition of stars.

INQUIRING FURTHER

The Doppler effect occurs when the wavelength of waves changes due to an object's speed. This is very obvious in something such as a race car. As it comes towards you the pitch of the engine's sound appears to rise until it passes you and then the pitch seems to drop. Research examples of the Doppler effect as it relates to sound and light. Present the research as an A4 poster.

INQUIRING FURTHER

Research modern ideas on the structure of the universe. As part of your answer outline some of the issues astronomers have in observing the universe and in making inferences based on this evidence. You may want to look into areas such as dark matter and gravitational waves. Communicate your research as a short PowerPoint presentation.

INVESTIGATION 5.2.1

Gravity

AIM

To compare how long it takes for different objects to fall to the ground

HYPOTHESIS

Objects will fall to the ground with the same acceleration regardless of mass.

VARIABLES AND CONTROLS

- Independent variable: type of ball dropped
- Dependent variable: time taken to fall
- Controls: balls are dropped from the same height

»

NOTE

This experiment is best done in small groups. Clearly assign roles for members of your group.

MATERIALS

- several different types of balls (at least four)
- stop watch or timer (with seconds)

HAZARD	MANAGEMENT
Falling objects may hit people	Ensure area is clear
Falling from heights may cause injury	Ensure people do not climb to conduct experiment

METHOD

1. Choose at least four different balls and drop them from a height of at least 2 metres. A first or second floor balcony is ideal. Make sure that the area below is safe.
2. Drop the balls from the same height and record the time it takes for each to hit the ground.
3. Conduct and record your results ten times for each ball.
4. Calculate the average drop time for each ball to two decimal places.

RESULTS

Copy and complete the table below.

	BALL 1	BALL 2	BALL 3	BALL 4
Test 1				
Test 2				
Test 3				
Test 4				
Test 5				
Test 6				
Test 7				
Test 8				
Test 9				
Test 10				
Average				

DISCUSSION

1. Was the hypothesis supported? Explain why or why not with reference to your results.
2. Is this a fair and valid experiment? In your answer refer to the dependent and independent variables, and controls.
3. Science can be conducted individually or in groups. Explain why this experiment is best done as a group. Describe the roles that people in your group performed.

EXTENSION

How could you improve this experiment? Write a new outline for your improved experiment and conduct the experiment.

9780170411196

Atomic models

Ancient ideas

Technology often determines how fast scientific models can progress. In the study of atoms one of the main difficulties is that atoms are incredibly small, well beyond the vision of humans. For most of human civilisation, it was impossible to directly observe atoms; therefore, early atomic ideas were developed through inference and clever thinking. The ancient Greek philosopher Democritus argued in around 400 BCE that matter was made of tiny indivisible particles, which could not be broken down any further.

5.2.1 The 2400-year search for the atom

However, it wasn't only the ancient Greeks who were wondering about the smallest components in the world around them. The Indian philosopher, Kanada, is thought to have developed the same idea centuries before Democritus.

The ancient atomic model remained untested for thousands of years. The size of individual atoms made it impossible to see them, let alone to test any of their properties. There was no technology available that could make observations of atoms.

John Dalton

The science of chemistry as we know it began in the 1700s, as scientists were able to make more accurate measurements using new technologies. In the early 1800s John Dalton developed the law of multiple proportions. He observed that elements will combine in fixed ratios. His experiments involved mixing known volumes of gases and getting them to react.

Dalton also proposed that there were a set of basic chemical elements that were unable to be broken down any further. However, these elements could combine to make different compounds, and these compounds always combined in fixed ratios. For example, two parts of hydrogen gas combined with one part of oxygen gas would make water. This ratio of 2:1 would always be the same. He applied the ancient idea of indivisible atoms to formulate his own theory.

J. J. Thomson

By the late 1800s a new range of scientific tools had been made. One of the most important was the cathode ray tube. J. J. Thomson suggested that the cathode rays came from the atoms in the cathode. He suggested that they were much smaller than atoms, as they were able to travel greater distances through air than what had been observed with atoms. It was also observed that cathode rays could be deflected by electric charges.

Thompson suggested that cathode rays were negative particles that he called corpuscles, and that they were normally embedded in the positive matter of the atom.

INQUIRING FURTHER

Discharge tubes are thin glass tubes containing either a vacuum or a small volume of gas. Electrodes within the tube allow electricity to pass through it. Early tubes allowed properties of atoms, such as magnetic and electric deflection, and momentum, to be discovered, and eventually led to the invention of television. Research the impact cathode ray tubes have had on society.

Ernest Rutherford

In 1909 the New Zealand physicist, Ernest Rutherford, conducted an experiment that led to the discovery of the nucleus of the atom.

If atoms were just regular blobs of matter, then it was thought that the alpha particles would force their way through obstacles and be found to travel in almost straight lines. Rutherford's experiment used radium as the source of alpha particles which were fired at a thin sheet of gold foil. Gold, like most metals, is very malleable, so malleable that it can be made into a sheet of foil 0.00004 cm thick. This was so thin that the sheet was transparent.

A fluorescent screen was used to measure the path of the alpha particles. When the experiment was run, most of the particles did go straight through the foil directly to the screen at the back. However, some particles were deflected at large angles, including some that were deflected back toward the source of the alpha particles.

Rutherford was quoted as saying it was, 'as if you fired a 15-inch shell at a sheet of tissue paper and it came back and hit you.'

Rutherford explained that the deflection was due to the majority of the atom's mass being found in a very small region called the nucleus. This region had a positive charge which the small, negative electrons orbited. This explained the results from the experiment.

Below is a summary of Rutherford's explanation.

- The alpha particle is relatively large and has a positive charge.
- Most of the atom is empty space.
- Most of the alpha particles pass through this empty space.
- A small number move close to the nucleus. The positive charge in the nucleus and alpha particles repel each other, with the alpha particle deflecting a little.
- Occasionally an alpha particle comes very close to the nucleus and is deflected at a large angle.

Niels Bohr

In 1913 Niels Bohr further developed the atomic model to explain how electrons could interact with energy and move to different orbital energies. The ideas of Bohr laid the foundation for the development of the modern science of quantum mechanics.

In the Bohr model, electrons orbited at certain energy levels. Electrons could move from one energy level to another, and either absorb or release energy to do this. This is observed as the spectral patterns discussed previously.

James Chadwick

The discovery that different atoms of the same element had different atomic masses led to the discovery of the neutron by James Chadwick. This in turn led to research in the development of atomic weapons and power.

Quantum mechanics

5.2.2 Atoms: from A to easy
5.2.3 Quantum mechanics: particles and waves

The 1900s saw a radical shift in the way scientists viewed atoms. Atoms were no longer seen as being indivisible structures; they were now composed of electrons, protons and neutrons. The very notion of matter being definable by its mass and volume also changed. These particles were also thought to have a wavelike nature.

The science of quantum mechanics could describe many of the observable properties of these particles using wave equations.

INVESTIGATION 5.2.2

Designing an experiment

Design an experiment using common materials to build three-dimensional models of atoms.

DISCUSSION

Compare and contrast the two atomic models shown in terms of their ease of use, their ability to demonstrate sub-atomic properties and their use in a junior science classroom.

9780170411196

Inside molecular model kits

The molecular model kit allows scientists to have a physical understanding of what the compounds of materials actually look like. They are composed of two main items: atoms and bonds. Atoms are shown using small spheres. Different types of atoms can be shown using different types of sphere. Each sphere has one or more holes on its surface. These holes represent the number of electrons the atom is either willing to give, receive or share. For example, hydrogen has one electron in its outer shell, and easily gives it away to another atom to become more stable. In most molecular model kits hydrogen is represented by a small white sphere with one hole. Oxygen has an outer shell of six electrons. It only needs two more electrons to completely fill this shell. Oxygen is usually represented by a red sphere with two holes on its surface. Water is a compound formed when two atoms of hydrogen combine with one atom of oxygen.

To create a molecular model of water, you will need some bonds. A bond is essentially an amount of energy that holds atoms together. In the molecular model kits a bond can either be a grey stick or a short white plug. When creating a water model it is common to use the white plug. Insert the white plug into both of the holes in the oxygen sphere. Two hydrogen spheres are then placed over the other ends of the plugs. And you now have a water molecule.

INVESTIGATION 5.2.3

Using molecular models

AIM

To use molecular model kits to build basic molecular structures

HYPOTHESIS

Common compounds will only be able to be formed in specific structures.

MATERIALS

- molecular model kits for water, carbon dioxide, oxygen gas, hydrogen gas, methane, nitrogen gas and ammonia

HAZARD	MANAGEMENT
Some of the parts of the kit are small and may present a choking hazard.	Keep pieces of the kit away from your mouth.

» METHOD

1 Use the molecular model kits to build some common compounds.
2 Sketch the models that you make.

RESULTS

Copy and complete the table below, including sketches of your models.

MOLECULAR NAME	MOLECULAR FORMULA	MOLECULAR SKETCH
Water	H_2O	
Carbon dioxide	CO_2	
Oxygen gas	O_2	
Hydrogen gas	H_2	
Methane	CH_4	
Nitrogen gas	N_2	
Ammonia	NH_3	

DISCUSSION

Assess the advantages of using the molecular model kits to demonstrate atomic structure in common compounds.

Climate models

5.2.5 Climate change in Australia
5.2.6 Climate models
5.2.7 Global climate modelling

Few contemporary scientific issues have caused more controversy than the debate over the nature of our climate. While climate change theories came to prominence in the 1970s, theories concerning the impact of gases in the atmosphere on the climate have existed since the ancient Greeks.

Energy use

For most of human history the main form of energy use was the burning of wood to warm living spaces and cook food.

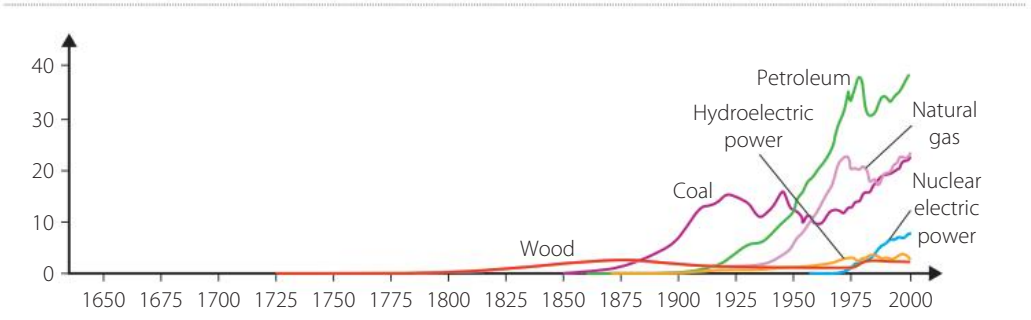
The mid-1700s saw the start of the Industrial Revolution, where machinery was developed to do large amounts of work. Jobs such as farming, which previously required a lot of people, could be done more effeciently using industrial methods. Windmills and watermills also provided power.

These large industrial machines, which were originally operated by people turning cranks and wheels, were then powered by steam and then by internal combustion engines burning fossil fuels.

The age of cars

After World War II automobiles became a common form of transportation, leading to a boom in the use of petroleum products. In many respects crude oil became the global currency, such was its usefulness in developing the modern world. Figure 5.2.7 represents the amount of power consumed over time. The graph is the result of running computer models using raw data.

9780170411196



Data: US Energy Information Administration - Annual Energy Review 2009

FIGURE 5.2.7 Power consumption over time

WS
5.2.1 Types of models

Getting hot in here

As mentioned earlier, the idea of the gases in the atmosphere influencing climate goes back thousands of years. However, like many ideas from the past, evidence for this idea needed to wait for technology to develop to a sufficient level. Svante Arrhenius, a Swedish scientist, first proposed the modern idea that increases in atmospheric carbon dioxide might warm the planet. Infrared spectroscopy in the 1940s showed carbon dioxide absorbed infrared radiation.

Models linking increased carbon dioxide with rising temperatures were developed in the 1960s. In the 1970s and 80s these models were further developed with the aid of computer technology which allowed scientists to make faster, more complex calculations.

As the 21st century progressed, many of these computer predictions have started to come to fruition.

INQUIRING FURTHER

Design and build a simple machine that has been used to make life easier for people. Examples might include windmills and water mills. Present your model to the class.

INQUIRING FURTHER

Choose one kind of farming that is of interest to you; for example, wheat, sheep or produce. Compare modern farming methods, with those of 500 and 1000 years ago. Present the research as a compare and contrast chart or similar. Extension: make recommendations based on the research to improve farming methods in the immediate future.

SECTION REVIEW 5.2

REMEMBERING

1 Define the following terms:
   - **a** 'epidemic'.
   - **b** 'geocentric'.
   - **c** 'heliocentric'.
   - **d** 'gravity'.

UNDERSTANDING

2 Describe why astronomy was an important tool for ancient people.

3 Use labelled diagrams to explain each of the following phenomena. Assess the positive aspects of each model and its limitations.
   - **a** The spread of disease
   - **b** The geocentric versus heliocentric universe
   - **c** The Rutherford atomic model
   - **d** Global warming

4 Propose reasons why the structure of the atom could not be easily determined until the early 20th century.

5 Outline reasons why the study of climate science may not have progressed until the 1970s.

6 Construct annotated timelines to show the development of the following models. You should use information from this module as well as your own research.
   - Epidemic models
   - Models of the universe
   - Atomic models
   - Models of climate change

7 Construct an annotated timeline of one scientific model not studied in this module.

8 Analyse how changes in technology have influenced each of the four scientific models mentioned in this chapter. As part of your answer, mention the specific technologies developed.

APPLYING

9 Research a scientific model that has not been explored in this text; for example, superconductivity. Outline how the development of this model has led to greater scientific understanding and impacted people's lives.

10 Outline potential future research directions that the models mentioned in this chapter may take.

5.3 Constructing a model

Planning a model

5.3.1 Constructing models – the scientific model fair

When constructing a model, it is important to consider your areas of interest as well as your strengths in various styles of presentation. Considering this may influence the model that you construct (Table 5.3.1). Once you have an idea of the areas you might be interested in, you need to reflect on whether you will be able to achieve what you want to achieve. For example, do you have the equipment available to construct the model?

TABLE 5.3.1 Planning a model

QUESTION	POSSIBLE MODELS TO EXPLORE
Are you concerned about climate change?	Consider building a model that shows a natural process. An example might be building a terrarium that demonstrates or compares how plants grow under the influence of additional heat.
Are you interested in music?	Make a simple instrument that demonstrates how tension affects pitch.
Are you good at drawing or art?	Could you construct a set of posters that demonstrate a concept such as predator–prey relationships in an Australian ecosystem?
Are you good at making things with your hands?	Could you make a physical model of a machine that launches projectiles at different angles?
Are you good at mathematics?	Could you devise a mathematical model that shows the relationship between a mass hanging off a spring?
Are you a good writer?	Could you write an analogy that describes a scientific concept to primary school children? You might turn this analogy into a children's book.
Can you use computer code?	Could you develop a computer simulation that demonstrates natural selection?

9780170411196

Choose a model

Your model must explain a scientific concept. For example:

- how evolution works
- how stars form
- how joints work
- ligament augmentation and reconstruction system (LARS) surgery
- a house alarm
- tectonic plate boundaries
- covalent bond formation in atoms.

Background research

When creating a scientific model, you need to conduct background research. It is important for you to have a good understanding of the basic concepts that you are trying to demonstrate with your model. This research can then be compiled into a background paper on your idea. Questions to ask include:

- What do scientists currently know about the phenomenon?
- What is still unknown about the phenomenon?
- Why is the phenomenon interesting?
- Why did scientists choose this as the current model?
- Did this model replace an older model? If so, why?

Constructing

If you are building a physical model, you will have to acquire the materials and put them together. Building a computer simulation may also require you to learn how to code in computer languages.

Presenting

Finally you are ready to present your model to the class. In your presentation, you should explain some of the following questions. You may also include other ideas from your background research to enhance your presentation.

- What are you attempting to demonstrate?
- How does your model simplify the scientific concept?
- How could your model be used to make a prediction?

Members of your class will provide feedback. Use this feedback to refine and improve your model.

SECTION REVIEW 5.3

REMEMBERING

1 Briefly describe two models presented in your class to your peers.

2 Outline why it is important to plan before attempting to construct a scientific model.

UNDERSTANDING

3 Outline some of the difficulties you faced when constructing your own scientific model.

APPLYING

4 Prepare a short presentation that describes:

- your background research in constructing your model.
- a brief summary of how you built your model.
- improvements made after peer feedback.
- how your final model can be used to make prediction.

9780170411196

CHAPTER REVIEW QUESTIONS

REMEMBERING

1. Define 'scientific model'.
2. List two examples of scientific models.
3. Describe how scientific models can be used to simplify a concept or process. Use at least one example of a model in your answer.

UNDERSTANDING

4. Use one scientific model as an example of how models can be used to make predictions.
5. Assess the effectiveness of the following model types, using at least one example in your answer.
   - a Diagrams
   - b Physical replicas
   - c Mathematical representations
   - d Analogies
   - e Computer simulations
6. Give an example of a simple and a complex scientific model.
7. Briefly describe our current understanding of the following scientific models.
   - a Epidemic models
   - b Models of the universe
   - c Atomic models
   - d Climate models
8. Construct an annotated timeline outlining the development of each of the scientific models listed in question 7. Your timelines should include important dates, relevant scientists, reasons why the model changed and references to any technological innovations that influenced the change to the model.
9. Outline how epidemic models can be used to help predict or contain a potential outbreak of a disease.
10. Propose reasons why models of the universe did not change significantly for a long period of time in human history.
11. Demonstrate, using examples, why it might be difficult to explain the quantum theory of the atom.
12. Outline why it is sometimes difficult to analyse large systems such as those affected by climate change.
13. Choose one type of model studied in this module and make a judgement on its effectiveness.
14. Describe in detail how one scientific model has been influenced by different branches of science.
15. Briefly describe one scientific model that gives qualitative data and one that gives quantitative data.
16. Outline one primary investigation you have completed in this module. As part of your outline, describe how you ensured the data obtained was valid and reliable.
17. Discuss one secondary investigation you have completed in this module. As part of your discussion, explain how you ensured the data obtained was valid and reliable.

APPLYING

18. Discuss difficulties that can be encountered when developing a scientific model.
19. Outline why peer feedback can be an effective tool in refining a scientific model.
20. Analyse one model not discussed in this module. Describe how it attempts to simplify the scientific concept being studied and indicate how it is used to predict scientific processes.

DEPTH STUDY
BIOLOGY

THE DEVELOPMENT OF MICROSCOPES

Suggested length: 10 hours including research and submission of report

Focus: Analyse secondary sources, report

5.4.1 Secondary investigation scaffold

SECONDARY-SOURCED INVESTIGATION SCAFFOLD

Syllabus outcome

Identify the syllabus outcome you will be investigating and write a summary of the outcome.

Syllabus statement: *Research the history of microscope technology and evaluate the effect it has had on society*

Hypothesis (if applicable)

A hypothesis is an educated (informed) guess that is tested through investigation to explain and reach answers to scientific questions.

The development of microscope technology has had a positive/negative impact on society due to …

Aim

Write the aim as a sentence. Start the sentence with 'To' followed by a verb; for example, 'investigate', 'measure' or 'test'.

5.4.1 Microscope timeline
5.4.2 History of microscopes
5.4.3 History of the microscope

Secondary sources

List all of the sources that you are using in your investigation and cite them using the correct citation protocols.

Suggested sourcres:

- Nobel Media AB
- Vision Engineering Ltd.

Investigation design

Outline how you are designing the final presentation (refer to Chapter 2 for further information).

Method

The method is written as numbered steps. Each sentence must start with a verb.

Results

The results may be recorded in tables, graphs or diagrams, or written as observations in sentence form.

Validity and reliability

Remember that validity is related to ensuring that the sources come from educational, government, university or scientific web pages, journals and textbooks. Reliability is associated with finding similar explanations of the concepts across many sources.

Discussion and conclusion

In the discussion and conclusion, analyse your findings to answer your hypothesis, aim and inquiry question/s.

9780170411196

DEPTH STUDY
CHEMISTRY

MODELLING ATOMIC BONDING

Suggested length: 5 hours including research, construction and presentation

Focus: Developing, using and explaining models

Task: Construct a model that demonstrates how atoms bond with each other. Your model should be designed to teach a year 10 class.

5.5.1 Primary investigation scaffold

PRIMARY INVESTIGATION SCAFFOLD

Syllabus outcome

Identify the syllabus outcome you will be investigating and write a summary of the outcome.

Syllabus statement: *Using models to demonstrate how atoms bond with each other*

Introduction

This is the background information about the topic. In a primary investigation, identify the experiment you will be conducting. In a secondary investigation, make sure your sources are valid.

Hypothesis (if applicable)

A hypothesis is an educated (informed) guess that is tested through investigation to explain and reach answers to scientific questions.

Aim

Write the aim as a sentence. Start the sentence with 'To' followed by a verb; for example, 'investigate', 'measure' or 'test'.

Secondary sources

List all of the sources that you are using in your investigation and cite them using the correct citation protocols.

Suggested sources:

- How atoms bond
- Bonding basics

5.5.1 How atoms bond
5.5.2 Bonding basics

Investigation design

Outline how you are designing the final presentation (refer to Chapter 2 for further information). Make sure you include the following (if applicable):

- Variables (independent, dependent, controlled)
- Treatments / control

Method

The method is written as numbered steps. Each sentence must start with a verb.

Results

The results may be recorded in tables, graphs or diagrams, or written as observations in sentence form.

Validity and reliability

Remember that validity is related to the method and equipment used to perform your experiments, whereas reliability is associated with the repetition of the experiment obtaining similar results with minimal error.

Discussion and conclusion

In the discussion and conclusion, analyse your findings to answer your hypothesis, aim and inquiry question/s.

DEPTH STUDY
PHYSICS

QUANTUM MECHANICS

Suggested length: 10–15 hours including research and presentation of models

Focus: Scientific research, development of models

5.6.1 Secondary investigation scaffold

SECONDARY-SOURCED INVESTIGATION SCAFFOLD

Syllabus outcome

Identify the syllabus outcome you will be investigating and write a summary of the outcome.

Syllabus statement: *Demonstrating quantum mechanics with the assistance of models*

Hypothesis (if applicable)

A hypothesis is an educated (informed) guess that is tested through investigation to explain and reach answers to scientific questions.

Aim

Write the aim as a sentence. Start the sentence with 'To' followed by a verb; for example, 'investigate', 'measure' or 'test'.

5.6.1 Quantum mechanics 101

5.6.2 Making sense of a visible quantum object

Secondary sources

List all of the sources that you are using in your investigation and cite them using the correct citation protocols.

- Quantum mechanics 101
- Making sense of a visible quantum object

Investigation design

Outline how you are designing the final presentation (refer to Chapter 2 for further information).

Method

The method is written as numbered steps. Each sentence must start with a verb.

Results

The results may be recorded in tables, graphs or diagrams, or written as observations in sentence form.

Validity and reliability

Remember that validity is related to ensuring that the sources come from educational, government, university or scientific web pages, journals and textbooks. Reliability is associated with finding similar explanations of the concepts across many sources.

Discussion and conclusion

In the discussion and conclusion, analyse your findings to answer your hypothesis, aim and inquiry question/s.

9780170411196

EVALUATING A SCIENTIFIC MODEL

Suggested length: 10–15 hours including research and submission of model and report

Focus: Analysis of scientific models, report

WS
5.7.1 Secondary investigation scaffold

SECONDARY-SOURCED INVESTIGATION SCAFFOLD

Syllabus outcome

Identify the syllabus outcome you will be investigating and write a summary of the outcome.

Syllabus statement: *Investigate a chosen scientific model, assess its effectiveness and suggest ways to improve that model.*

Hypothesis (if applicable)

A hypothesis is an educated (informed) guess that is tested through investigation to explain and reach answers to scientific questions.

Aim

Write the aim as a sentence. Start the sentence with 'To' followed by a verb; for example, 'investigate', 'measure' or 'test'.

Secondary sources

List all of the sources that you are using in your investigation and cite them using the correct citation protocols.

Investigation design

Outline how you are designing the final presentation (refer to Chapter 2 for further information).

Method

The method is written as numbered steps. Each sentence must start with a verb.

Results

The results may be recorded in tables, graphs or diagrams, or written as observations in sentence form.

Validity and reliability

Remember that validity is related to ensuring that the sources come from educational, government, university or scientific web pages, journals and textbooks. Reliability is associated with finding similar explanations of the concepts across many sources.

Discussion and conclusion

In the discussion and conclusion, analyse your findings to answer your hypothesis, aim and inquiry question/s.

6

MODULE 4 THEORIES AND LAWS

Scientific theories and laws result from scientific research based on testing hypotheses, collecting a substantial amount of data, analysing results and drawing final conclusions. Those are the steps of the scientific method. The development and testing of scientific theories and laws is what drives science to reach new breakthroughs, and to create and improve technologies in all branches of sciences. Consequently, the most important outcome from the progress and advances in science is that theories and laws are applied to improve the wellbeing of the entire society.

INQUIRY QUESTIONS

- Why is the theory of plate tectonics not a law?
- Why is the law of conservation of mass not a theory?
- What are the differences and similarities between theories and laws?
- What is the purpose of a theory in science?
- Why are theories disproved over time?

CONTENT

Students investigate:

- introduction to scientific laws and theories
- development of a theory
- development of laws
- application of laws and theories in science

OUTCOMES

A student:

- analyses and evaluates primary and secondary data and information INS11/12-5
- solves scientific problems using primary and secondary data, critical thinking skills and scientific processes INS11/12-6
- communicates scientific understanding using suitable language and terminology for a specific audience or purpose INS11/12-7
- describes and assesses how scientific explanations, laws and theories have developed INS11-11

9780170411196

Getty Images / SueBurtonPhotography

9780170411196

6.1 Introduction to scientific theories and laws

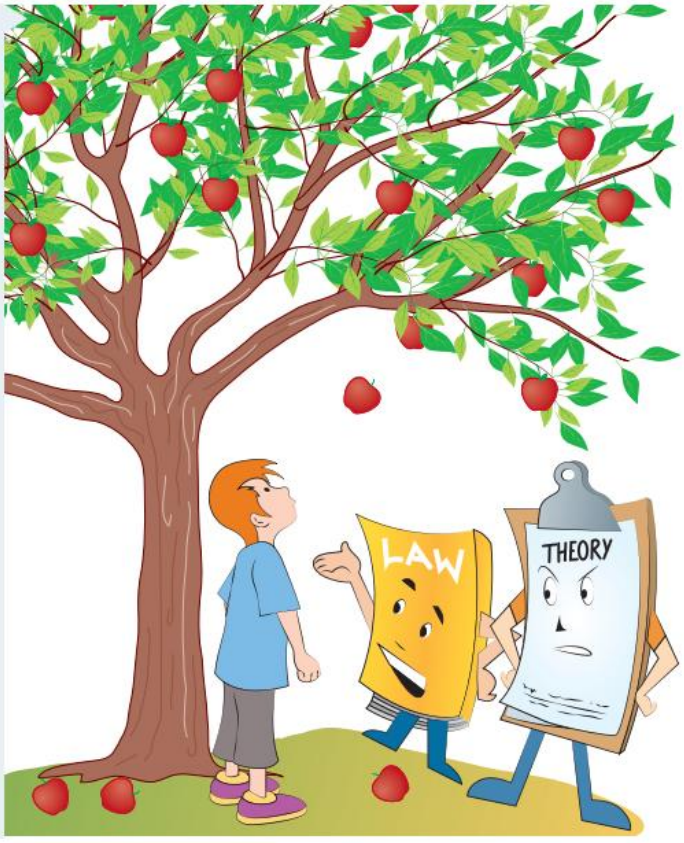


FIGURE 6.1.1 A cartoonist's interpretation about the differences between theories and laws. Laws are descriptions about phenomena but theories explain why those phenomena happen.

Look, kid, *I* don't know why. Ask *him* to explain it!

6.1.1 What is the difference between a scientific law and theory?

INQUIRING FURTHER

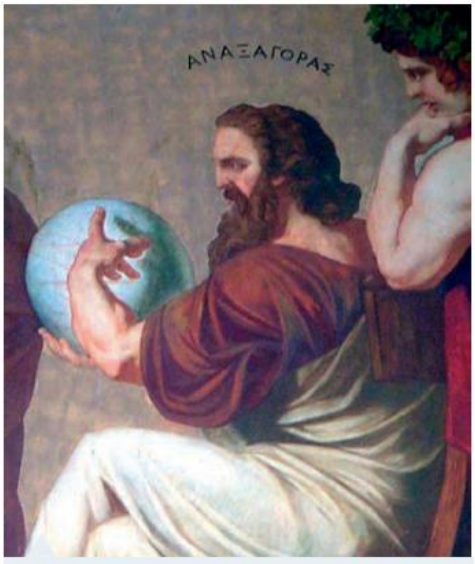
Over the centuries many philosophers contributed to advances in science and many of their ideas influenced society for many year to come.

Some influential ancient philosophers were Aristotle, Plato, Pythagoras, Socrates and Descartes.

Research their lives, and identify and analyse the impact that their ideas had on the advance of science.

The beginning of the development of theories and laws

At the beginning of the development of science, philosophers, as scientists were called many centuries ago, were trying to answer the 'what' and the 'why' associated with situations and events (phenomena) that were happening in the world they observed. The first written observations of phenomena date from ancient Babylonian tablets (20–16th century BCE) and tried to explain the movement of the planets. In the 5th century BCE the philosopher Anaxagoras stated his idea of the molecular theory of matter. Whilst the ideas behind those terms were implicitly in the mind of the first philosophers, the terms theory and law were not used.



Alamy Stock Photo / ART Collection

FIGURE 6.1.2 Anaxagoras (500–428 BCE) is credited as being the first to describe the idea of the molecular theory of matter.

philosopher person who studies all the truths related to knowledge

theory explanation of why phenomena happen

law description, usually expressed as a mathematical relationship, of what happens in a phenomenon

9780170411196

Defining theory and laws

Both theories and laws are conclusions based on a large amount of collected experimental data and observations over a long period of time. Theories provide a coherent understanding of phenomena. This means that a theory is an explanation of why phenomena happen and allows predictions to be made. Examples of theories are: theory of evolution, theory of plate tectonics and the Big Bang theory. Each of these theories explains the processes that occur in phenomena.

A law is a statement, usually expressed as a mathematical relationship, about what happens in phenomena. Laws are descriptions of how things work in the natural world. Examples of laws are: the law of conservation of mass, the law of conservation of energy and Newton's laws of motion. Each of these laws describes what happens with energy, **mass** or the motion of objects, but they do not try to explain why those phenomena happen.

mass
amount of matter in a solid, liquid or gas

Law of conservation of mass

The law of conservation of mass was developed by Antoine Laurent Lavoisier (1743–94) in 1785.

In the 18th century there was a theory that **phlogiston** existed in all combustible bodies and that it was released when a **compound** was burned. Lavoisier was conducting experiments by burning phosphorus and sulfur, both of which burned readily, in closed vessels. Lavoisier showed that they gained weight by combining with air. With lead **calx** (lead oxide is formed when heated), he was able to capture a large amount of air that was liberated when the calx was heated. Lavoisier did not believe that these results were explained by phlogiston. In 1783, he presented his paper titled *Reflection on Phlogiston* to the Academy of Science, attacking the phlogiston theory of **combustion**. His experiments showed that water was not an **element** and that matter can change states in chemical reactions. Lavoisier's experiments and meticulous collection of quantitative data led to the formulation of the law of conservation of mass.

phlogiston
chemical that was thought to be released during combustion prior to the discovery of oxygen

compound
substance that is made of more than one element

calx
oxide that remains after a substance has been burned or gone through combustion

combustion
rapid chemical combination of a substance with oxygen

element
substance that cannot be separated into smaller substance by chemical means

Lavoisier wrote:

'Nothing is created, either in the operations of art or in those of nature, and it may be considered as a general principle that in every operation there exists an equal quantity of matter before and after the operation; that the quality and quantity of the constituents is the same, and that what happens is only changes, modifications.'

In other words, the law states that in any chemical reaction the mass of the reactants is equal to the mass of the products of the reaction. Consequently, no matter is created or destroyed: the elements are re-arranged to form new compounds.

FIGURE. 6.1.3
Lavoisier developed his law of conservation of mass in this laboratory, which is now displayed at the Musée des Arts et Métiers in Paris.

Alamy Stock Photo/Hemis

KEY LAW

Law of conservation of mass

The law of conservation of mass states that the mass of the reactants and the mass of products in a chemical reaction are equal. This refers to matter not being destroyed or created.

WORKED EXAMPLE 6.1.1

In the formation of water two hydrogen atoms combine with one atom of oxygen. Figure 6.1.4 shows that the mass of the reactant atoms is equal to the mass of the products. In many experiments performed in the laboratory the masses of products and reactants do not match up exactly. This imbalance is related to the formation of gas that it is difficult to capture in laboratories where not all the conditions of the experiment can be controlled.

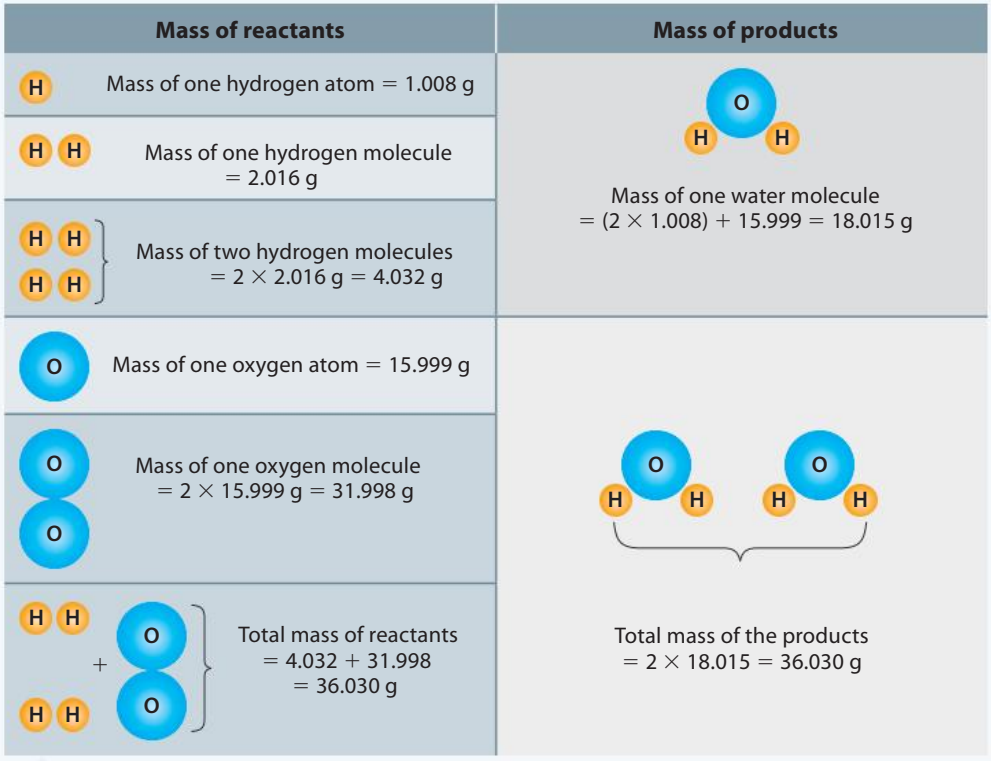


FIGURE 6.1.4 The mass of products and reactants in the formation of water.

6.1.1 Introduction to scientific theories and laws

In relation to worked example 6.1.1, the law of conservation of mass describes how the oxygen and hydrogen atoms reacted in a chemical reaction and that they formed a new product, water, but the law does not explain why or how those atoms reacted with each other. The atomic theory explains the why behind those reactions at atomic level.

6.1.2 The law of conservation of mass

6.1.3 The chemical revolution of Lavoisier

INQUIRING FURTHER

Lavoisier was executed during the French Revolution. Conduct a secondary investigation into the reasons for his execution and discuss the ethics behind these reasons.

INQUIRING FURTHER

Ancient societies were hierarchical and only a small group of people were literate and therefore able to participate in the development of scientific ideas. The majority of the ancient philosophers were men; women were not considered part of the scientific community. The role of women in science has changed since those days.

Discuss this statement using research and evidence to support your conclusions.

9780170411196

INVESTIGATION 6.1.1

Law of conservation of mass

AIM

To investigate the law of conservation of mass

MATERIALS

- test tube
- 50 mL beaker
- electronic balance
- water balloon
- 10 mL acetic acid (vinegar)
- sodium bicarbonate

HAZARD	MANAGEMENT
Splash vinegar or sodium bicarbonate on eyes	Wear eye protection (goggles)
Broken glass	Advise the teacher to clean it

RISK ASSESSMENT

METHOD

1. Place the test tube inside the beaker.
2. Tare the electronic balance and weigh the test tube and beaker. Record this in your table.
3. Add 10 mL of vinegar to the test tube and weigh the test tube with the vinegar and beaker. Record the weight.
4. Remove equipment from the balance.
5. Weigh the small water balloon and record the weight.
6. Add sodium bicarbonate inside the balloon and weigh it. Record this weight.
7. Carefully place the balloon with the sodium bicarbonate on top of the test tube and allow the sodium bicarbonate to drop inside the vinegar.
8. Hold the balloon with your hands to avoid it coming off the test tube.
9. Observe the reaction.
10. Once the reaction has slowed down, place the equipment back onto the electronic balance and record the weight.
11. Calculate the total mass as a weight of reactants and products using the formula in Table 6.1.1.
12. Collect data from other students in the classroom and calculate the average. This will ensure reliability in the data.

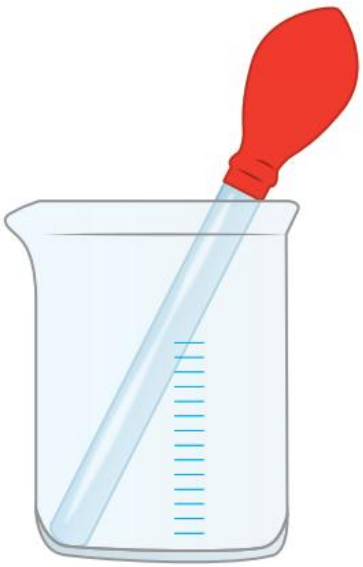


FIGURE 6.1.5 Experimental set-up

RESULTS

Copy and complete Table 6.1.1 to record your results.

TABLE 6.1.1 Calculation for the mass of reactants and products in the chemical reaction between sodium bicarbonate and vinegar.

STEPS TO CALCULATE THE MASS OF REACTANTS AND PRODUCTS	WEIGHT (g)
Mass of reactants	
Test tube + beaker	
Test tube + beaker + vinegar	
Final mass for Reactant 1: vinegar (Test tube + beaker) – (Test tube + beaker + vinegar)	
Balloon	
Balloon + sodium bicarbonate	
Final mass for Reactant 2: bicarbonate (balloon) – (balloon + sodium bicarbonate)	
Final mass for reactants Reactant 1 + Reactant 2	
Mass of products	
Test tube + beaker + vinegar + balloon + sodium bicarbonate	
Final mass of products (mass of products – total mass of reactants)	

1. Copy and complete the word equation:
   acetic acid + sodium bicarbonate → sodium acetate + _____ + _____
2. Repeat the previous equation using the mass of the chemicals:
   Total reactants _____ (g) → Total products _____ (g)
3. Identify whether the mass of the reactants was conserved in comparison to the mass of the products.
4. Describe any differences or similarities between the mass of the products with the mass of the reactants.
5. Outline evidence that supports the law of conservation of mass from the experiment.

DISCUSSION

1. State how you know that a chemical reaction has occurred.
2. Explain the reliability and accuracy of the experiment.
3. Discuss why this experiment reflects a law and not a theory.
4. Describe how you could improve this experiment.

hypothesis
educated guess tested through experimentation to answer the inquiry question; states the relationship between the independent and dependent variables

Pangaea
from the Greek 'pan' meaning all and 'gaea' meaning Earth; therefore, 'all of the Earth'

Theory of plate tectonics

Early observations

In the 16th century, cartographers (map makers) had observed that the shorelines of the continents appear to 'fit' together. The cartographers could not explain the phenomenon and they didn't have any ideas as to how to collect evidence to support their hypothesis. In 1912, Alfred Wegener proposed that the continents were once connected to form a bigger mass called Pangaea. According to his theory, this supercontinent started to drift apart during the Triassic–Jurassic time periods (250–150 million years ago). Wegener's theory was not well accepted among the geologists of his time because he could not explain the forces that were acting on the continents to force them to drift apart.

9780170411196

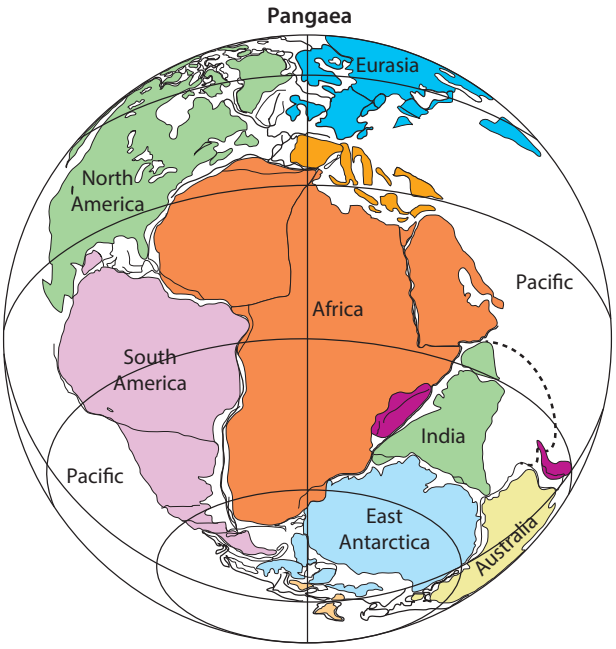


FIGURE 6.1.6 Alfred Wegener hypothesised that the continents once fitted together to form a supercontinent called Pangaea.

INQUIRING FURTHER

Research Alfred Wegener's expeditions to Greenland and the influence that those trips had on the development of his ideas about continental drift. Present your research in a PowerPoint or Prezi.

Evidence

The theory of plate tectonics was formed by collecting evidence over many years. Scientists used a range of technologies, from simple experiments in the laboratory to satellite images. This evidence supported the theory that the continents had drifted apart, and were continuing to drift apart. Continental drift is driven by the convection currents of the mantle and new crust that is formed in **ocean ridges** around the world.

Geological evidence

- Convection currents in the mantle are the forces driving continental drift.
- By mapping the ocean floor, the Earth's crust can be seen to form and spread out laterally along mid-ocean ridges.
- Rocks closer to the mid-ocean ridges are younger than rocks found further away.
- Patterns of **magnetic stripes** in the newly formed crust follow the geomagnetic field of the planet.
- Earthquakes and volcanic activity are more active at the edges of the tectonic plates.
- Specific glacial deposits are common across the continents.

Biological evidence

- Common **fossils** are found across the supercontinents, **Gondwana** and **Laurasia**. For example, in Gondwana, the reptile *Mesosaurus* and some brachiopods were present in what is now South America, Africa and India.
- The flora and fauna of two the main supercontinents that drifted apart after Pangaea, Laurasia to the North and Gondwana to the South, have common ancestors in the evolutionary tree.
- Common flora fossils between Africa, South America and Australia, for example, *Glossopteris spp.*
- Common ancestors in the evolution of marsupials between the Gondwana continents.

The theory of plate tectonics is considered a theory because it explains the processes, using evidence, of how and why the continents drift toward or away from each other over millions of years.

ocean ridge
underwater mountain system formed by plate tectonics

magnetic stripe
area of newly formed crust that aligns with the magnetic field of the planet

fossil
remains or impression of a prehistoric plant or animal preserved in petrified form

Gondwana
supercontinent thought to have existed in the southern hemisphere after the Mesozoic era, now Australia, South America, Africa, Antarctica and India

Laurasia
supercontinent thought to have existed in the northern hemisphere, now North America, Greenland, Europe and Asia

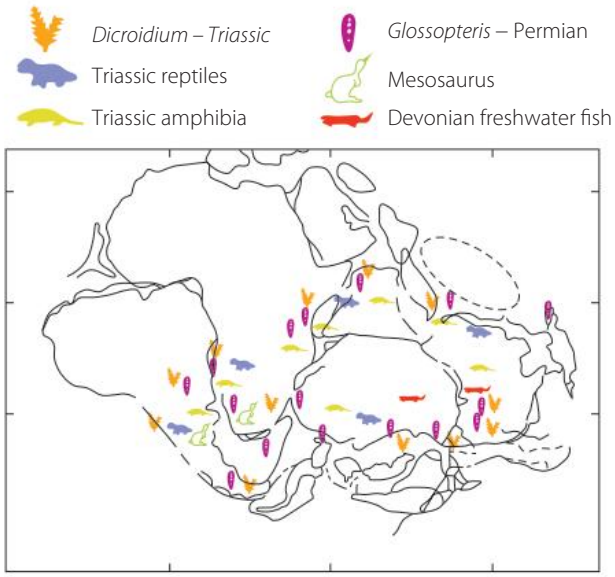


FIGURE 6.1.7 Map of common fossils across the Gondwana continent. Common fossils are used as biological evidence to support the theory of plate tectonics.

6.1.4 Evidence of plate tectonics
6.1.5 The Pangaea pop-up

INVESTIGATION 6.1.2

The theory of plate tectonics

AIM

To gather evidence to support the theory of plate tectonics using secondary sources

MATERIALS

- world map to cut out
- textbooks that contain information on plate tectonics
- Internet to research further secondary sources

METHOD

1. Gather a copy of the world map.
2. Cut out all the major continents and match them up as pieces of a puzzle to form the supercontinent Pangaea.
3. Separate your Pangaea continent into the two supercontinents: Laurasia to the north and Gondwana to the south.
4. Paste your continents in your science book.
5. Using the Internet and other resources answer the questions below to collect evidence for the theory of plate tectonics.

9780170411196

» DISCUSSION

1 Outline and explain the issues that you encountered when matching the continents to create Pangaea.
2 Describe what scientists believed about the Earth's crust before the theory of plate tectonics.
3 Describe the geological and biological evidence that supports the theory of plate tectonics.
4 Explain why it took a long time to collect evidence for the theory of plate tectonics.
5 Describe the technologies that helped scientists to collect evidence.
6 Analyse whether it was only Wegener's idea of continental drift, plate boundaries, sea-floor spreading or a combination of all of these theories that led to the development of the theory of plate tectonics.
7 Analyse what the theory of plate tectonics says about the movement of continents over time.
8 Seashells have been found in the middle of the Australian continent and on top of Mount Everest. What is the most likely explanation for this occurrence?
9 Evaluate why the theory of plate tectonics is not a law.
10 Cite all of the secondary sources you have used to answer these questions (e.g. web pages, textbooks).
11 Analyse the validity and reliability of the secondary sources used for this investigation.

Comparing the characteristics of theories and laws

Theories and laws have many aspects in common. They both start from the formulation of a hypothesis, both involve the process of making **inferences** and predictions, both involve the collection of a large amount of data and evidence, and both reach conclusions about a phenomenon. While both theories and laws follow the scientific method, differences exist between the two that often lead to confusion and misconceptions. Theories explain why phenomena happen. For example, why living things evolve, why all living things are made of cells or why continents drift. Laws state what is happening after making observations and reaching conclusions. For example, using the law of conservation of mass, the mass of the reactants is always equal to the mass of the products in the chemical reaction. In addition, according to Newton's second law where force is proportional to the mass and acceleration of an object, it does not matter what the size of the object is or its acceleration, the force will be always proportional.

inference
conclusion that is rationally and logically made based on observations and available information

Theories are not more important than laws nor are laws more important than theories; both have different roles to play in the understanding and application of knowledge. Neither theories nor laws dictate what 'must be' in science because theories and laws do not denote dogma; in other words, current theories and laws do not stop scientists from developing new ones. In fact, theories and laws are in constant validation due to new ideas, hypotheses, data sets and technological advances, all of which play an important role in clarifying how theories and laws explain phenomena in our world.

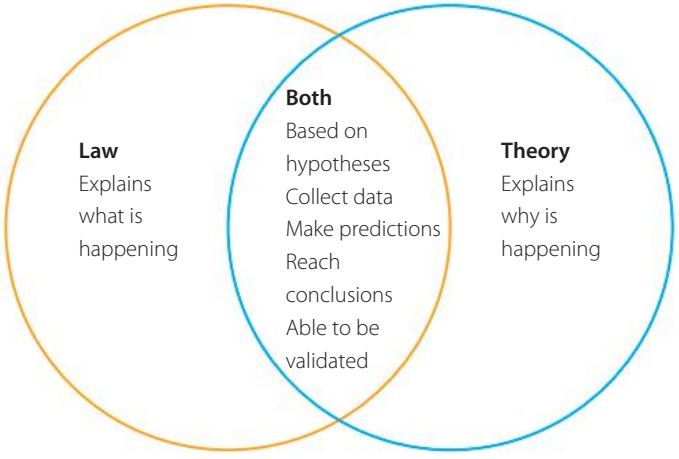


FIGURE 6.1.8 The similarities and differences between a theory and a law.

SECTION REVIEW 6.1

REMEMBERING

1 Define 'theory' and 'law'.
2 Define the law of conservation of mass.
3 Define the theory of plate tectonics.

UNDERSTANDING

4 Explain the differences and similarities between a theory and a law.
5 Discuss why the law of conservation of mass is a law and why the theory of plate tectonics is a theory.

APPLYING

6 Assess the validity of the collection of evidence for the law of conservation of mass and the theory of plate tectonics.
7 Name a law or theory that is currently being tested and identify the technology, or technologies, that are being used to validate this law or theory.

6.2 The development of a theory

A theory is based in concepts and principles. Concepts are symbolic representations of objects or how something works; for example, movement, a tree, a car or a computer. Principles explain the relationships between those concepts; for instance, the movement of the car. Therefore, concepts and principles help to understand and explain what is going on in the world around us and in many cases predict future events. In science, theories are constantly revised as new knowledge is discovered through research, and new technologies provide new data and evidence to prove or disprove the theory.

Stages in the development of a theory

The development of a theory follows four stages.

1 Speculative stage

The speculative stage attempts to explain the event or phenomena. The process starts with a question about the event. For example, observe Figure 6.2.1 and think how many times you sit under the stars and wonder about the vastness of the universe. It seems that the stars are moving or some of them 'turn off' and you might question yourself about it: is the universe finite or does it go on forever? Imagine if you saw an article in the newspaper or on the television about an earthquake showing the consequences for the people living in those areas. Again, you might think about what forces are driving this natural event? What is happening underneath the continents to cause the tremors? To answer these questions, hypotheses and inferences are developed, which can then lead to the development of a theory.


iStock.com/den-belitsky


Shutterstock.com/think4photop

FIGURE 6.2.1 Observe the photographs and write down as many questions as you can about the two phenomena pictured.

9780170411196

2 Descriptive stage

During the descriptive stage data is collected to gather evidence to support the hypothesis. In Chapter 1 the differences between the types of data that can be collected is explained. Data can be qualitative (collection of observations or non-measurable data) or quantitative (measurable data). The amount of data collected must be from a representative sample. To be representative, a sample may need to include hundreds, or even thousands, of data points.

3 Constructive stage

At this point, the gathered data is analysed and compared to previous theories. This is an important part of the development of the final theory. Statistical analysis of the data will show the significance of the differences between the observations and results. Once the analysis is completed, the theory statements are formulated to answer the hypothesis and explain the concept and principles around the phenomena.

4 Validation stage

Once the theory is constructed, other scientists may start performing their own experiments, making new calculations and collecting additional data from different situations. During this process, the theory is being validated and sometimes the new evidence might disprove the original theory and replace it with a new one.

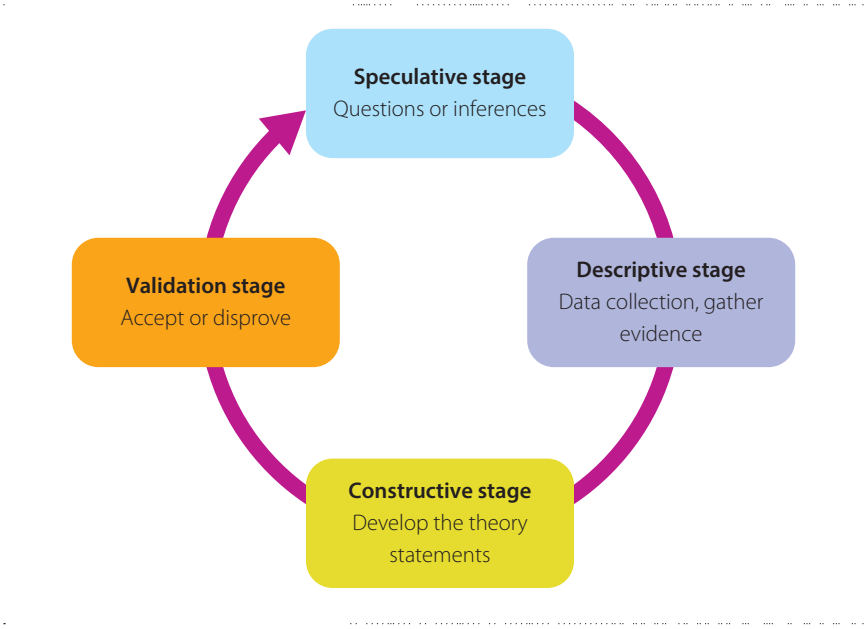


FIGURE 6.2.2 Steps in the development of a theory, from first pondering the questions to the validation by other scientists.

INQUIRING FURTHER

Many scientific theories have been developed over a long time. Think about some theories that have been created after a large amount of data has been collected over many years. Discuss why it took so long to collect data and validate the hypothesis.

anthrax
bacterial disease, originally from sheep and cows, that affects the skin and lungs

germ theory
theory that infectious diseases are caused by the presence and actions of specific micro-organisms

The germ theory

Since the first use of a microscope by Antonie van Leeuwenhoek in 1677, scientists have been observing germs on different surfaces and in different organisms, including in human blood. Early scientific research did not conclude that germs were the cause of disease; rather scientists thought that the germs were an effect of the disease. At the end of the 19th century Louis Pasteur's research on anthrax and Robert Koch's creation of postulates helped in the development and acceptance of germ theory in the scientific

6.2.1 The germ theory

gene
sequence of DNA considered the unit of heredity, as it is transferred to the next generation

community. Today, many microbiologists use Koch's postulates as a guide for examining diseases from their molecular point of view and encoding the gene responsible for the virulence factor. Pasteur and Koch's work changed the way that diseases were researched, as well as accelerated the research, with an aim to develop treatments and cures.

6.2.2 The history of vaccines: Koch's postulates

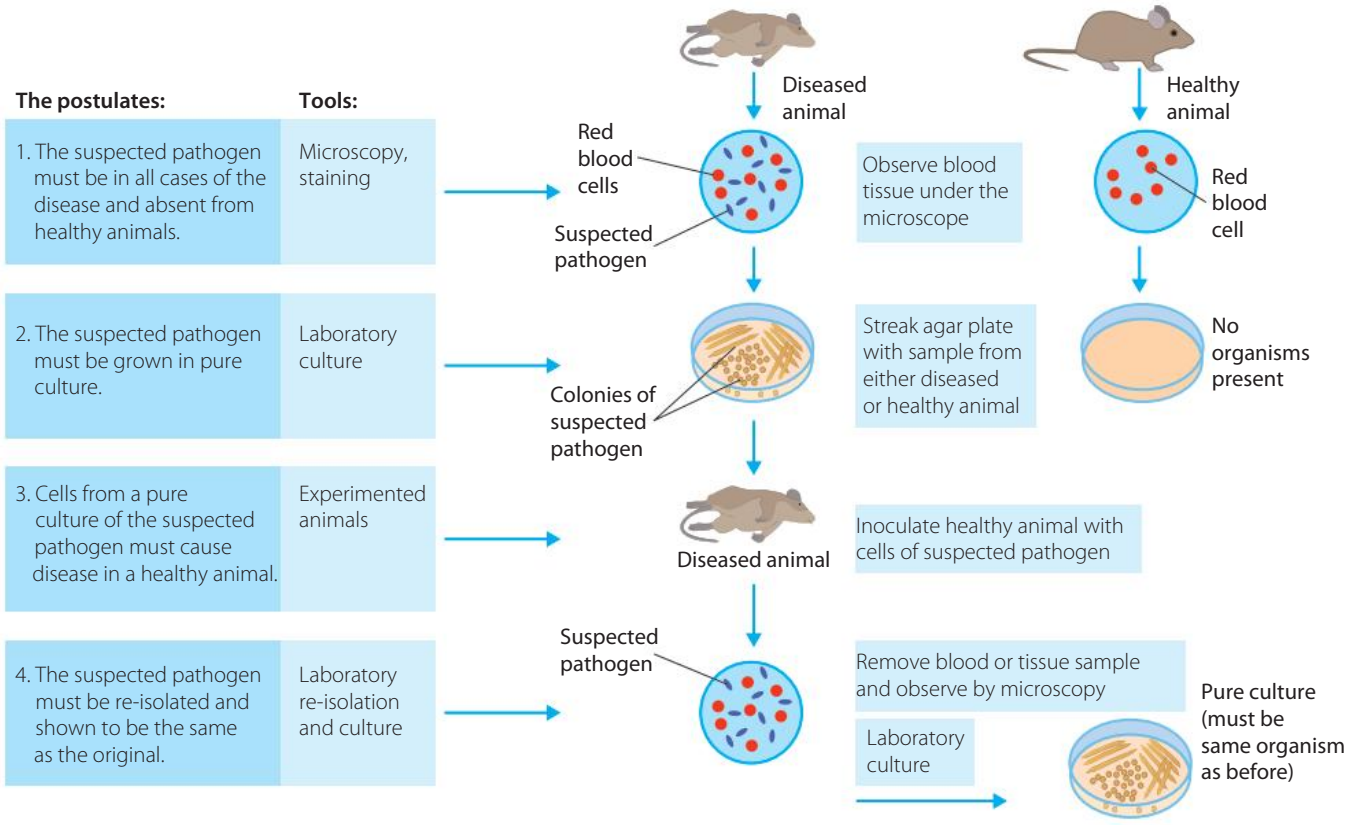


FIGURE 6.2.3 Koch's postulates are four sequential steps to isolate and identify the pathogen that causes a specific disease.

Oxygen theory of combustion

At the beginning of the 18th century, the German scientist Georg Stahl developed the concept of phlogiston, a component that every flammable substance possessed. The measurement of phlogiston in a substance was related to how much residue was left after the substance was burned. Lavoisier challenged the phlogiston theory and began to gather qualitative and quantitative data by precise weighing and meticulous observations. Lavoisier suggested that oxygen was the key element in the chemical reaction of combustion and his experiments led to the formulation of the oxygen theory of combustion.

9780170411196

INVESTIGATION 6.2.1

The development of the germ theory and the oxygen theory of combustion

METHOD

Copy and complete Table 6.2.1 by gathering secondary-sourced data on how the germ theory and the oxygen theory of combustion were developed and accepted as valid theories.

TABLE 6.2.1 Comparing germ theory and the oxygen theory of combustion.

THE GERM THEORY			
	Your answers	Theory developmental stage	List of valid sources
Briefly state the germ theory.			
Timeline of the development of the theory			
Explain the type of data collected as evidence (qualitative, quantitative or both).			
List evidence supporting the theory. Include diagrams if necessary.			
Explain how the development of technologies, such as the microscope and tissue culture, helped in collecting evidence.			
Discuss if the theory is fully accepted today.			
Describe what concepts in the theory are still unanswered (if any).			
THE OXYGEN THEORY OF COMBUSTION			
	Your answers	Theory developmental stage	List of valid sources
Briefly state the oxygen theory of combustion.			
Timeline of the development of the theory			
Explain the type of data collected as evidence (qualitative, quantitative or both).			
List evidence supporting the theory. Include diagrams if necessary.			
Explain how the development of technologies has helped in collecting evidence.			
Discuss if the theory is fully accepted today.			
Describe what concepts in the theory are still unanswered (if any).			

Disproving theories

As new data is collected and new technologies are emerging to improve the analysis and the understanding of phenomena, many theories have been disproved. Some theories were disproved entirely, like the geocentric model of the Solar System. Sometimes only parts of a theory might be disproved; for example, the theory of inherited acquired characteristics.

Disproved theories over time: Geocentric model of the Solar System

The geocentric model of the Solar System was developed by Aristotle in 400 BCE and remained the accepted model for more than 1000 years. It wasn't until 1474 that two astronomers named Peurbach and Regiomontanus started the task of locating the errors in Aristotle's and Ptolemy's work. However, it was Copernicus in 1514, who published an early version of his heliocentric view of the Solar System in a manuscript entitled *Commentariolus* (*Little Commentary*). His major work was published 39 years later, *De revolutionibus orbium coelestium* (*On the Revolutions of the Heavenly Spheres),* and contained the radical idea that the Sun was the centre of the Solar System.

Copernicus' new statements to disprove the geocentric model were based on mathematical calculations, and included:

- the Sun is the centre of the Solar System not the Earth
- the Earth spins on its axis
- planets move in perfect circles around the Sun
- simple explanation about the retrograde motion of the planets (the Earth passes other planets once a year).

6.2.3 Geocentric and heliocentric systems

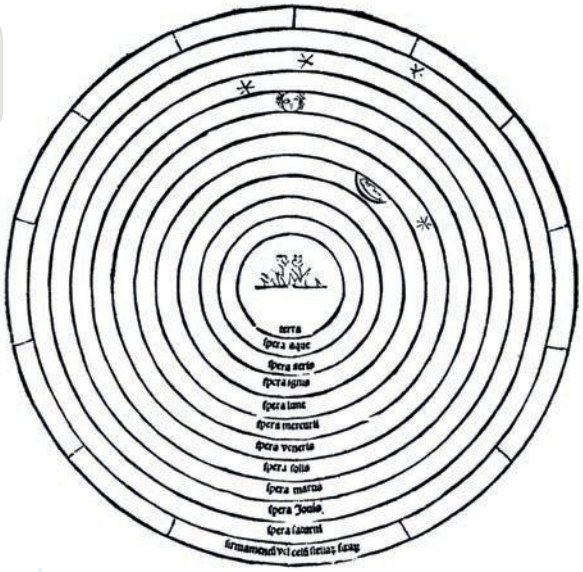


FIGURE 6.2.4 Ptolemy's geocentric model of the Solar System.

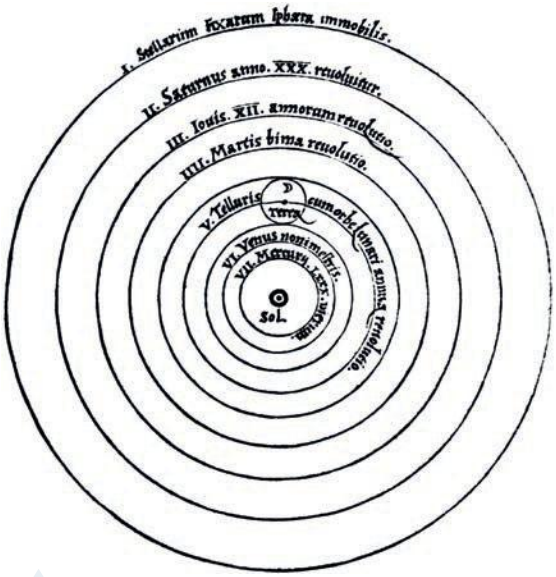


FIGURE 6.2.5 Copernicus' heliocentric model of the Solar System.

9780170411196

While ground-breaking, Copernicus' ideas were not perfect. It took another 50–100 years to disprove the geocentric model completely and develop a new valid heliocentric model. The research of Tycho, Galileo and Kepler were pivotal in improving Copernicus' model. Through extensive observation and calculations, these scientists collected enough evidence to prove the hypothesis of the heliocentric model and refine it.

The following describes some of the new evidence collected by Tycho, Galileo and Kepler.

- The planets move in elliptical orbits around the Sun as a focus, not the centre.
- The planet Venus showed phases similar to those of the Moon.
- The shapes of the Moon and the Sun were not perfect spheres.

INQUIRING FURTHER

Copernicus, Galileo and Kepler knew that their ideas were against the beliefs of society at the time. Research the different approaches that those scientists took to avoid the death penalty due to heresy. Present your research as a scientist profile article.

6.2.4 Copernicus, Kepler, Galileo

INVESTIGATION 6.2.2

Collecting data and evidence using Tycho's invention

AIM

To collect data using Tycho's invention, the sextant

MATERIALS

- straw
- protractor
- tape
- string
- paper clips or washer
- pictures of celestial objects
- compass

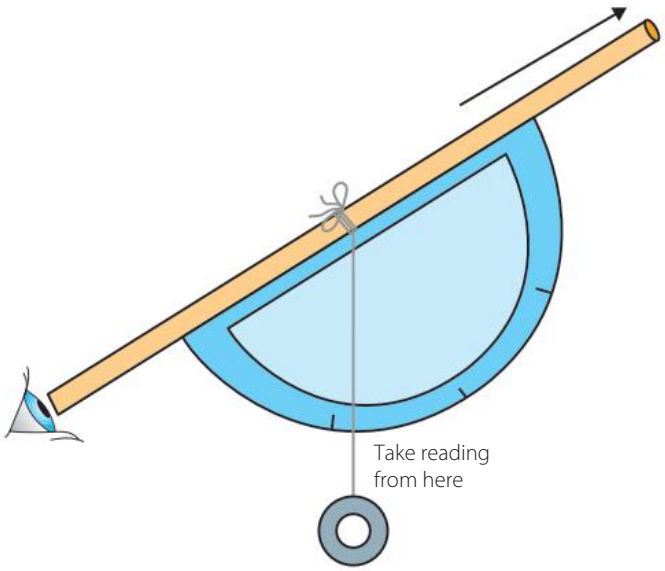


FIGURE 6.2.6 Diagram of the sextant set-up.

METHOD

1. Tie a washer or paper clips to one end of the string. Tape the string to the midpoint of the protractor (90°). The string is called a plumb line.
2. Tape the protractor to the straw as shown in Figure 6.2.6.
3. Place the pictures of different celestial objects high on a wall in the classroom.
4. Sight the celestial object by placing your eye at one end of the straw. The protractor will be upside down and the plumb line will hang down.
5. Work with a partner to determine where the plumb line falls on the protractor.
6. Read the inner set of numbers on the protractor (0° to 90°), and record this number on your data sheet. This is the zenith angle.
7. Calculate the object's altitude angle (or height in degrees) by subtracting the angle measured from 90°.
8. Move the celestial objects slightly to the west and repeat your measurements.

RESULTS

Copy and complete the table below with your data.

CELESTIAL OBJECT		
Positions	Zenith angle	Altitude angle (Zenith angle – 90° – zenith angle)

DISCUSSION

1. Explain what the change in position of the celestial object in one night, days or weeks indicates.
2. Compare your data with others, and discuss the trends and patterns in your results.
3. As a conclusion, discuss the type of evidence collected in this experiment and how it supports the hypothesis of a heliocentric model of the Solar System.

Disproved theories over time: The theory of inherited acquired characteristics and the subsequent development of the theory of evolution

Throughout the Middle Ages, one predominant feature of the European world was the thought that all aspects of nature, including all forms of life and their relationships to one another, never changed. This view was partly shaped by a feudal society that was itself a hierarchical, rigid class system that hadn't changed significantly for centuries. It was also influenced by an extremely powerful religious system, and the teachings of the Church were taken literally. Consequently, it was generally accepted that all life on Earth had been created by God exactly as it exists in the present, and the belief that life forms couldn't change came to be known as **fixity of species**.

fixity of species
notion that species, once created, can never change; an idea diametrically opposed to theories of biological evolution

species
group of living organisms with similar characteristics that can interbreed

adaptation
process of change over time by which an organism or species becomes better suited to its environment

At the end of the 18th century, Jean-Baptiste Lamarck attempted to explain the evolutionary process of living things. He suggested that the relationship between **species** and the environment was dynamic; this means if the external environment changed, an animal's physical appearance would also change to accommodate the new environmental conditions. According to Lamarck, those physical changes would occur in response to 'needs', so that if a particular part of the body needed to change, 'fluids and forces' would be directed to that point and the structure would be modified. Consequently, the animal would be better suited to its habitat and the new trait would be passed on to its offspring. This theory is known as the inheritance of acquired characteristics, or the use and disuse theory.

KEY THEORY

The theory of the inheritance of acquired characteristics is based on the idea that **adaptations** in animals occur as the animal needs them during its lifetime. The animal then becomes well adapted to its environment and the new traits are passed on to their offspring.

9780170411196

Late in the 19th century, the evidence to disprove Lamarck's theory of acquired characteristics was based on a collection of qualitative data, drawings and written observations by Charles Darwin and Alfred Wallace. Independently, Darwin and Wallace recognised that animals do not acquire new adaptations or **traits** during their lifetime. Environmental changes create a **selection pressure** on individuals which compete for resources (e.g. food, shelter, mating). Individuals with favourable characteristics survive and pass those traits on to the offspring. Therefore, those animals will have both increased fitness and higher reproductive success. Thus, over time, advantageous traits accumulate in a population (because they have been selected for) while disadvantageous ones are eliminated (selected against). This is a simple summary of the theory of evolution by means of natural selection, published in Darwin's famous book *On the Origin of Species* (1859).

trait
physical or chemical characteristic that is genetically determined

selective pressure
change in the environment that causes organisms to adapt to that change with the aim to survive

KEY THEORY

The theory of evolution by natural selection states that individuals within a species that have favourable traits are able to respond to changes in the environment. Therefore, they survive the selective environmental pressure, reproduce and pass on those traits and adaptations to the offspring.

The two theories can be compared using a hypothetical example, such as with the giraffes shown in Figure 6.2.7. According to Lamarck's theory of acquired characteristics a giraffe that tries to reach leaves on upper branches will have 'vital forces' moving to the tissues of the neck. The neck then becomes slightly longer and the giraffe can reach the higher branches. The trait of longer neck is then passed on to the offspring, with the eventual result that all giraffes have longer necks than their predecessors. On the other hand, the Darwin-Wallace theory of evolution by the means of natural selection states that there is variation in neck length among giraffes. Giraffes with longer necks have advantages for feeding, and they are able to survive and reproduce. The favourable trait for a longer neck is then passed on to the offspring, leading to an overall increase in the length of giraffe necks over many generations.

6.2.5 Fixity of species

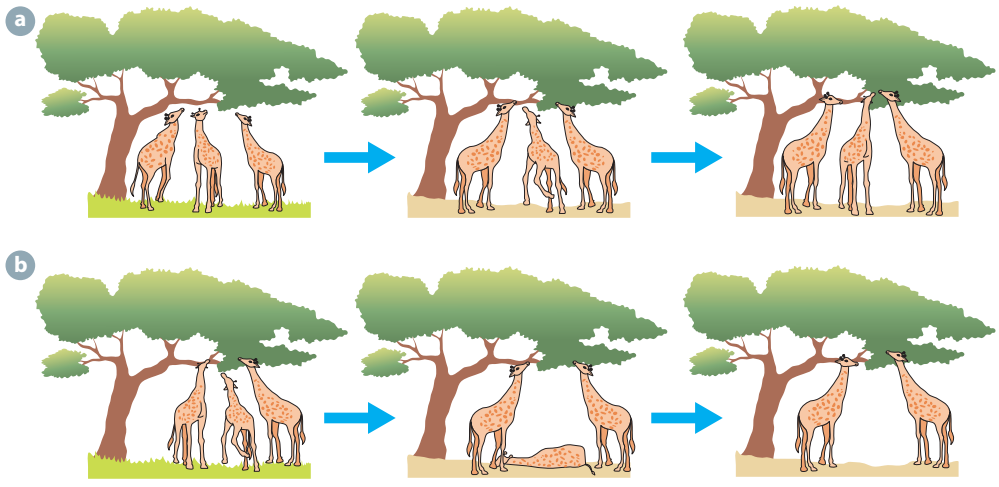


FIGURE 6.2.7
Contrasting ideas about the mechanism of evolution.
(a) Lamarck's theory holds that acquired characteristics in an animal's lifetime can be passed to subsequent generations.
(b) The Darwin-Wallace theory of evolution by natural selection states that there is a variation within the species, and those individuals with favourable traits will survive, reproduce and pass on the traits to the offspring.

Disproved theories over time: Dalton's atomic theory

Scientists have tried to explain the structure of matter since ancient times. However, it was only during the late 19th and 20th centuries that, with the help of technological advances to collect quantitative experimental data, the structure of matter at particle level was understood.

INQUIRING FURTHER

Investigate the ancient view of the particle theory of matter. Discuss how this theory of matter relates to current atomic theory.

John Dalton (1766–1844) was an English chemist and physicist who developed the atomic theory. He stated that:

1. Elements are made of small particles called **atoms**.
2. Atoms of each element are identical in mass, size and chemical properties.
3. Atoms cannot be divided, created or destroyed.
4. Atoms of different elements combine in whole-number ratios.
5. In chemical reactions, atoms are rearranged.

atom
from the Greek word 'atomos' meaning cannot be divided

electron
negatively charged particle in the atom spinning around the energy shells of the atomic nucleus

alpha particle
helium nucleus emitted by radioactive substances

However, in 1904, J. J. Thomson disproved part of Dalton's atomic theory when he discovered the **electron**, which he called corpuscles. He hypothesised that the model of the atom was a round liquid substance whose total charge is cancelled out by the charge of the electrons embedded within it (Figure 6.2.8). His theory was disproved by his own student, Rutherford, who, after bombarding a piece of gold foil with **alpha particles**, proved that the atom has a positively charged nucleus, the greater part of the atom consists of empty space and electrons are spinning around the nucleus.

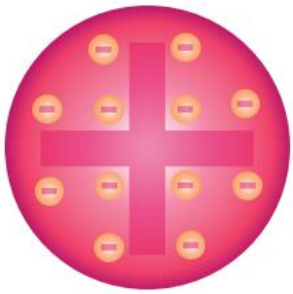


FIGURE 6.2.8 J. J. Thomson's 'plum pudding' model of the atom: a positively charged sphere with embedded negatively charged electrons.

After Rutherford's experiment, scientists drifted away from Thomson's ideas and adopted the theory proposed by Rutherford. The evidence collected to disprove the 'plum pudding' model of the atom was based on the collection of quantitative data from experiments performed in the laboratory and applied in mathematical formulae. Those calculations did not show the electromagnetic behaviour of the electron and therefore the model was impossible. Niels Bohr (1885–1962), working closely with Rutherford, came up with the idea that electrons should have specific energies, that the electrons can accept or release energy as discrete **quanta**. Bohr published his ideas in the scientific magazine *Nature* in 1923. In his article, Bohr described the atomic structure as a planetary system where the distance between the electrons and the nucleus is greater than the size of the electrons themselves. The new atomic model was perfected by Bohr and today it is known as the Rutherford-Bohr model (Figure 6.2.9).

quanta (quantum)
discrete amount of energy

INQUIRING FURTHER

Rutherford used Geiger and Marsden's equipment to create his famous experiment with gold foil. Research how this apparatus worked and how it helped Rutherford to change Thomson's model. Present your research as a report.

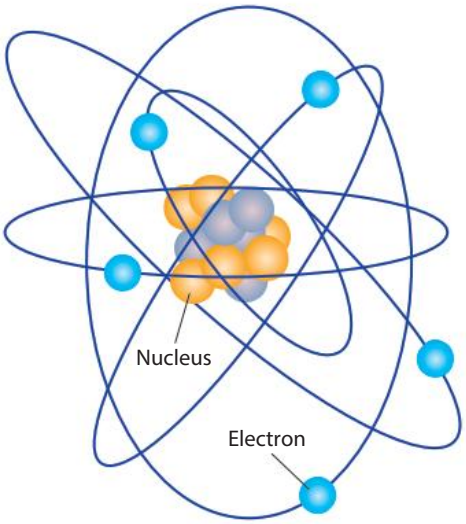


FIGURE 6.2.9 Bohr-Rutherford model of the atom showing a central nucleus and electrons spinning around it.

6.2.6 Dalton atomic theory
6.2.7 The development of atomic theory

9780170411196

Disproved theories over time: Steady state theory of the universe in cosmology

The steady state theory of the universe is based on the principle that the universe is the same everywhere; this means that it keeps the same average density of matter at all times. Therefore, the observable universe remains the same because matter is created continually. The steady state theory gained popularity during the 20th century; however, new data collected using space exploration and observations by the Hubble telescope led to scientists questioning the steady state theory and the Big Bang theory gained more acceptance in explaining the origin of the universe. The evidence to disprove the steady state theory is a mixture of qualitative and quantitative data.

6.2.8 The Big Bang and expanded universe
6.2.9 The beginning of the universe for beginners

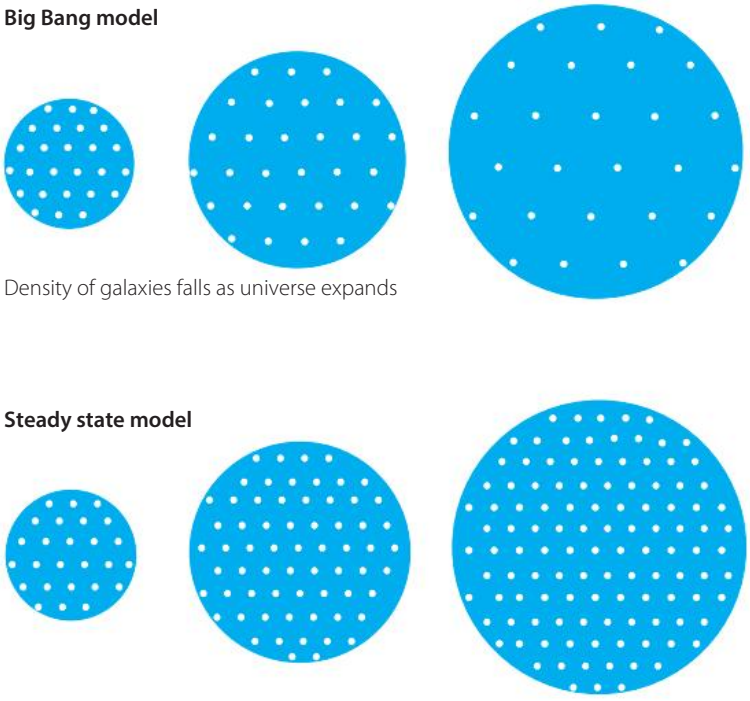


FIGURE 6.2.10 Comparison of the ideas from the Big Bang and steady state models on the density of matter in an expanding universe.

The evidence collected to disprove the steady state theory of matter can be summarised as follows.

- Redshift is a Doppler effect which indicates that the rest of the galaxy is moving away from the Earth (Figure 6.2.11).
- Cosmic microwave radiation from the original explosion of the Big Bang can be detected at all times.
- Abundance of hydrogen, helium and other common elements across the universe that are part of galaxies and stars.

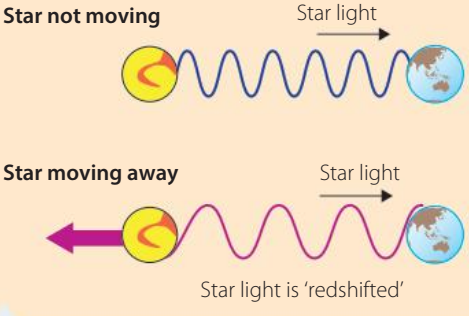


FIGURE 6.2.11 Redshift effect: when a star moves away from the Earth, its light moves towards the red colour frequencies.

redshift
displacement of spectral radiation towards longer wavelengths

cosmic microwave radiation
electromagnetic wave radiation in the range between 0.3 and 300 GHz

6.2.1 Development of a theory

SECTION REVIEW 6.2

REMEMBERING

1 Define 'evidence'.
2 Recall the four stages in the development of a theory.
3 Identify the four stages of the development of a theory using the germ theory and the oxygen theory of combustion as examples.

UNDERSTANDING

4 Discuss why it takes a long time to accept or disprove theories.
5 Compare the types of evidence gathered to develop a theory or disprove it. Are there similarities or differences in the type of evidence collected to develop or disprove a theory?
6 Choose one of the theories described and discuss why the theory was once accepted and then became disproven.

APPLYING

7 Examine an idea or hypothesis about observed phenomena that interests you. Outline how you can develop a theory around your hypothesis.

6.3 The development of laws

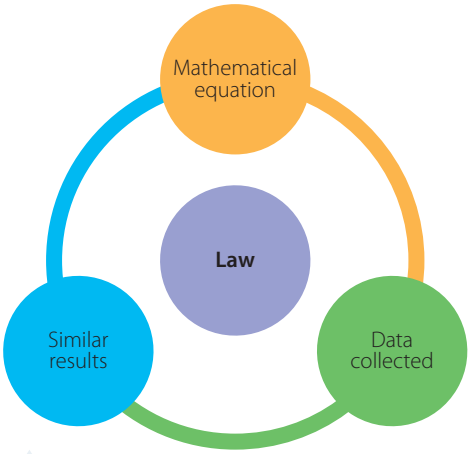


FIGURE 6.3.1 Diagram representing the acceptance of a law based on the collection of numerical data, applied into an equation to obtain similar results in all of the tested situations.

Laws in science are statements based on the empirical collection of data. They are usually expressed with a mathematical equation. Scientific laws do not try to explain an event or natural phenomenon; they describe what is happening at that moment of time when the phenomenon is being observed. They can also be used to predict future events under similar or different circumstances. The experiments to accept a law are repeated many times and the results have to show similar patterns for the law to be valid.

Acceptance of laws by supporting evidence

The process to develop and later accept a scientific law follows the steps in the scientific method with a strong collaboration and peer review by other scientists (see Chapter 1).

Laws usually have a mathematical equation to illustrate the concept that they are trying to describe and prove. Each time the numerical data is collected and applied into the equation, the results should be similar and the scientific error minimal. The process in the acceptance of a law based on quantitative data is illustrated in Figure 6.3.1.

Acceptance of a law: Newton's second law of motion

An example of how a law can be accepted by supporting evidence is the development of Newton's second law.

6.3.1 Newton's laws

9780170411196

KEY LAW

Newton's second law of motion

The force applied to an object is proportional to the mass of the object and its acceleration.

KEY FORMULA

$$f = ma$$

where

f = force measured in Newtons
m = mass measured in kg
a = acceleration measured in m/s^2

INVESTIGATION 6.3.1

Supporting evidence for Newton's second law

AIM

To investigate and assess Newton's second law of motion

MATERIALS

- dynamic cart
- four 500 g masses
- 1.5 m piece of string
- 1 kg mass and mass holder
- pulley clamp
- metre ruler
- sticky tape

METHOD

1. Collect the materials and set up the apparatus as shown in Figure 6.3.2.
2. Place the 1 kg mass on the hanging mass holder from the pulley and hold it close to the top of the table.
3. Place the 500 g mass on the cart and release the mass holder.
4. Record the time and distance that the trolley travels.
5. Repeat steps 3 and 4 three more times adding an extra 500 g mass each time.
6. Record the distance covered and the time in your table.
7. Conduct an additional three trials for reliability.
8. Use the formula $a = \frac{2}{t^2}$ to calculate the acceleration for each mass loaded.
9. Calculate the force for each set of trials.
10. Plot your results on a graph.

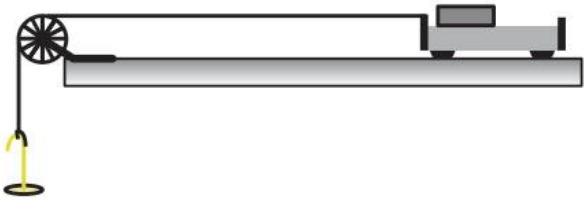


FIGURE 6.3.2 Experimental set-up

RESULTS

Copy and complete the following table.

MASS ON CART (g)	TIME (s)				ACCELERATION (m/s^2)	FORCE (N)
	Trial 1	Trial 2	Trial 3	Trial averages	$a = \frac{2}{t^2}$	$f = ma$
0 (no mass on cart)						
500						
1000						
1500						
2000						

DISCUSSION

1. Identify the dependent, independent and controlled variables in this experiment.
2. Identify which mass on the dynamic cart had the fastest and the slowest acceleration. Explain the reasons for your observations.
3. Describe the magnitude of the force in each trial and discuss whether Newton's second law is demonstrated in each trial.
4. From this experiment, assess the evidence that supports Newton's second law.

Avogadro's law

molecule
group of atoms bonded together, representing the smallest fundamental unit of a chemical compound that can take part in a chemical reaction

Lorenzo Avogadro was an Italian scientist who was researching the idea that all gases have the same number of **molecules** if they are under the same conditions. In other words, a litre of oxygen will have the same number of molecules as a litre of carbon dioxide. The number of molecules is 6.022×10^{23} and it is the same for the lightest gas hydrogen as for a heavier gas, such as bromine.

In 1811, very little was known about atoms and molecules and it was believed that only compounds can form molecules and that elements only exist as single atoms. Avogadro demonstrated that when two gases combine, the resultant gas is two-thirds of the original volume. For example, when pure oxygen combines with pure hydrogen to form gaseous water, the resultant volume of water is less than the original volume. This gave Avogadro the idea that the same single element forms molecules in simple whole number ratios.

KEY LAW

Avogadro's law

Equal volumes of gases under the same conditions of temperature and pressure contain equal numbers of molecules

KEY FORMULA

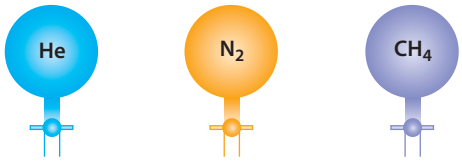
Avogadro's law

$$\frac{V}{n} = k$$

where:

V is the volume of the gas
n is the amount of substance of the gas
k is a proportionality constant.

9780170411196



Volume	22.4 L	22.4 L	22.4 L
Pressure	1 atm	1 atm	1 atm
Temperature	0°C	0°C	0°C
Mass of gas	4.00 g	28.0 g	16.0 g
Number of gas molecules	6.02×10^{23}	6.02×10^{23}	6.02×10^{23}

FIGURE 6.3.3 Three different gases: helium (He), nitrogen (N_2) and methane (CH_4) have the same number of molecules when they are at the same temperature and the same pressure.

6.3.2 Avogadro's law

6.3.3 The ABCs of gas: Avogadro, Boyle, Charles

INQUIRING FURTHER

Investigate Avogadro's experiments. Use the research to help you design your own experiment to gather evidence about his law.

Law of superposition

On Earth, **sediments** are deposited over millions of years at different rates. During that time, animals and plants can get buried in those sediments. If the series of depositions is undisturbed, the older sediment will remain at the bottom and the youngest sediment will remain at the top. Layers of chronological sediment deposition were observed in the 17th century by Nicholas Steno (1638–1686). He was fascinated by how a solid piece from an animal can be recovered from rocks, even though the word 'fossil' was not known at that time. Steno, after analysing primary data collected from the field, formulated the law of original horizontality and the law of superposition that are still used in **stratigraphy** today.

sediment
solid fragmented material that is transported and deposited by water, ice or wind, forming layers on the Earth's surface

stratigraphy
branch of geology which studies the position of layers of sediments

index fossil
fossil that is common across the same layers of strata for a specific period of geological time

KEY LAW

Law of original horizontality

Layers of rocks form in the horizontal position and any deviation from this position is due to later disturbance.

KEY LAW

Law of superposition

Layers of rocks are arranged in a time sequence, with the oldest layers at the bottom and the youngest layers at the top, unless later disturbance affects this arrangement.

6.3.4 Law of superposition

Evidence that supports the law of superposition

The following evidence supports Steno's law of superposition.

- Older dated fossils are usually found at the bottom of the rock layers or strata.
- Younger dated rocks are usually found at the top of the rock layers.
- **Index fossils** are always found in the same dated layer; for example, trilobites.

INQUIRING FURTHER

In Australia, layers of rocks have not been disturbed in geological time as much as in other continents. Therefore, many fossil sites are easy to excavate and date. Research what is an index fossil, what is the most common index fossil in Australia and in what layer is it found?

6.3.5 Fossils in Australia

FIGURE 6.3.4
Observation of the law of superposition on a cliff, where the older layers of rocks are at the bottom of the cliff and the younger layers are at the top of the cliff. No disturbance of the strata is observed since the layers follow a horizontal sequence in accordance with the law of original horizontality.

Shutterstock.com/Jaroslav Sekeres

INVESTIGATION 6.3.2

Law of superposition

AIM

To gather secondary-sourced data to investigate and assess the law of superposition

MATERIALS

- map of Australia
- Internet: search engines and textbooks which contain valid information about fossil sites in Australia

METHOD

1. Using the Internet, research two different Australian fossil sites; for example, Lightning Ridge, NSW and Inverloch, Victoria.
2. Mark your two chosen sites on the map of Australia.
3. In your research, identify:
   - types of sediments deposited over time
   - dating of those sediments
   - types of fossils found in the site
   - depth of the excavations to reach the fossils
   - disturbances that the layers may have experienced over time (e.g. volcanism, earthquakes).

DISCUSSION

1. Assess if the law of superposition is followed in the sites investigated.
2. Discuss what type of evidence is gathered from the investigated sites to support the law of superposition.
3. Explain the type of disturbances which affected the site over time and how that has influenced the identification of rock layers and fossils.
4. Discuss why the law of superposition is not a theory.

9780170411196

Mendel's law of dominance

KEY LAW

Law of dominance

One factor of the inherited trait will be dominant and the other one recessive.

Gregor Mendel (1822–1884) was a scientist and a monk living in what is now known as the Czech Republic. He was a teacher and also looked after the large garden at the monastery. He became curious about how the pea plants that he was cultivating changed sizes, flower colour, and seed colour and texture from one season to another.

He started the meticulous work to gather evidence in the hope of discovering the reason behind his observations. He isolated the 'pure parents' for a particular characteristic; for example, purple flowers, and he started crossing those parents with each other to identify how the **trait** was transferred to the next generation. At the beginning of his research, Mendel did not know which traits were dominant (what he thought of as being more frequent) or recessive (less frequent). He collected thousands of items of quantitative and qualitative data as evidence. This evidence helped to calculate the ratios of the dominant and recessive traits in future generations. Mendel's observations and calculations led to the formulation of the law of dominance:

6.3.6 Mendel
6.3.7 Animation: how Mendel did his experiments
6.3.8 How Mendel's pea plants helped us understand genetics

WORKED EXAMPLE 6.3.1

The following example explains one of the traits that Mendel studied and followed: flower colour.

QUESTION

Which flower colour is dominant, purple or white?

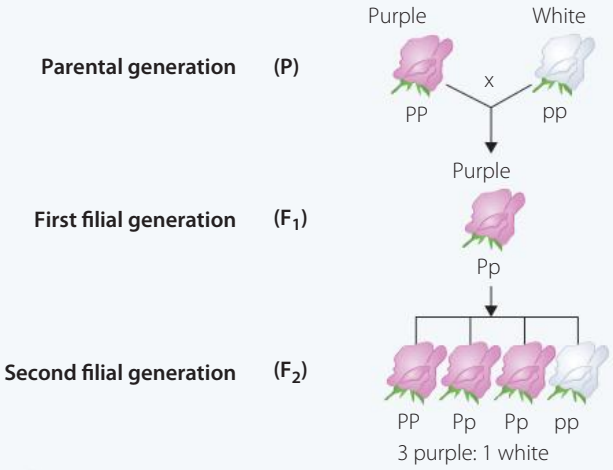


FIGURE 6.3.5 Cross between two pure-bred parents for the trait (gene) flower colour. The dominant colour is purple and the recessive white. The dominant trait overshadows the recessive trait and the majority of the flowers in the second generation of plants are purple in a ratio of 3:1.

ANSWER

The flower colour purple is dominant over the white colour. It appears more frequently in future generations and follows the ratio 3:1.

INVESTIGATION 6.3.3

Mendel's law of dominance

AIM

To investigate and gather secondary-sourced data to assess evidence that supports the law of dominance

MATERIALS

- Internet search engines (use valid and reliable sources)
- science textbooks where Mendel's law of dominance is explained

METHOD

1. Complete an advanced search on the Internet about how Mendel collected evidence from his research.
2. Choose at least two traits to investigate; for example, seed texture, flower colour or plant height.
3. Collect as much evidence as possible to show that the chosen traits follow the law of dominance, such as:

- amount of crossings between generations
- amount of counted traits (e.g. seeds, plants, flowers)
- ratio calculations in each generation
- diagrams, such as punnet squares.

RESULTS

Write a summary of the data collected and ratios.

DISCUSSION AND CONCLUSION

The following questions will help to create your final discussion and conclusion.

1. Did each of the dominant traits follow the law of dominance? Explain using evidence from your results.
2. What is the evidence to conclude that the trait followed the law of dominance?
3. Were Mendel's experiments valid and reliable? Explain.
4. Discuss if your secondary-sourced data was valid and reliable.

6.3.1 Development of a law

Results can be predicted by laws

Laws are very useful in predicting future events or to explain the results of events. Predictions in science are important because future inferences can be drawn before any experimental data is collected. For instance, using the principles behind Newton's laws we can predict the behaviour of objects with different masses, their acceleration or how the forces on those objects are under different gravitational fields. The mathematical equations used to express the statement of laws can be used in computational models to create hypothetical scenarios that can help solve real situations when they arise.

current
flow of electrons around a circuit

resistance
amount by which a circuit tries to stop the flow of electrons

Predictions using Ohm's law

Georg Ohm was a German physicist who studied the relationship between electrical current and the resistance of materials to conduct electricity. In his book *Die galvanische Kette, mathematisch bearbeitet*, Ohm first explained the mathematical background of his equations. In those days, physics was very theoretical and very few formulae were used in gathering data and making predictions.

9780170411196

In his book, Ohm stated what we now call Ohm's law: the relationship of a current passing through most materials is directly proportional to the potential difference (**voltage**) applied across the material.

voltage
force pushing electrons around the circuit

KEY LAW

Ohm's law

The current (I) passing through a conductor or resistor (R) is directly proportional to the potential difference (voltage, V) at a given temperature.

KEY FORMULA

Ohm's law

$V = I \times R$

V = voltage, measured in volts (V)

I = current, measured in amperes (A)

R = resistance, measure in Ohms (Ω)

INQUIRING FURTHER

Investigate different materials and how they conduct electricity. Questions to ask in preparation for this investigation include: What makes materials good conductors of electricity? Is electricity conducted only in solids? What temperatures are the best for conducting electricity?

Applying Ohm's formula to different examples, predictions can be made about the amount of voltage, current or resistance of different materials at a given temperature.

6.3.9 Ohm's law

6.3.10 Ohm's law simulation

WORKED EXAMPLE 6.3.2

Predictions using Ohm's law can be done in two ways.

1. Using a graph where resistance is plotted against current and the line of the graph is the resistance.
2. Applying the mathematical formula of the law after collecting empirical data from an experiment.

The following is a worked example to make predictions using a graph.

To predict the resistance from the graph, the following formula is applied:

Resistance = gradient
= rise/run

So, to predict the resistance for a light bulb with a voltage 0.8 V and a current of 0.45 A:
Resistance = V / I
= 0.8 V / 0.45 A
= 1.7 Ohms

Applying the formula, the resistance for a particular point can be calculated from the graph.

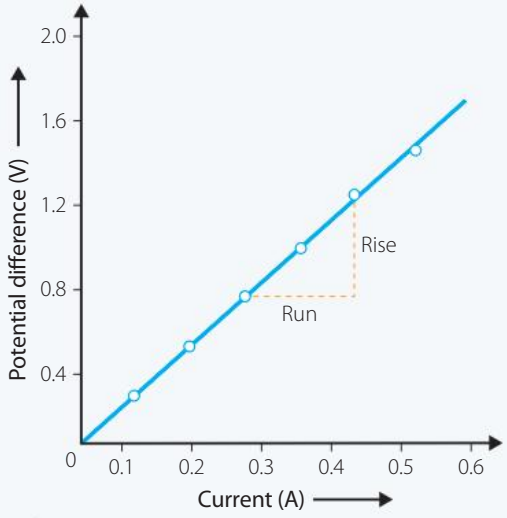


FIGURE 6.3.6 Graph showing the relationship between voltage (V, potential difference) and current (A) for a light bulb. The slope of the line represents the resistance in the circuit.

INVESTIGATION 6.3.4

Predicting results using Ohm's law

AIM

To design and conduct a primary investigation to predict results using Ohm's Law

MATERIALS

- ammeter
- voltmeter
- light bulbs
- cables with alligator clips
- switch
- power source

METHOD

1. Gather the equipment listed in the materials section.
2. Design your own experiment to test Ohm's law and make predictions.
3. Tabulate and plot your results.

HINT

Set up an electrical circuit and place the voltmeter in parallel in the circuit to measure voltage and the ammeter in series to measure current.
Then calculate the resistance using Ohm's formula.
Once you have your measurements you can make predictions about how the voltage and current decrease or increase if you add more or fewer light bulbs.

DISCUSSION

1. Predict what happens to the resistance when you add more resistors (i.e. light bulbs)
2. Discuss the validity of your experiment in terms of making predictions with Ohm's law.
3. From your graph, predict the resistance for higher and lower voltages and currents.

Predictions using the law of conservation of energy

The ride of a roller coaster always starts from a very high hill and comes down steeply. During the ride, hills and steep descents are part of the thrill of the experience. However, this design is not only for you to have an exhilarating and fun experience, it also follows the law of conservation of energy.

Since the Classical Greek period (5th and 4th centuries BCE), philosophers have been attempting to explain the 'substance' that is conserved across the universe. Empedocles (490–430 BCE) said that in a universal

iStock.com/daboost

FIGURE 6.3.7 The law of conservation of energy is evident in a roller coaster where the potential energy at the top of the hill is transformed into kinetic energy to create a fun and safe experience for all to enjoy.

9780170411196

system, nothing comes to be or perishes and the elements (water, air, earth and fire) are continually rearranged. Due to the lack of knowledge and technology available at that time, the law of conservation of energy was just a hypothesis. In 1847, a German surgeon called Joseph Mayer, working with gas pressure generated by heat in a piston, stipulated the first notion about the law of conservation of energy. Mayer understood the sequence of steps from a chemical reaction that produces heat and **work** (the product of an applied force), and that work can then produce a definite amount of heat. Sadly Mayer's work was not accepted until many years later because he was not part of the scientific community; he was just the town surgeon.

James Joule (1818–1889) was living in Manchester, England, during the Industrial Revolution. Observing steam engines and electric motors competing for the best results in producing work, Joule reached similar conclusions about the conservation of energy. He set up a series of experiments with a simple apparatus (Figure 6.3.8) and, just as Mayer did, understood that the energy transformations generated by the movement of the paddles in his apparatus increased the temperature of the water. Joule showed that the gravitational potential energy lost by the weight in descending was equal to the thermal energy gained by the friction of the paddle in the water.

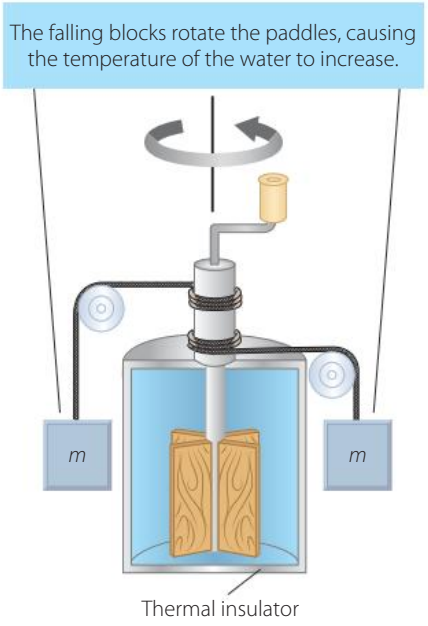


FIGURE 6.3.8
Joule's apparatus consisted of a thermal insulator (tin) with a paddle wheel immersed in water. The weights attached to the roller allowed the paddle to move and the temperature of the water to rise.

6.3.11 Joule and the law of conservation of energy

KEY LAW

Law of conservation of energy

The total amount of energy in an isolated system remains constant: the energy is never created nor destroyed–it is transformed.

work
product of an applied force

INVESTIGATION 6.3.5

Predictions using the law of conservation of energy

AIM

To investigate the law of conservation of energy in a roller coaster

MATERIALS

- cardboard
- marble
- sticky tape
- string
- ruler
- calculator
- camera or mobile phone to record marble movement

»

METHOD

1. Build a simple roller coaster with one hill and one loop.
2. Copy and complete the table to describe your roller coaster.

	MEASUREMENTS
Mass of the marble	
Height at the top of the hill	
Total length of the roller coaster	
Length from the top to the bottom of the hill	
Length of the loop	
Diameter of the loop	

3. Roll the marble from the top of the hill. Ensure you also record the movement of the marble with a camera or mobile phone.
4. Record data of the time taken for the marble to roll from the top of the hill to the bottom, to complete the loop and to complete the roller coaster circuit (Trial 1).
5. Repeat your time trials twice and record your results (Trials 2 and 3).
6. Calculate the average time and include this in your results.
7. Reduce and increase the height of the hill and repeat steps 3–6.
8. Create two additional tables to record your results from step 7.
9. Plot a work-energy bar chart using your results.
10. Analyse the data.

RESULTS

DATA	TRIAL 1	TRIAL 2	TRIAL 3	AVERAGE
Time from top to bottom of hill				
Time around the loop				
Time to complete the roller coaster circuit				

PARAMETERS	FORMULA	DESCRIPTION
Gravity and potential energy	$U_g = mgh$	U_g is potential energy, m is mass in kilograms, g is acceleration due to gravity and h is the distance above the ground in metres.
Kinetic energy	$K = ½ mv^2$	K is kinetic energy, m is mass in kilograms and v is velocity in metres per second.
Conservation of energy	$E = K + U$	E is the total mechanical energy, K is kinetic energy and U is potential energy.
Speed in each section and average speed	$V = s/t$	s is distance of the entire roller coaster and t is the time that the marble takes to complete the circuit of the roller coaster.

9780170411196

EXTENSION

Further calculations can be completed to investigate the law of conservation of energy, and energy transformations.

Average velocity and displacement	$V_{av} = \Delta r / \Delta t$	V_{av} is the average velocity, Δr is the total change in displacement and Δt the time for the change in displacement.
Newton's second law	$\Sigma F = ma$	ΣF is the net unbalanced force acting on the object, m is the mass of the marble and a is the resulting acceleration.
Momentum	$P = mv$	P is the momentum measured in kilogram-metres per second, m is the mass of the object in kilograms and v is the velocity of the object.
Impulse	$I = \Sigma Ft$	I is the impulse measured in Newton-second, ΣF is the net force acting on the object in Newtons and t is time.
Centripetal acceleration	$a_r = v^2 / r$	a_r is centripetal acceleration, v is velocity in metres per second and r is the radius of the circle in metres.
Circular motion	$F = \frac{mv^2}{r}$	F is centripetal force, m is the mass of the object in kilograms, v is the linear orbital velocity or speed in metres per second and r is the radius of the circle in metres.

DISCUSSION

1. Observe the data collected and the work-energy bar chart, and explain whether the law of conservation of energy can be predicted from the data.
2. When the height of the hill changed, could the marble complete the roller coaster circuit? Explain.
3. Discuss how the roller coaster system predicted the law of conservation of energy.

6.3.2 Applications of scientific theories and laws

SECTION REVIEW 6.3

REMEMBERING

1. Describe the process and procedures undertaken to accept a law.
2. State Newton's second law and identify an example.
3. Describe Avogadro's law.
4. Using an Australian example, describe the law of superposition.
5. State Ohm's law and the law of conservation of energy, and describe using an example of where each of the laws can be applied.

UNDERSTANDING

6 Observe the situations in Figure 6.3.9 and discuss how Newton's second law can be applied.

FIGURE 6.3.9 Students investigating Newton's second law by (a) pulling different size rocks and (b) observing a balloon car.

7 Plot a graph using the data from the table below and use Ohm's formula to predict the resistance at 5 V with a current of 0.75 A at 25°C.

	CURRENT (A) AT DIFFERENT TEMPERATURES		
Voltage (V)	0°C	25°C	40°C
4	0.51	0.49	0.47
6	0.77	0.70	0.71
8	1.0	0.98	0.95

8 A dog breeder is observing the segregation of the gene for ear size. He notices that the long ear allele is dominant over the short ear allele. Explain, using the law of dominance, how the breeder can produce more puppies with long ears.

APPLYING

9 Think about a topic of interest to you. Discuss whether a law can be developed to demonstrate a hypothesis related to your topic; for example, the movement of waves in the ocean.

10 You are a renowned scientist and the Academy of Science has assigned you to investigate and validate Newton's second law of motion. Discuss how you would conduct this validation.

11 Data collected applying a very well-known law was used in a theoretical computational model to predict the movement of Earth's crust during earthquakes. However, during an earthquake, the predicted results do not occur. Give possible reasons why the predicted results did not occur.

6.4 Application of laws and theories

Everything that we do, observe or try to understand in our life is based on an application of a scientific theory and/or law. All branches of science become closely related when theories and laws are applied to understand concepts. If we did not have scientific theories and laws it would be very difficult, nearly impossible, to reach the advances that we have in medical science, space exploration or the understanding of natural events. Consequently, the application and use of the current theories and laws are essential today because we rely on them to create new technologies and pathways towards a more sustainable future.

9780170411196

Applications of laws across different science disciplines: Law of conservation of energy

In Figure 6.4.1 you can see some of the overlapped interactions between laws in chemistry, physics and biology. Identify some of these laws and principles. Why did you choose those laws and not others?

Today, the law of conservation of energy is used across many science disciplines where transformations of energy to create work need to be applied. It is one of the most fundamental principles of all science. The law can be applied from a large scale to particle level. For example, thermal energy produced by burning coal can drive a turbine which generates electricity, or a battery creates enough electrical energy to turn on a lamp in a torch and illuminate the surroundings (Figure 6.4.2). At an atomic level, the law is applied in the **Large Hadron Collider** to understand the energy transformations in particle collisions.

Imagefolk/NASA/SCIENCE PHOTO LIBRARY

FIGURE 6.4.1 Scientists need to combine, understand and apply the laws of physics, chemistry and biology to safely and accurately launch the shuttle and transport astronauts to the International Space Station.

6.4.1 The Large Hadron Collider

Large Hadron Collider
particle accelerator that propels subatomic particles (hadrons) at high speed

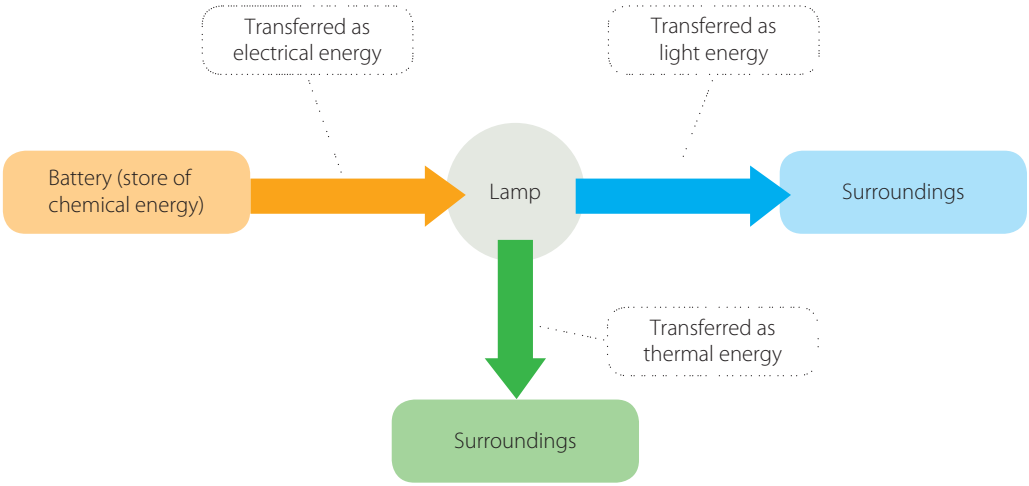


FIGURE 6.4.2 Flow chart showing the energy transformation in a battery operated lamp.

Applications of the law of conservation of energy in physics

In physics the law of conservation of energy can be applied to the motion of objects. An object at rest has potential energy and as soon as a force is applied to it that potential energy is transformed into kinetic energy. A good example of this is Newton's cradle.

In the Newton's cradle all the suspended metallic balls are at rest, therefore they have potential energy. As soon as one of the balls at the end is moved and it hits the other balls, the kinetic energy is transferred across all the balls and the one at the opposite end moves (Figure 6.4.3).

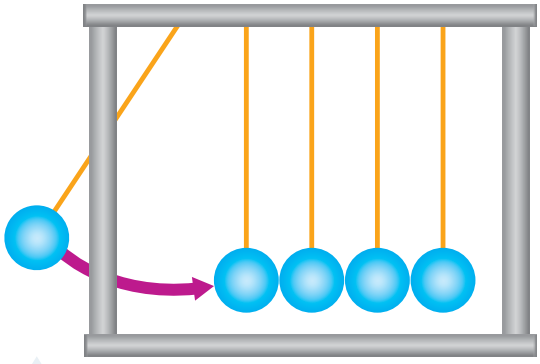


FIGURE 6.4.3 Newton's cradle. A ball is moved to hit the stationary balls, and as a consequence of energy transfer across the balls, the last ball will move with the same amount of energy as the first one.

6.4.2 Simple pendulum interactive

INVESTIGATION 6.4.1

Law of conservation of energy in physics

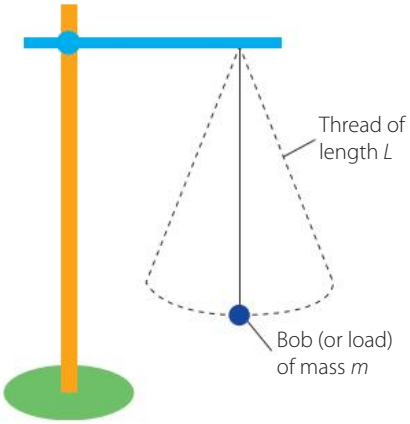


FIGURE 6.4.4 Pendulum set-up for this experiment.

AIM

To investigate the law of conservation of energy in a pendulum

MATERIALS

- tennis ball, ping pong ball or marble
- retort stand
- clamps
- two pieces of string, 1 m and 50 cm
- scale
- 1 m ruler

RISK ASSESSMENT

HAZARDS	MANAGEMENT
Hit by pendulum	Manage the movement of the pendulum with care

METHOD

1. Weigh the bob (load) of the pendulum.
2. Set up the pendulum from the clamp attached to the retort stand as shown in Figure 6.4.4.
3. Attach the string to the bob of the pendulum to a final length of 1 m.
4. Lift up the pendulum and record the height that it will be released from.
5. Release the pendulum and record the height that the pendulum reached on the opposite side.
6. Repeat steps 4 and 5 using a string length of 50 cm.
7. Calculate the kinetic and potential energy for each situation using the formulae given.

CALCULATIONS

The law of conservation of energy can be calculated using the formula.

KEY FORMULA

$$E_i = E_f$$

E_i = initial energy of the pendulum

E_f = final energy of the pendulum

The pendulum will experience two kinds of energy at the beginning and end of its motion: kinetic and potential energy. Therefore, we can conclude that the initial potential and kinetic energy of the pendulum will equal the final potential and kinetic energy of the pendulum.

9780170411196

KEY FORMULA

$PE_i + KE_i = PE_f + KE_f$

where
PE is potential energy in Joules
KE is kinetic energy in Joules
and the subscript i implies initial energy and f implies final energy

If we replace the *PE* and *KE* by their extended formulae:

KEY FORMULA

$KE = ½\ mv^2$

where

KE is kinetic energy

m is mass in grams

v is velocity in m/s

and

$PE = mgh$

where *PE* is potential energy in Joules

m is the mass of the object in grams

g is defined acceleration due to gravity at 9.8 m/s^2

and *h* is the object's height with respect to a chosen reference point

If we substitute the equations for potential and kinetic energy by their extended formulae, we can see that:

KEY FORMULA

$mgh = ½\ mv^2$

RESULTS

Copy and complete the table.

Mass of the bob = _____

HEIGHT (m)	SPEED (m/sec)	PE	KE
0			
0.25			
0.50			
0.75			
1			

DISCUSSION

1. Identify the independent, dependent and controlled variables of the experiment.
2. Explain whether the length of the string affected the swing of the pendulum.
3. Discuss how the law of conservation of energy was demonstrated in this experiment.
4. Outline the validity and reliability of this experiment.
5. Evaluate in what other situations the movement of the pendulum can be applied.

Applications of the law of conservation of energy in biology

The law of conservation of energy can be applied in living systems because organisms use energy to perform their metabolic functions in order to live, survive and reproduce. In 1892, Ryder published an article with the Academy of Natural Science in Philadelphia called *The Principle of the Conservation of Energy in Biological Evolution: A Reclamation and Critique*. In this he discussed that the energy in living things is rendered or stored from anabolic (formation of substances) or catabolic (breakdown of substances) steps and consequently energy in the form of heat, muscular motion or nerve interaction is released. Ryder concluded that all changes in organisms are at the expense of changes in internal and external energies. This was a very good attempt to describe the law of conservation of energy in living things at a time where little was known about cellular metabolism and chemical interactions within and between cells.

Today, the law of conservation of energy is applied from cellular level to ecological interactions, such as trophic relationships involving the consumption of plants by herbivores to the decomposition of dead matter (Figure 6.4.5).

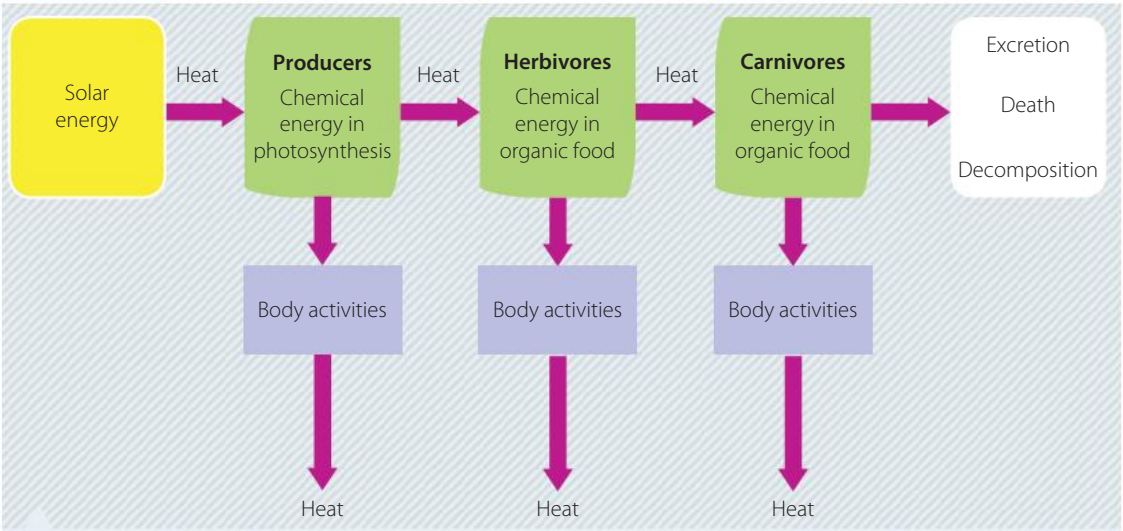


FIGURE 6.4.5 Flow of energy in an ecosystem. The majority of the energy released is in the form of heat and the energy transferred is chemical energy. However, the chemical energy transferred is converted to perform different body activities.

autotrophic when an organism produces its own energy (sugars) by the process of photosynthesis

heterotrophic when an organism gathers its energy from external sources of food

ATP (adenosine triphosphate) high energy molecule present in every cell

At the cellular level, the process of photosynthesis and respiration are the key energy pathways for all autotrophic and heterotrophic organisms. Photosynthesis occurs in the chloroplasts of plant cells, and in the process, carbon dioxide from the air and water are transformed into sugars (glucose) using the energy from sunlight. In the process, oxygen is released as waste. Cellular respiration takes place in the mitochondria of the cell and uses oxygen from the air to break down sugars and release carbon dioxide, water and heat as waste. The process of cellular respiration creates ATP as a form of chemical energy (Figure 6.4.6).

9780170411196

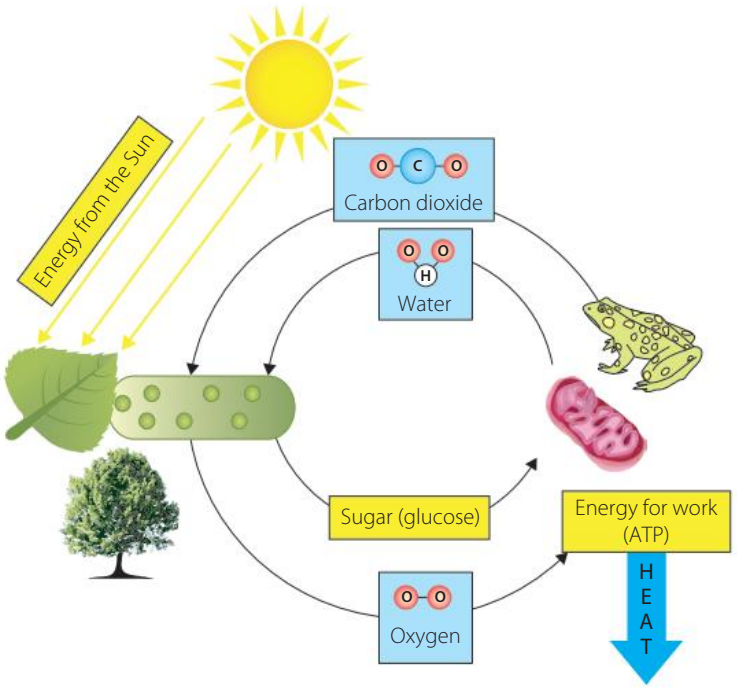


FIGURE 6.4.6 Photosynthesis and cellular respiration cycles showing the energy transformations taking place in autotrophic and heterotrophic organisms.

The law of conservation of energy in living things is based on the chemical energy utilised by organisms to perform the functions vital for their survival. For example, every organism needs nutrition to grow and have energy to move, escape or camouflage itself from predators and to reproduce. The energy within a living thing is transformed from the chemical energy stored in food into kinetic energy and released as heat energy.

6.4.3 Photosynthesis
6.4.4 Energy from respiration
6.4.5 The simple story of photosynthesis and food

INVESTIGATION 6.4.2

Law of conservation of energy in biology

AIM

To investigate the application of the law of conservation of energy in fermentation

MATERIALS

- dry yeast
- warm water at 40°C
- sugar
- teaspoons
- four 250 mL beakers
- scale
- ruler
- cling wrap

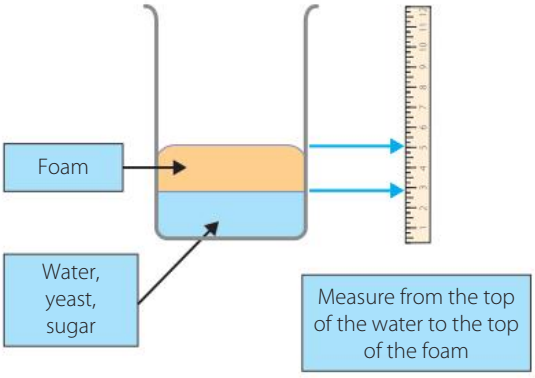


FIGURE 6.4.7 Fermentation apparatus and how to measure the amount of foam produced in the process.

RISK ASSESSMENT

HAZARD	MANAGEMENT
Broken glass	Handle glassware with care, tell the teacher if there is broken glass
Allergy to yeast	Avoid tasting or consuming yeast
Hot equipment	Handle hot equipment with care
Splash of fermented solutions	Wear goggles

METHOD

1. Gather the equipment.
2. Label each beaker as follows: no sugar, 2.5 g sugar, 5 g sugar and 10 g sugar.
3. Weigh and add the correct amount of sugar to the correct beaker.
4. Add 100 mL of warm water (40°C) to each of the four beakers. Stir gently.
5. Add 5 g of yeast to each beaker. Stir gently and cover with cling wrap.
6. Leave the beakers in a warm place for 30 minutes.
7. After 30 minutes, measure the height of the foam in each beaker and record the results in a table.
8. Collect data from other students to increase the reliability of the experiment and calculate the averages.
9. Graph your averaged results.

RESULTS

Copy and complete your table of results.

AMOUNT OF SUGAR (G)	FOAM HEIGHT (CM)
0	
2.5	
5	
7.5	
10	

DISCUSSION

1. Identify the variables in this investigation and the purpose of the beaker without sugar.
2. Explain if the amount of chemical energy added to each beaker (sugar) was qualitatively equal to the production of foam.
3. Describe the trend in your graph.
4. Explain how this investigation proves the law of conservation of energy in a biological system.

Applications of the law of conservation of energy in chemistry

chemical reaction chemical process that involves the rearrangement of the elements of the reactants into new products

Chemical reactions involve energy which is used to rearrange elements from the breakdown of **chemical bonds** in the reactants into new substances or products as a result of the chemical reaction. Some chemical reactions, such as combustion, release energy when the chemical bonds are broken. Those reactions are called exothermic reactions. However, in other chemical reactions the energy needed to break down the bonds is more than the energy released to make the new products of the reaction.

This type of reaction is called an endothermic reaction because more energy is absorbed in the chemical system than is released (Figure 6.4.8).

chemical bond electrical attraction between the atoms of elements that enables the formation of molecules and compounds

6.4.6 Energy in tied reactions

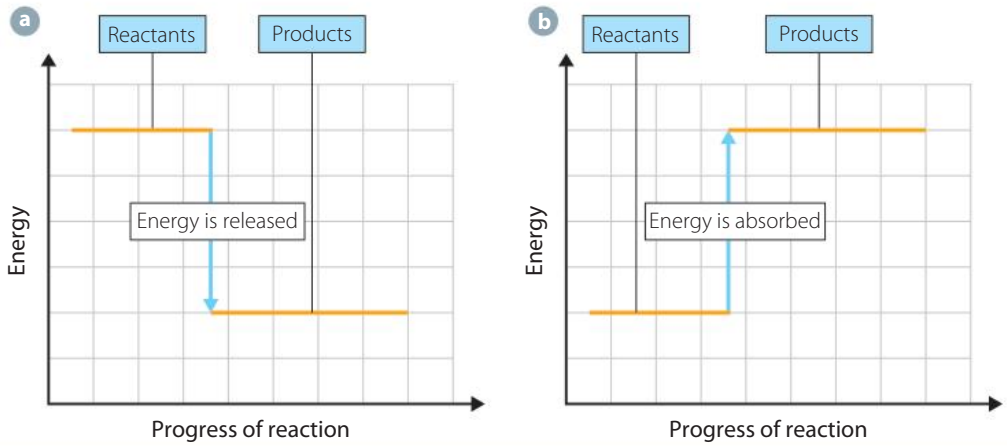


FIGURE 6.4.8 The graphs show the differences in energy between exothermic (a) and endothermic (b) reactions.

Whether a chemical reaction releases or absorbs energy, the overall amount of energy does not change in breaking down or forming new chemical bonds. This follows the law of conservation of energy which states that energy is never created or destroyed, it is always transformed.

INQUIRING FURTHER

Why are most of the chemical reactions found in nature exothermic and only a few endothermic?

INVESTIGATION 6.4.3

Law of conservation of energy in chemistry

AIM

To investigate the law of conservation of energy in endothermic and exothermic chemical reactions

MATERIALS

- anhydrous copper(II) sulfate
- citric acid crystals (2-hydroxy-1,2,3-propane tricarboxylic acid)
- sodium hydrogen carbonate
- copper(II) sulfate solution 0.5 M
- zinc powder
- water
- 50 mL measuring cylinder
- three test tubes
- three spatulas
- test tube rack
- thermometers
- two glass stirring rods
- safety goggles

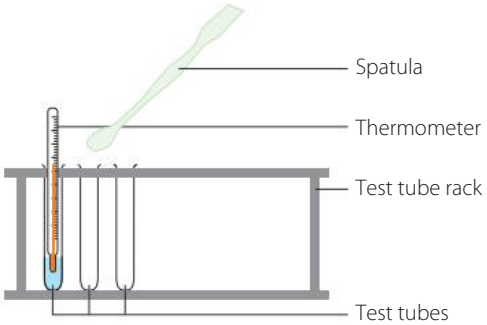


FIGURE 6.4.9 Experiment set-up

RISK ASSESSMENT

HAZARD	MANAGEMENT
Chemical spillage	Handle chemical containers with care, tell the teacher if a spillage has occurred
Chemical poisoning	Avoid ingesting or smelling chemicals
Chemical splashes or eye contact	Wear goggles
Hot materials	Use oven mitts and handle hot equipment with care
Broken glassware	Handle glassware equipment with care, tell the teacher if glassware is broken

METHOD

This investigation involves two experiments: an exothermic reaction and an endothermic reaction.

Experiment 1

1. Add 10 mL of water to a test tube and record the temperature of the water.
2. Add one spatula of anhydrous (white) copper (II) sulfate.
3. Stir carefully, using one of the glass stirring rods, and record the temperature again.

Experiment 2

1. In a dry test tube mix one spatula of citric acid and one spatula of sodium hydrogen carbonate.
2. Place 10 mL of water into another test tube and record the temperature of the water.
3. Add the mixture to the test tube with water and record the temperature again.

RESULTS

The chemical equations for each experiment are as follows.

Experiment 1

Word equation: Anhydrous copper (II) sulfate + water → hydrated copper (II) sulfate

Formula equation: $CuSO_4 + 5H_2O \rightarrow CuSO_4.5H_2O$

Experiment 2

Word equation: citric acid + sodium hydrogen carbonate → sodium citrate + water + carbon dioxide

Formula equation: $C_6H_8O_7 + NaHCO_3 \rightarrow C_6H_7NaO_7 + H_2O + CO_2$

Tabulate your results to compare the temperatures between the two experiments.

DISCUSSION

1. Describe whether the reactions were exothermic or endothermic.
2. Explain what you would have to change or add, in order to include independent variables in both experiments.
3. Write a conclusion, using your results as examples, to explain whether your investigation supported or did not support the law of conservation of energy.

Applications of the law of conservation of energy in earth and environmental science

Climate science is a modern branch of science that focuses on the study of the Earth's climate, its patterns and trends, and analyses data to predict future changes. Considering our planet as a dynamic system of changes at different levels in its many spheres (biosphere, lithosphere, atmosphere and hydrosphere), it is logical to think that there are energy transformations happening at large scales.

There is an energy budget between the heat generated on a planet and the heat coming to the planet from the Sun. For the temperature of the planet to be stable and constant, the amount of heat entering the planet might be equal to the heat radiated by the planet. The law of conservation of energy can be applied to the planet's energy budget because the law states that energy is not created or destroyed, it is always transformed.

As shown in Figure 6.4.10, it can be deduced that there are many energy transformations occurring on our planet, from processes happening within the Earth's various spheres to external processes affecting the Earth. According to scientific research, the heat energy budget of our planet is changing due to the burning of fossil fuels, which increases the level of carbon dioxide in our atmosphere, and is causing our planet to experience increased global warming.

INQUIRING FURTHER

What is the energy budget of Earth in numbers? Research the amount of solar radiation coming into Earth and calculate the balance of energy coming in versus the energy radiated out by our planet.

6.4.7 Global warming

6.4.8 Climate change: Earth's giant game of Tetris

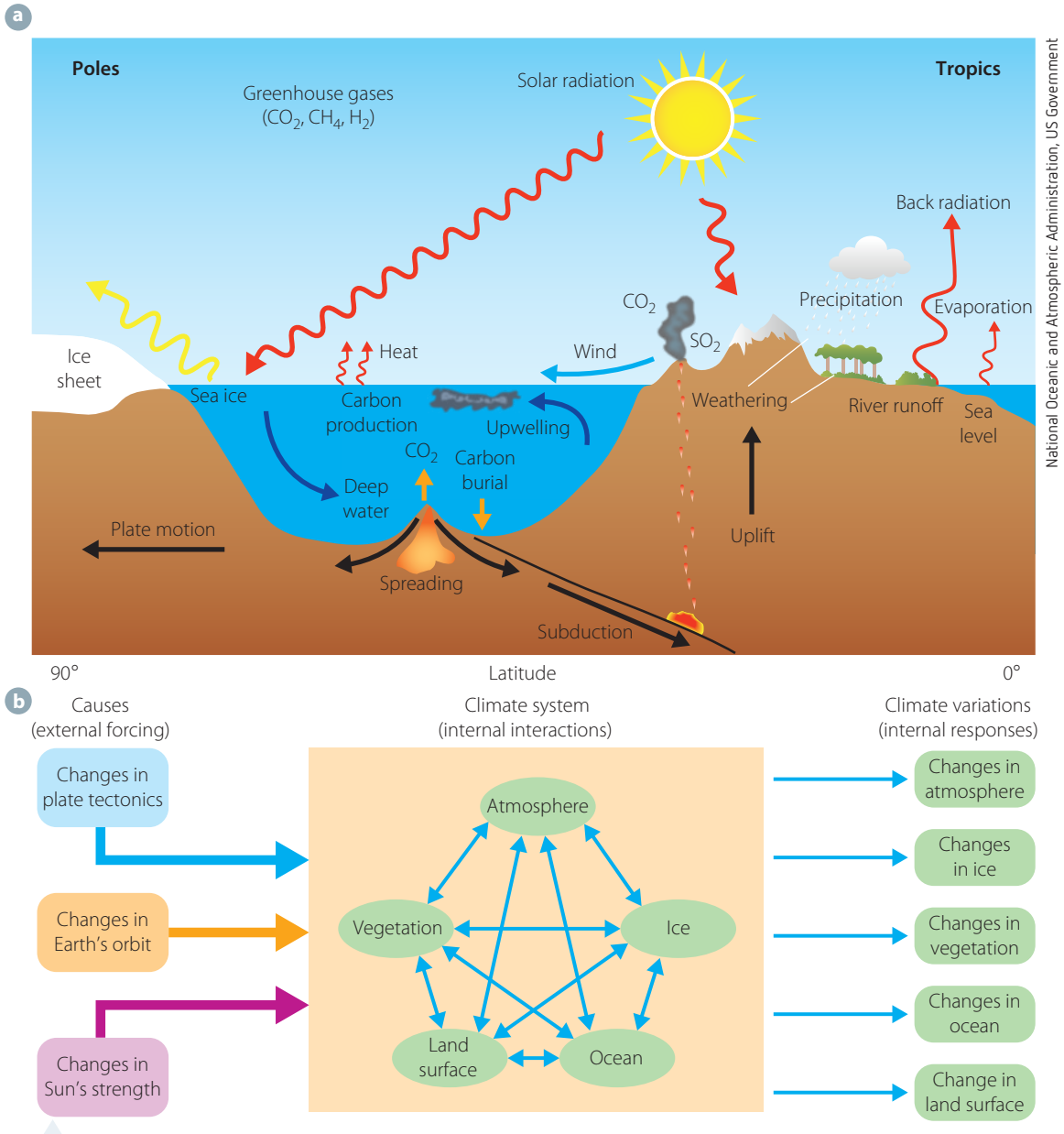


FIGURE 6.4.10 (a) Energy budget of Earth. The incoming solar energy ($342\,Wm^{-2}$) is radiated back to the atmosphere or absorbed into our planet. (b) If any of those processes is unbalanced the climate of our planet is affected.

INVESTIGATION 6.4.4

Law of conservation of energy in climate change

AIM

To investigate how the law of conservation of energy is applied to the climate of the planet using secondary sources

METHOD

1. Gather climate change information from valid and reliable resources such as educational and government agencies sites, online articles, and encyclopaedias and textbooks.
2. Analyse the information from the secondary resources and answer the research questions.

RESEARCH QUESTIONS

1. Explain the greenhouse gas effect and how it has been affected by greenhouse gas emissions since the 19th century.
2. Observe the graph below, and explain the patterns and trends between the temperatures and levels of atmospheric CO_2.

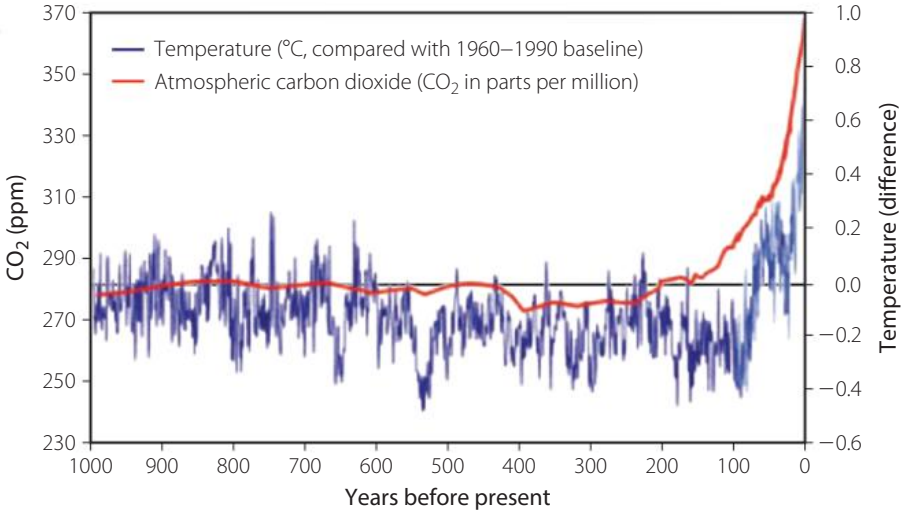


FIGURE 6.4.11 Relationship between the levels of CO_2 and temperature changes over time.

3. Analyse how the planet as a system tries to 'compensate' for the imbalance of energies caused by global warming.
4. Discuss the future changes at an energy level that the planet might suffer if the efforts to control CO_2 emissions are not successful.

9780170411196

Diverse phenomena are unified in specific theories

The unification of theories to explain many phenomena at once has been the dream of many scientists for centuries. In biology, the theory of evolution is considered the central theory that merges concepts from inheritance, ecology, climate, geology and human culture with biological processes. To understand how the theory of evolution unifies phenomena, it is imperative to analyse the concepts separately and link them into the big picture of the theory (Figure 6.4.12).

6.4.9 Evolution
6.4.10 The five fingers of evolution
6.4.11 Myths and misconceptions about evolution

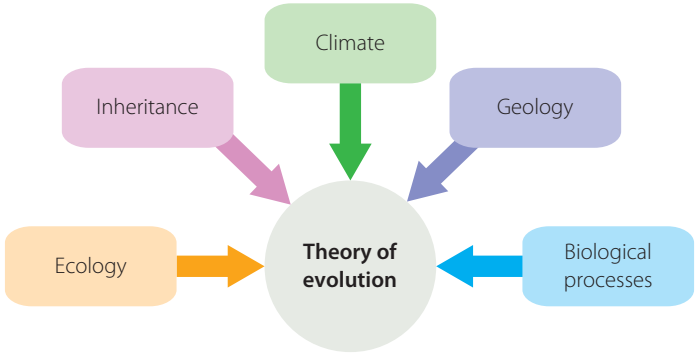


FIGURE 6.4.12 The theory of evolution unified different concepts and phenomena coming from other areas of study.

KEY THEORY

The theory of evolution

Evolution is the process by which all organisms, coming from a common ancestor, have adapted to their environment over a long period of time. Responding to natural pressures, they have survived, reproduced and passed on those favourable genes to the next generation, perpetuating the overall species.

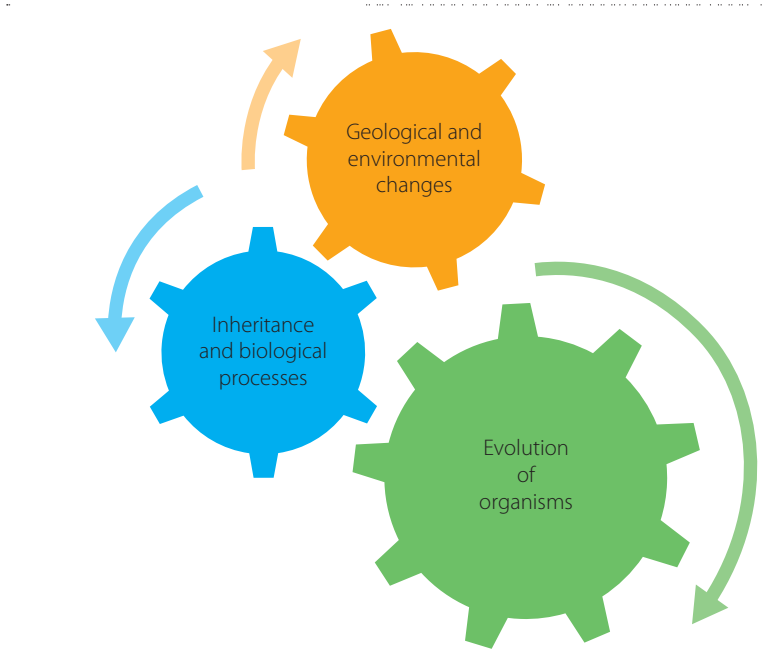


FIGURE 6.4.13 Unification of diverse phenomena by which the evolution of organisms is driven over long periods of time.

Table 6.4.1 describes the different phenomena that have been unified under the theory of evolution. It is important to understand that it is very difficult to separate each phenomenon because the evolution of living things is embedded into the geological and environmental processes that Earth went through over time. It is a never-ending cycle of changes, adaptations, survival, reproduction and passing on favourable genes to the next generation.

TABLE 6.4.1 Summary of the phenomena that become unified under the theory of evolution.

PHENOMENA	EVIDENCE	EXAMPLES
Ecological changes	Organisms live in specific ecological niches; this means that they are well adapted to the ecological features of that particular environment: for example, water and sunlight availability, shelter, food resources and competition with other organisms. If organisms are not responding to the ecology of their environment they would not survive, reproduce and pass on those adaptations to the next generation, and the species would become extinct.	Koalas live in a very specific ecological niche, they only feed on a few species of eucalyptus leaves and the majority of the day they are perched on trees, asleep.
Inheritance	Each individual organism has its own unique DNA blueprint, with genetic information passed on from the parents to the offspring during reproduction. Each gene can have different forms, called alleles. Alleles can be dominant (the presence of a recessive allele is 'hidden' and the dominant one is expressed, i.e. Bb) or recessive (the recessive allele can only be expressed if the individual carries both recessive alleles, i.e. bb). Favourable genes that allow individuals to survive in the environment will be passed on to the next generation and increase the survival of that species.	Different alleles for hair colour in rabbits can lead to different rates of survival. For example, there could be increased survival of white rabbits in the snow because they are camouflaged from predators, and can therefore survive, reproduce and pass on their white hair colour alleles.
Climate	The climate of an environment is part of the natural pressures placed on organisms. The availability of water from rainfall or snow, seasonal patterns such as wind to spread seeds, natural fires and the amount of sunlight all influence the way organisms respond to changes.	The delicate bilby from the Gibson Desert in Australia hides during the day in 2-metre deep burrows to avoid the extreme heat and sunlight. The availability of water is limited; therefore, the bilby is very efficient in conserving water obtaining enough moisture to survive from seeds, spiders and insects. The theory of evolution merges the knowledge from climate science to understand how the bilby's adaptations have evolved from a common ancestor to today.
Biological processes	Homeostasis (the process to maintain the internal stability of an organism body), cell division for growth and repair (mitosis) or reproduction (meiosis and cell fertilisation) and the development of body systems are well related to the theory of evolution. Adaptations to the selective pressures from the environment are answered at a genetic level and expressed in the organism which then survives, reproduces and passes on those favourable genes.	Mangrove trees are well adapted to a tidal environment where their roots are covered by water for long periods of time. The trees have developed a homeostatic adaptation called pneumatophores to increase the level of oxygen delivered to the roots, avoiding the effect of water logging and rotting.
Geological events	The movement of plate tectonics, earthquakes, landform creation and soil formation have influenced the evolution of organisms. This occurs mainly by isolating populations over time and consequently creating environments with specific ecological features leading to the organism adapting and surviving in the new environment.	Australia became isolated from the Gondwana super continent 350 million years ago. All organisms living on our continent became isolated from the influences of organisms living on other continents. They also became diversified and well adapted to specific environmental niches, consequently creating the unique Australian flora and fauna.

Nuclear reactions and the interpretation of the laws of conservation of mass and energy

6.4.12 Einstein

In 1905, Albert Einstein published his theory of relativity and challenged the laws of conservation of mass and energy in a nuclear system. In a nuclear reaction, the amount of mass reacting is not equal to the amount of mass and energy generated from it. Therefore, these reactions do not follow the statements of the laws, which states that nothing is destroyed or created. Consider the amount of energy released from an atomic bomb and compare it with the amount of mass of enriched uranium used to create the explosion.

9780170411196

Imagefolk / Ewing Galloway / UIG

Imagefolk / Richard Levine

FIGURE 6.4.14 Aerial photographs of the atomic bombs dropped on Japan in 1945 showing the gigantic cloud of debris, gas and ashes.

INQUIRING FURTHER

What were the theories and laws that Einstein based his special and general theory of relativity on?

KEY THEORY

Theory of special relativity: energy–mass equivalence

Energy and mass are equivalent and are interconvertible.

KEY FORMULA

$E = mc^2$

where

E = energy, measured in Joules

m = mass, measured in kilograms

c = speed of light, 3×10^8 m s^{-1}

Einstein proposed the energy–mass equivalence. This means that mass can be created sacrificing energy and energy can be created by destroying mass.

The relationship between mass and energy in the energy–mass equivalence proposed by Einstein is $E = mc^2$.

WORKED EXAMPLE 6.4.1

QUESTION

If you are able to convert the 250 g of mass of cereal that you eat for breakfast every morning, how much energy can you produce?

ANSWER

Applying the formula $E = mc^2$; given mass $(m) = 250$ g and speed of light $(c) = 3 \times 10^8$ m s^{-1}

$E = 0.25 \text{ kg} \times (3 \times 10^8)^2$

$E = 2.25 \times 10^{16}$ Joules

This amount of energy is similar to the amount of energy produced by a massive power station.

Einstein's formula and the equivalence of mass–energy can be applied to nuclear reactions and nuclear decay.

Nuclear reactions

To understand how mass and energy are linked in nuclear reactions, two concepts need to be clear: **mass defect** and **binding energy**.

Mass defect refers to the concept that the total mass of the atom, as a whole, is smaller than the total mass of the component particles (protons, neutrons and electrons). Binding energy is the energy needed to separate the atom into its components. The relationship between the two concepts is shown in Figure 6.4.15.

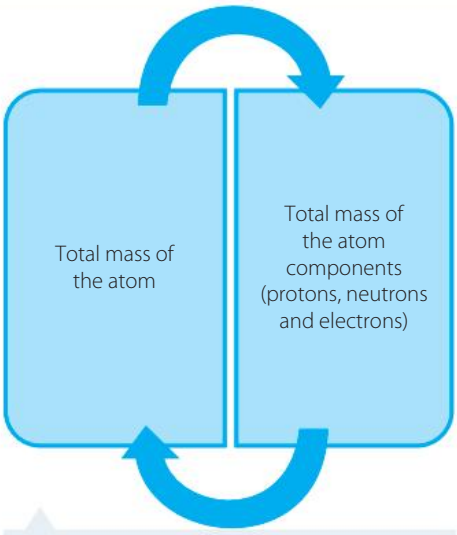


FIGURE 6.4.15 The relationship between the total mass of an atom and the total mass of all of the components of an atom.

6.4.13 Nuclear reactions

mass defect mass of the whole atom is less than the total mass of its components (protons, neutrons and electrons)

binding energy energy required to completely separate the atomic nucleus into its components (protons, neutrons and electrons)

Applying the knowledge of mass defect and binding energy, it can be shown that a nucleus that is stable has higher binding energy compared with a nucleus of an unstable atom. This has enormous implications in the two types of nuclear reactions: **fission** and **fusion**. In fission nuclear reactions, a large element is split to form smaller daughter elements. Energy is liberated in fission reactions and the binding energy in the daughter elements is smaller. An example of fission reactions is the splitting of uranium in a change reaction (Figure 6.4.16).

fission
nuclear reaction when a heavy atomic nucleus is split into smaller ones

fusion
nuclear reaction when smaller nuclei fuse to form heavier ones releasing energy in the process

On the other hand, in fusion nuclear reactions, smaller elements are fused together to form heavier elements and consequently release energy. Our Sun fuses hydrogen to produce helium and an enormous amount of energy is released.

6.4.14 Mass defect

Nuclear decay

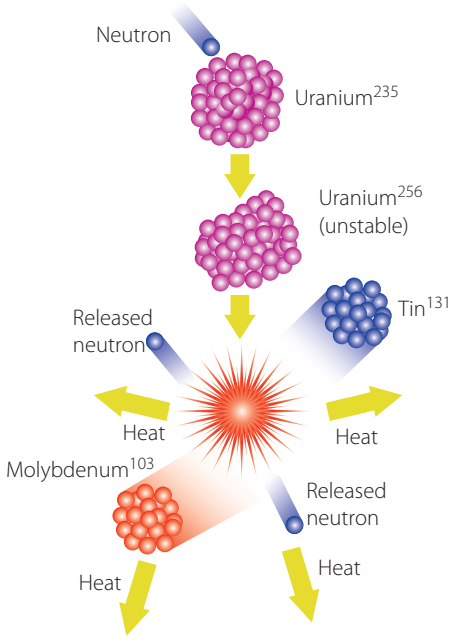
Unstable atoms transform (transmute) over time and become other elements. The process of transmutation is natural for many elements and can occur through alpha, beta and gamma decay. When elements decay, energy radiation and particles are emitted. The resultant new atom after the decay is called a daughter atom.

nuclear decay
process by which an unstable atomic nucleus loses energy by emitting radiation in the form of gamma rays or particles in the form of alpha and beta radiation

beta particle
fast moving electron emitted by radioactive decay

gamma radiation
penetrating radiation released from an atomic nucleus during radioactive decay

The relationship between mass and energy in **nuclear decay** is given by the reduction of mass when alpha or **beta particles** are emitted, or when energy is released as **gamma radiation** because atoms discharge the excessive amount of energy from the nucleus (Figure 6.4.17).



'Physical Resources: Energy - Nuclear', McGraw-Hill, © Mc Graw-Hill Education

FIGURE 6.4.16 Chain nuclear reactions are an example of the unification of the laws of conservation of mass and energy into the mass–energy equivalence. The amount of mass of the reactants is not equal to the mass of the products due to the fact that some of the mass is converted into energy in the forms of photons, heat and new smaller elements. From uranium-236 other elements are formed, such as molybdenum-103 and tin-131.

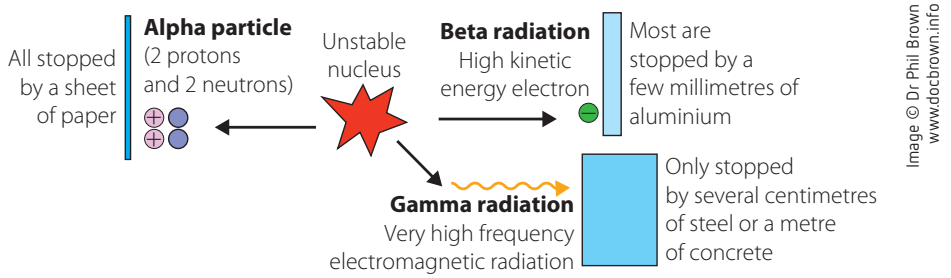


Image © Dr Phil Brown www.docbrown.info

FIGURE 6.4.17 Mass and energy relationship in nuclear decay as alpha, beta and gamma emissions.

INQUIRING FURTHER

The OPAL reactor is used to develop a wide range of technologies. Choose one and investigate its development and purpose. As part of the investigation, research the ethics of using nuclear energy and reactions. Present your investigation as a short scientific magazine article.

The understanding of the mass–energy equivalence proposed by Einstein led to the creation of nuclear technologies using nuclear reactions and nuclear decay. Some examples are nuclear medicine and carbon dating. However, it also allowed the creation of nuclear weapons.

9780170411196

INVESTIGATION 6.4.5

Merging of energy–mass conservation laws

AIM

To investigate using secondary-sourced data on the merging of the energy–mass conservation laws

MATERIALS

- Internet search engines
- calculator

METHOD

1. Define 'alpha', 'beta' and 'gamma emissions'.
2. Define 'parent element' and 'daughter element'.
3. Define 'half-life' and identify the half-life of five different elements.
4. State the formula used to calculate nuclear decay.
5. Choose three or more elements, such as carbon, uranium and thorium, and research their atomic structure and calculate their nuclear decay.
6. Analyse your data in terms of the law of conservation of mass and energy.

DISCUSSION

1. List the type of emissions released in each of the elements that you have chosen.
2. Considering your calculations, explain how the energy–mass conservation laws can be interpreted.

INQUIRING FURTHER

In the paper-making industry, beta radiation is used to check that the paper is being produced to the correct thickness. Investigate why beta radiation is used here rather than alpha or gamma radiation. Present your research as an oral presentation with a short video, PowerPoint or animation.

SECTION REVIEW 6.4

REMEMBERING

1. Describe the applications of laws and theories in science.
2. Define 'the law of conservation of energy'.
3. State Einstein's formula and what it means.

UNDERSTANDING

4. Explain how the law of conservation of energy is applied in each of the following areas of science. Give an example for each.
   - a Physics
   - b Chemistry
   - c Biology

APPLYING

5. Global warming is a fact for our planet. Discuss how the law of conservation of energy can be applied to understand the effect of global warming on Earth.
6. Einstein unified the laws of conservation of mass and energy into one theory. Discuss how the laws were unified and the application for today's nuclear research.

CHAPTER REVIEW QUESTIONS

REMEMBERING

1. Define 'theory' and list two examples.
2. Define 'law' and list two examples.
3. Describe the differences between a theory and a law using examples.
4. Describe the steps in the development of a theory.
5. Describe the steps in the development of a law.

UNDERSTANDING

6. Explain why the theory of plate tectonics is not a law. Use the evidence for the theory as examples.
7. Provide the corresponding theories and laws for the following evidence:
   - **a** convection currents
   - **b** redshift
   - **c** cosmic microwave radiation
   - **d** common fossils across continents
   - **e** mid-ocean ridges and crust formation
   - **f** same elements across the universe
   - **g** amount of mass in reactants is equal to the amount of mass in products
   - **h** energy is always conserved in a pendulum
8. Dr Smith is researching a new law in physics. He has collected data from experiments. Explain the next step that Dr Smith has to follow in order to demonstrate his law.
9. Over time, many theories have been disproved. Choose a theory that has been disproved and explain the evidence gathered which led to the development of a new theory.
10. Ohm's law can be used to predict different situations relating to voltage, current and resistance. Explain this statement.

APPLYING

11. Jannette is a student researching new species of snails in the rainforest. She is observing a snail that has a particular shape of shell that can fit inside small burrows in decomposed branches. Explain how this snail provides further evidence to support Darwin's theory of evolution.
12. A roller coaster is being designed for a new theme park in Sydney. However, the carts cannot finish the first loop. Analyse this situation using the law of conservation of energy.
13. A new species of beetle has been introduced into the ecosystem. Previously, frogs in the area fed on a native species of beetle but now they prefer the new beetle because it does not camouflage itself in the environment. Explain this ecological situation using the law of conservation of energy.
14. Design a simple experiment to apply the law of conservation of mass in a chemical reaction.
15. Select three facts involved in the application of the law of conservation of energy to climate change.

ANALYSING

16. Use a Venn diagram to compare and contrast the similarities and differences between the law of conservation of mass and the theory of plate tectonics in terms of the types of evidence and data gathered.

9780170411196

17 For many years it was believed that the emus in Australia, ostriches in Africa and rheas in South America evolved from a common ancestor that lived when the continents were part of Gondwana. However, recent DNA studies have demonstrated that this is not the case. Analyse this information using the theory of evolution and the theory of plate tectonics.

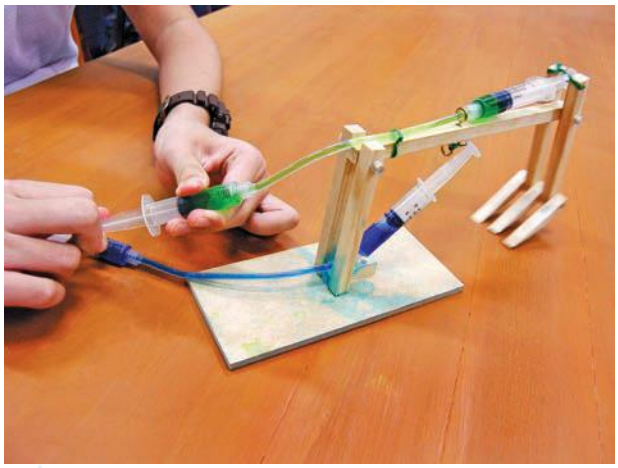
18 As a chief astronomer of a cosmological research facility, you have the mission to disprove the steady state theory of the universe. Develop the steps that you are going to follow to disprove the theory and discuss what theory will replace it.

19 Create a short survey to investigate the understanding of the theory of evolution in a sample population.

20 Analyse why it was very difficult for societies living before the 20th century to accept many of the laws of physics, chemistry and biology.

SYNTHESISING

21 Observe the experimental set-up shown in Figure 6.5.1. Design a method to gather evidence for the law of conservation of energy and infer what possible results you might observe when conducting this investigation.



Dreamstime.com / Joanne Zheng

FIGURE 6.5.1 Hydraulics investigation

22 Suppose that you could go back in time and visit Aristotle. Write a short essay on how you would explain to him the current theories and laws about the universe.

EVALUATION

23 Assess the type of evidence that shows that the theory of evolution is accepted as a unified theory for biological phenomena.

24 Discuss the contribution of Einstein in the interpretation of the laws of conservation of mass and energy in nuclear reactions.

DEPTH STUDY
BIOLOGY

NATURAL SELCTION IN AUSTRALIA

Suggested length: 10 hours including research and submission of report

Focus: Analyse secondary sources, report

6.5.1 Secondary investigation scaffold

SECONDARY-SOURCED INVESTIGATION SCAFFOLD

Syllabus outcome

Identify the syllabus outcome you will be investigating and write a summary of the outcome.

Syllabus statement: *Investigating the theory of evolution by means of natural selection*

Introduction

This is the background information about the topic. In a primary investigation, identify the experiment you will be conducting. In a secondary investigation, make sure your sources are valid.

Write around 800 words

Explain briefly the theory of evolution by means of natural selection

Outline an example

Hypothesis (if applicable)

A hypothesis is an educated (informed) guess that is tested through investigation to explain and reach answers to scientific questions.

Aim

Write the aim as a sentence. Start the sentence with 'To' followed by a verb; for example, 'investigate', 'measure' or 'test'.

To investigate the process of natural selection in an Australian animal

6.5.1 Natural selection
6.5.2 Australian flora and fauna and Darwin
6.5.3 Natural selection fact sheets
6.5.4 Darwin in Australia

Secondary sources

List all of the sources that you are using in your investigation and cite them using the correct citation protocols.

Suggested sources:

- Futuyma, Douglas (2016). *Natural Selection, how evolution works*. ActionBioscience
- National Library of Australia
- Cool Australia
- Nicholas, Frank

Investigation design

Outline how you are designing the final presentation (refer to Chapter 1 for further information).

Method

The method is written as numbered steps. Each sentence must start with a verb.

Results

The results may be recorded in tables, graphs or diagrams, or written as observations in sentence form.

Validity and reliability

Remember that validity is related to ensuring that the sources come from educational, government, university or scientific web pages, journals and textbooks. Reliability is associated with finding similar explanations of the concepts across many sources.

Discussion and conclusion

In the discussion and conclusion, analyse your findings to answer your hypothesis, aim and inquiry question/s.

9780170411196

LAW OF CONSERVATION OF MASS

DEPTH STUDY
CHEMISTRY

Suggested length: 10 hours including research and oral presentation of a PowerPoint in a mock 'Chemistry Conference'

Focus: Primary investigation, PowerPoint presentation in a mock 'Chemistry Conference'

PRIMARY INVESTIGATION SCAFFOLD

Syllabus outcome

Identify the syllabus outcome you will be investigating and write a summary of the outcome.

Syllabus statement: *Investigating the law of conservation of mass*

Introduction

This is the background information about the topic. In a primary investigation, identify the experiment you will be conducting. In a secondary investigation, make sure your sources are valid.

Write around 800 words

Explain the law of conservation of mass, using an example that will support your experimental design and results

Hypothesis (if applicable)

A hypothesis is an educated (informed) guess that is tested through investigation to explain and reach answers to scientific questions.

The masses of the products will be equal to the masses of the reactants in the chemical reaction between…

Aim

Write the aim as a sentence. Start the sentence with 'To' followed by a verb; for example, 'investigate', 'measure' or 'test'.

To investigate the law of conservation of mass in the chemical reaction between…

Secondary sources

List all of the sources that you are using in your investigation and cite them using the correct citation protocols.

Suggested sources:

- AlgebraLAB
- Mugup.in
- BBC – GCSE Bitesize

Investigation design

Outline how you are designing the final presentation (refer to Chapter 1 for further information). Make sure you include the following (if applicable):

- Variables (independent, dependent, controlled)
- Treatments/control

Method

The method is written as numbered steps. Each sentence must start with a verb.

Results

The results may be recorded in tables, graphs or diagrams, or written as observations in sentence form.

Validity and reliability

Remember that validity is related to the method and equipment used to perform your experiments, whereas reliability is associated with the repetition of the experiment obtaining similar results with minimal error.

Discussion and conclusion

In the discussion and conclusion, analyse your findings to answer your hypothesis, aim and inquiry question/s.

6.6.1 Primary investigation scaffold

6.6.1 Conservation of matter
6.6.2 Law of conservation of mass
6.6.3 Conservation of mass

DEPTH STUDY
PHYSICS

LAW OF CONSERVATION OF ENERGY

Suggested length: 10 hours including research and video presentation of the Goldberg machine

Focus: Primary investigation and investigation report

6.7.1 Primary investigation scaffold

PRIMARY INVESTIGATION SCAFFOLD

Syllabus outcome

Identify the syllabus outcome you will be investigating and write a summary of the outcome.

Syllabus statement: *Investigating the law of conservation of energy*

Introduction

This is the background information about the topic. In a primary investigation, identify the experiment you will be conducting. In a secondary investigation, make sure your sources are valid.

Write around 800 words

Define the law of conservation of energy

Explain the timeline of the discovery of the law of conservation of energy

Describe a Goldberg machine and give examples

Hypothesis (if applicable)

A hypothesis is an educated (informed) guess that is tested through investigation to explain and reach answers to scientific questions.

The law of conservation of energy can be proven using a Goldberg machine.

Aim

Write the aim as a sentence. Start the sentence with 'To' followed by a verb; for example, 'investigate', 'measure' or 'test'.

To investigate the law of conservation of energy in a Goldberg machine

6.7.1 Rube Goldberg Ideas

6.7.2 ideas for Goldberg machines

6.7.3 Water and energy

Secondary sources

List all of the sources that you are using in your investigation and cite them using the correct citation protocols.

Suggested sources:

- Rube Goldberg
- Mashable Inc
- The Physics Classroom

Investigation design

Outline how you are designing the final presentation (refer to Chapter 1 for further information). Make sure you include the following (if applicable):

- Variables (independent, dependent, controlled)
- Treatments/control

Method

The method is written as numbered steps. Each sentence must start with a verb.

Results

The results may be recorded in tables, graphs or diagrams, or written as observations in sentence form.

Validity and reliability

Remember that validity is related to the method and equipment used to perform your experiments, whereas reliability is associated with the repetition of the experiment obtaining similar results with minimal error.

Discussion and conclusion

In the discussion and conclusion, analyse your findings to answer your hypothesis, aim and inquiry question/s.

9780170411196

DEPTH STUDY
INVESTIGATING SCIENCE

PLATE TECTONICS FROM GONDWANA TO AUSTRALIA

Suggested length: 10 hours including research and submission of video production (mock film documentary festival)

Focus: Analysis of secondary sources, video production

SECONDARY-SOURCED INVESTIGATION SCAFFOLD

Syllabus outcome

Identify the syllabus outcome you will be investigating and write a summary of the outcome.

Syllabus statement: *Investigating the theory of plate tectonics*

Introduction

This is the background information about the topic. In a primary investigation, identify the experiment you will be conducting. In a secondary investigation, make sure your sources are valid.

Write around 800 words

Explain briefly the theory of plate tectonics

Outline an example of the evidence for this theory that will support your research

Hypothesis (if applicable)

A hypothesis is an educated (informed) guess that is tested through investigation to explain and reach answers to scientific questions.

Aim

Write the aim as a sentence. Start the sentence with 'To' followed by a verb; for example, 'investigate', 'measure' or 'test'.

To investigate the theory of plate tectonics using Australia as a case study

Secondary sources

List all of the sources that you are using in your investigation and cite them using the correct citation protocols.

Suggested sources:

- Hammonds, M
- Australian Museum
- Australian National University Research School of Earth Sciences

Investigation design

Outline how you are designing the final presentation (refer to Chapter 1 for further information).

Method

The method is written as numbered steps. Each sentence must start with a verb.

Suggested steps:

1. *Research the movement of the Australian plate over millions of years from Pangaea to today.*
2. *Draw a timeline of the movement.*
3. *Analyse the climate changes, flora and fauna changes during the 'migration' of Australia from Pangaea to today.*
4. *Predict and analyse the future of the Australian continent's climate, flora and fauna in the next 10 000 years.*

Results

The results may be recorded in tables, graphs or diagrams, or written as observations in sentence form.

Validity and reliability

Remember that validity is related to ensuring that the sources come from educational, government, university or scientific web pages, journals and texts. Reliability is associated with finding similar explanations of the concepts across many sources.

Discussion and conclusion

In the discussion and conclusion, analyse your findings to answer your hypothesis, aim and inquiry question/s.

6.8.1 Secondary investigation scaffold

6.8.1 Plate tectonics
6.8.2 Plate tectonic processes
6.8.3 Australia in time and space

ANSWERS

CHAPTER 3

SECTION REVIEW 3.1

Remembering

1 See, hear, taste, smell, feel

2 a Quantitative observation: data that is observed using measuring equipment and recorded in numerical form.

b Qualitative observation: data that is observed and recorded as a description.

c Inference: an attempt to explain an observation using reasoning.

Understanding

3 Archimedes used water displacement to determine the density of the crown in relation to its mass. He submerged a piece of gold with the same mass as the crown to observe its water displacement. When he realised the water displacement was different between the two, he could confirm that the two were not made of the same material.

4 Answers may vary.

Applying

5 a quantitative observation

b qualitative observation

c inference

d qualitative observation

e inference

f inference

6 Answers may vary.

7 Answers may vary.

SECTION REVIEW 3.2

Remembering

1 Observations may vary between scientists; there is not one definitive answer.

2 Radiometric dating is a quantitative observation that determines the age of rocks by using the rate of decay in the radioactive isotopes present.

Understanding

3 pH can be quantitatively described through the use of a pH data logger. pH can be qualitatively described by comparing the colour of universal indicator exposed to a substance.

4 Quantitative data from diagrams of cells includes cell size. Cell size is related to its function and by gathering data on size, scientists may be able to gain insight regarding the function of the cell.

Applying

5 a Answers may vary.

b Answers may vary.

6 Quantitative data is the most accurate form of data as it relies on scientific equipment to collect definitive measurements. Qualitative data is less accurate as it involves describing information that can be interpreted differently by different individuals.

7 a Outcrop II and outcrop III both have 6 layers. Outcrop I only has 5 layers. Other answers are possible.

b Sedimentation between layers N and O has been affected in some way. Other answers are possible.

c Outcrop I. The deeper the rock, the older the fossils; Outcrop I has more layers underneath the same type of trilobite found in Outcrop II and III.

8 Answers will vary.

SECTION REVIEW 3.3

Remembering

1 a Dependent variable: the factor being measured in the investigation.

b Independent variable: the factor being deliberately changed during an investigation.

c Controlled variable: the factors that are kept the same in an investigation.

2 To foresee any possible risks and ensure that a plan is put in place to prevent personal injury.

3 Student answers may vary but could include three of; allergy, insect bite, sunburn, dehydration and trip hazards.

Understanding

4 Developing a research question, forming a hypothesis, assessing risk, constructing a method.

5 A hypothesis must state a relationship between the independent and dependent variables. This relationship may not be correct but it is what the scientist conducting the experiment aims to support or disprove.

6 Answers may vary.

Applying

7 Controlling any variables that are not being studied is very important in primary scientific investigations as there can only be one factor that is changed and all other factors must be kept the same. Having variables controlled ensures that the investigation is measuring what it intends to measure by removing any other factors that may affect the result of the experiment. If these variables are not controlled, a scientific investigation is not valid and therefore cannot be used as evidence to support further investigation.

8 Valid data is derived from an investigation where all variables have been considered and controlled. There can only be one independent variable and all other factors must be kept the same (controlled). For example, if an investigation is designed to test how different fertilisers affect plant growth, the fertiliser is the only factor that can differ between each plant. The species and age of the plant, pot size, amount of soil and water given,

9780170411196

availability of sunlight and exposure to other environmental factors must be the same. If anything else is different, then the results are not valid and can not be used for further investigation.

9 Figure 3.3.8 shows two plants that are not identical (one with red flowers and the other with white flowers). When conducting a valid experiment, all factors must be controlled other than the independent variable. In this experiment, the independent variable is the fertiliser and therefore the plants should be exactly the same. Because the plants are different, the scientist will not be able to confirm that it is only the fertiliser increasing the flower growth as the plant with red flowers may naturally bloom more than the white (or vice versa).

SECTION REVIEW 3.4

Remembering

1 Tables, graphs, visual representations, digital representations

2 a numerical

b numerical

c numerical and categorical

d percentage

3 Simulations

Understanding

4 Diagrams are an efficient way to present data as they remove any scientific jargon from the results and show the data in its simplest form, making it more accessible to a wider audience. Diagrams such as graphs not only show whether a relationship exists between two factors but also depict the direction and strength of the relationship.

5 Qualitative and quantitative data can both be tabulated where the independent variable is represented in the columns and the dependent variable in the rows. When tabulating quantitative data, it is usually necessary to include multiple trials and an average column. All units must be also shown in the column headings, in brackets. Qualitative data does not usually involve units but data should be compared with other groups to ensure the results collected are reliable.

6 By conducting multiple trials and finding an average, the data collected is more reliable. It also allows scientists to remove any outliers that may have been a result of error.

Applying

7 Answers may vary but should be similar to that shown below.

	HEIGHT DRONE FLIES (m)			
	TRIAL			
Weight added to drone (kg)	1	2	3	Average (m)
3				
4				
5				
6				

8 The population of both predator and prey fluctuates over time. The graph shows that shortly after a spike in prey population, there is also a spike in predator population. Following the increase in predator population, the prey population decreases and then so too does the predator population. This pattern continues over the 80-year time period shown.

9 Stippling allows scientific drawings to emphasise small details in biological specimens. By using stippling, scientists can add dimension and depth to their drawings to create an illustration that is a true representation of the specimen under the microscope.

SECTION REVIEW 3.5

Remembering

1 A brief summary that answers the aim by referring to results.

2 Technology and societal norms.

3 Answers will vary but may include predicting chemical reactions, determining conductive properties of metals and DNA analysis.

Understanding

4 As fellow biologists, Charles Darwin and Alfred Wallace communicated with one another and realised they had both independently devised a similar theory. Shortly following their exchange of ideas, Charles Darwin published the theory of evolution by natural selection in his book, *On the Origin of Species*. Through collaboration, Darwin gained confirmation that his theory was plausible, which may have been the driving force behind his decision to publish the theory.

5 Answers may vary but could include: Aristotle, Ptolemy, Copernicus and Galileo.

Aristotle made observations and put forward the theory that the Earth is spherical rather than flat.

Ptolemy used mathematical principles such as 'spherical trigonometry' to develop the geocentric model of the universe. He placed the Earth in the middle of the Solar System with the Sun and other planets orbiting around it.

Copernicus used the same orbital structure but instead placed the Sun in the centre of the Solar System.

Galileo invented the telescope and observed that some planets have moons orbiting around them. In particular, he referred to Jupiter's moons.

6 Wegener used evidence including continental margins and fossils to conclude that over time the continents had drifted away from each other. Hess used this evidence to support his theory that new rock is formed at mid-ocean ridges, spreads across the sea floor and pushes the continents away from one another.

Applying

7 Answers will vary.

8 Answers will vary.

9 Answers will vary.

CHAPTER REVIEW

Remembering

1 Answers will vary depending on the terms selected.

2 Answers will vary but could include the following:

- Qualitative: smell of candle burning, colours of flame, direction of flame when tilted, colour of smoke, position of wick, sound produced by burning candle.
- Quantitative: time candle takes to burn out, number of times wax drips, height of the flame, width of unlit candle, duration of smoke when candle is extinguished.

3 Mohs' hardness scale

Understanding

4 Observations of seed germination and plant growth following fires led to the development of controlled burning. Not only did it reduce the risk of spontaneous fires in the hotter months, but it also increased nutrient availability in the soil and germinated seed, triggered by heat and smoke.

Applying

5 Answers will vary but could include:

- Qualitative: labelled organelles
- Quantitative: magnification, objective used, size of cell/specimen

Analysing

6 Answers will vary but should include:

- An aim that states that the investigation is testing how a change in water pressure affects the speed at which it travels.
- A hypothesis that outlines the relationship between water pressure and speed of movement.
- A method that includes how pressure will be changed and how speed will be measured. It must also consider and control all other factors such as water temperature, length of water canal, and environmental conditions (e.g. wind).
- A results table that includes an average of three trials.

Evaluating

7 Yes, the student is correct. Quantitative data is collected using scientific equipment that gives a numerical value. This form of data collection requires less guesswork and personal opinion than qualitative data. There is less error when collecting data quantitatively which therefore makes it more accurate than qualitative data collection.

8 Answers will vary but must describe the importance of Mendel's work. For example, he was the first person to carry out experiments in which he analysed the patterns of inheritance of observable characteristics and explained these patterns mathematically.

Creating

9 Answers will vary but should follow the guidelines of scientific drawing, including:

- use of stippling (dots) to emphasise features
- at least half A4 size
- title with the magnification
- only draw what is seen under the microscope.

CHAPTER 4

SECTION REVIEW 4.1

Remembering

1 a Observation: data that is recorded on a particular phenomenon that is yet to be interpreted.

b Inference: an observation of phenomena is analysed using reasoning to produce a possible explanation for the phenomena.

Understanding

2 When a scientist makes an observation of phenomena they use reasoning to explain the phenomena. The reasoning they use is influenced by the scientist's past experiences, their assumptions about how things work, the amount of evidence available to them and the collective understanding of their culture. For this reason scientists need to be aware that these influences can lead them to make an inference that is incorrect. To account for this, scientists test their inferences using scientific processes such as experimentation and peer review. As a result a scientist can come closer to finding the truth and developing an understanding of phenomena and the natural world.

3 An observation is the data recorded on phenomena. These observations are used to make an inference that explains the phenomena. Once this inference is made it can be used to make a generalisation that explains similar phenomena even though an observation of them may not have been made.

Applying

4 Answers will vary; the following gives a possible answer.

An observation was made that calcium carbonate produced a large amount of bubbles and increased in temperature when added to hydrochloric acid. From this observation it was inferred that the calcium carbonate was reacting with the hydrochloric acid. I wondered if such a reaction would occur in all situations and decided to test this generalisation by conducting an experiment that tests the hypothesis, 'If the concentration of hydrochloric acid is increased then the reaction with calcium carbonate will be more vigorous'. I investigated this by having three different concentrations of hydrochloric acid and added to the same quantity of calcium carbonate to it (in the same form). I then ranked the amount of bubbles produced as small, medium or large, and measured the temperature change. The results indicated that my hypothesis was correct and suggested that it is possible to make a generalisation that the concentration of reactants influences reaction rates.

5 The claim that a person can catch the flu by being exposed to cold weather can be challenged using reasoning. There are four aspects to reasoning: personal experience, assumptions, available evidence and collective understanding. By addressing each of these in turn it is possible to generate an alternative inference. For example:

9780170411196

Reflecting on personal experience suggests you should examine occurrences where you have caught the flu without being exposed to the cold, or when you have been exposed to the cold but not caught the flu.

Examining assumptions would require that possible alternative explanations be sought for why you catch the flu, such as micro-organisms and viruses.

Analysing available evidence means assessing whether there is enough valid and reliable evidence to confirm or refute the inference that being exposed to the cold leads you to catch the flu or whether more evidence needs to be gathered.

Acknowledging collective understanding means recognising that knowledge is culturally transmitted and the knowledge you have depends on your cultural group. Seeking alternative explanations, perhaps from scientists or medical doctors, is likely to give an alternative explanation: that a virus is the reason you catch the flu.

By addressing the four areas that influence a person's reasoning it becomes possible to challenge the claim that you can catch the flu by being exposed to cold weather with an alternative inference that a virus is the reason people catch the flu.

6 Aboriginal and Torres Strait Islander peoples may have inferred that a plant was poisonous by first making a number of observations. One observation they may have made is noticing if and when native animals such as birds and mammals willingly ate the plant. If these animals did so then it is very likely that Indigenous peoples would infer that the plant was not significantly poisonous. An adult may then have tested a very small quantity and noted any observations such as taste, and feelings of nausea or other side effects. If no such observations were made then they may have inferred that it is possible to try more. If this process continued with close observations of any side effects until a full meal was consumed, then it could be concluded that the plant is not poisonous.

Analysing

7 An initial observation that Aboriginal and Torres Strait Islander peoples may have made to determine which plant foods could be leached to remove toxins was if a plant seed or tuber of a plant normally considered poisonous was left in some water by chance. Indigenous peoples may have observed that initially the fish in the water did not touch the plant but after a time they began to eat it. From this observation they may have inferred that leaving the plant in the water over time made the plant less toxic. Having made this inference they could have then tested for poison after the plant was leached, in the same way as for determining if a food was poisonous (see answer to question 6).

8 A number of observations may have indicated to Aboriginal and Torres Strait Islander peoples that there was a wonky hole under the surface of the water. These include the water appearing clearer at these points because fresh water is less dense than salt water and would float above the salt water, and that it does not refract light in the same way as salt water. Finally the increased presence of fish in the area would be an indication of the increased nutrients that are released with the fresh water.

SECTION REVIEW 4.2

Remembering

1 a Secondary sources: sources of information and knowledge that do not come from direct experimentation or observation of the subject. A journal article from a periodical is also a secondary source (examples may vary).

b Inquiry question: the question that drives an investigation and seeks to be answered. The question 'How do life forms evolve?' was the inquiry question that Charles Darwin sought to answer with his theory of natural selection (examples may vary).

c Hypothesis: is a causal statement that links an independent and dependent variable and can be tested empirically to produce evidence that supports or refutes it. For example, if gravity is a force then it should be able to change the motion of an object (examples may vary).

Understanding

2 It is a good idea to consult secondary sources when undertaking an investigation for a number of reasons. These include reviewing secondary sources to avoid unnecessary repetition of investigations that have been performed and verified in the past, thus reducing the potential for wasting time, energy and resources.

Critically analysing secondary sources to get an idea of which questions in an area of interest have not been (or were poorly) addressed can help identify the questions that most need to be answered and build a more complete understanding.

Learning from secondary sources to see how similar or related investigations were conducted in the past can inform you of the methods and techniques that were the most effective (or not).

Consulting secondary sources can save you a considerable amount of time, effort and resources, and helps to focus your efforts on an investigation that will build scientific knowledge and understanding.

3 When a scientist records their work for others to access they are creating a secondary source of information. In this way their observations, thoughts, results and conclusions can be accessed by a whole range of people over considerable distances and time frames. Therefore, a scientist working today is able to learn from fellow scientists who work in other countries or have lived generations before them. This significantly reduces the need to 'start from the beginning' to build knowledge and understanding, and instead allows scientists to continue building on the knowledge and understanding of those that came before them.

Applying

4 When you begin a scientific investigation it can be difficult to know where to start and to determine what question you want to investigate. Taking the time to consult secondary sources can help. As you read the secondary sources you will become more familiar with the field of research, the concepts and terminology used, and even conflicting and complementary theories and hypotheses that have been explored. A more complete picture of the issues can be formed and the areas where questions remain unaddressed or incompletely addressed become clearer. One of these questions can then be selected as the basis for your own investigation.

5 The inquiry question contains both the independent and dependent variables of the proposed investigation. Both variables will need to be searched to find relevant secondary sources. The independent variable is the air pressure in a soccer ball, suggesting key search terms would be soccer ball and air pressure, as well as units of air pressure; for example, kilopascals (kPa) or pounds per square inch (psi). The dependent variable is how far the soccer ball travels with the same force, suggesting key search terms such as distance and force. The terms soccer ball, distance and force are not interchangeable concepts and would require the use of 'and' during the search, whereas air pressure, kilopascals, kPa, pounds per square inch and psi are interchangeable concepts which can use 'or' during the search.

Possible search terms related to the inquiry question, from most to least effective, include:

- 'soccer ball' and 'distance' and 'force' and 'air pressure' or 'psi' or 'kPa'
- 'soccer ball' and 'force' and 'air pressure'
- 'soccer ball' and 'distance' and 'air pressure'
- 'soccer ball' and 'force'
- 'soccer ball' and 'distance'
- 'soccer ball' and 'kilopascals' or 'kPa'
- 'soccer ball' and 'pounds per square inch' or 'psi'
- 'air pressure' and 'kilopascals' or 'kPa'
- 'air pressure' and 'pounds per square inch' or 'psi'
- air pressure
- soccer ball
- force
- distance.

SECTION REVIEW 4.3

Remembering

1 A type I error is made when one sees a pattern or confirms a hypothesis that is not there. An example of this is seeing a face in the clouds. A type II error is when one fails to detect a pattern or rejects a hypothesis that is there. People who reject that climate change is caused by humans releasing CO_2 into the atmosphere can be said to be making a type II error.

2 The image in Figure 4.3.10 is an optical illusion. It is actually a two-dimensional image drawn on a wall; however, due to the shading and angle of the lines our brains interpret it as being three dimensional.

Understanding

3 The observations and data needed to confirm Alfred Wegener's hypothesis were collected from all over the globe from geological formations that extend into the Earth's ancient past. As a consequence it took a considerable amount of time and effort for a large number of scientists to collect and collate the observations and data required to be able to see the pattern Wegener's hypothesis described. Coordinating this effort and building the body of evidence is the most likely reason why it took so long to support the hypothesis.

4 Of the two investigations,Vin's experiment is likely to have the more reliable hypothesis than Bridgett's. This is because Vin's investigation had a statistical significance (p-value) of 0.01, which indicates there was a 1% chance that her hypothesis was incorrect. Bridgett's investigation had a statistical significance (p-value) of 0.2, which indicates that there was a 20% chance that her hypothesis was incorrect. This indicates that of the two investigations conducted, there is a statistically higher chance that Bridgett's hypothesis is not correct.

Applying

5

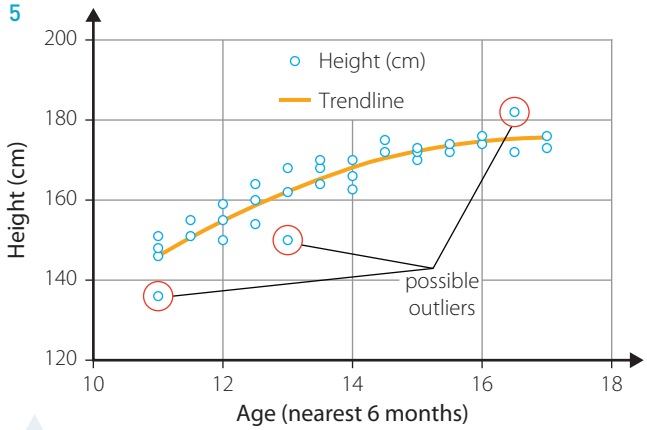


FIGURE A.4.3.1 Line graph showing height of girls by age (all data points included).

9780170411196

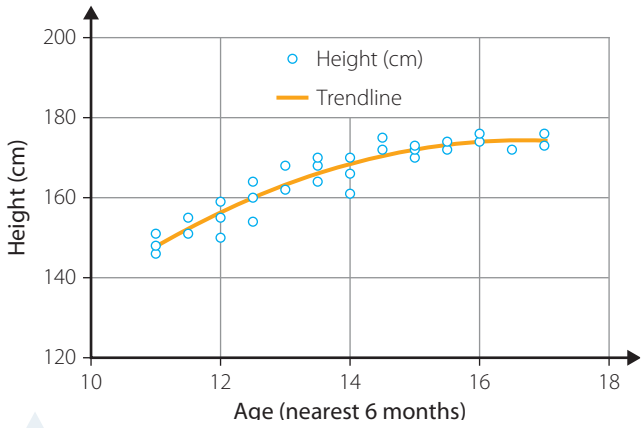


FIGURE A.4.3.2 Line graph showing height of girls by age (with outliers removed).

6 By removing the three outliers identified (the two students who were short for their age and one student who was tall for her age) the scatter plot was changed. The reason for these discrepancies is unknown but factors such as disease or hormonal imbalance may be introducing variables unrelated to the investigation's inquiry question. By removing these outliers the correlation between age and height is improved, as the regression line now goes through the centre of the data points instead of being dragged lower or pushed higher than the majority of points in the first scatter plot. For this reason it is possible to have greater confidence that the second scatter plot is more reflective of the correlation between age and height of girls.

SECTION REVIEW 4.4

Remembering

1 a Assumption: an idea in the form of an inference that was established in the past and is used to inform another inference or investigation. An example is that air resistance has no influence on how fast objects fall.

b Conclusion: a judgement based on evidence that is typically gathered during an investigation. The finding that the shape of a ball influences how fast that ball moves through air, made after conducting an investigation on air resistance, is an example of a conclusion.

c Generalisation: an idea or conclusion that can be applied more broadly to related phenomena. An example is that all objects, not just balls, will be influenced by air resistance as they move through the air.

Understanding

2 Scientists aim to ensure they are not basing their investigations on a false assumption by seeking alternative explanations through the review of related research and secondary sources as well as working collaboratively with other scientists. They also carefully use the scientific method and aim to be objective when reviewing their results.

Applying

3 Longstanding assumptions can be overturned by identifying the variables involved and using the scientific method to empirically test each variable in turn in a controlled experiment. An example of this is how Pasteur tested the idea of spontaneous generation (examples may vary). He did this by boiling a broth in a flask which was 'swan necked' to allow air to reach the broth while trapping any larger particles and germs in the neck. This was then left for some time and the broth did not spoil; however, when the neck was broken, the trap could no longer capture the particles and germs, and the broth soon spoiled. In completing his investigation Pasteur was able to demonstrate that it was germs in the air that caused food to spoil and that spontaneous generation was a false assumption.

SECTION REVIEW 4.5

Remembering

1 Two benefits include the following (other answers are also possible).

- Scientists can crosscheck each other's work, making it less likely that data is misinterpreted or false assumptions made that could influence the conclusions.
- Resources, talent and ideas can be pooled together to save time and effort, and increase efficiency.

Understanding

2 People of different backgrounds may interpret observations and findings differently, and offer different explanations for phenomena. This challenges scientists to evaluate their own perspectives and assumptions, forcing them to either defend their position with evidence or to reject or modify their stance in favour of the new perspective offered. Self-reflection increases the rigour of scientific advances, and ensures any advances that pass this scrutiny are more likely to be valid and reliable.

3 The primary reason that a scientific problem may remain unsolved is that not enough evidence has been gathered to give a definitive answer, or that the results are interpreted in different ways and scientists cannot reach an agreement. To resolve such a problem, more evidence must be gathered , which can be enabled through advances in technology, and improved collection and collation techniques.

Applying

4 Answers will vary based on the form of agriculture chosen. The following is for aquaculture.

- Aboriginal and Torres Strait Islander peoples traditionally practised aquaculture as evidenced by the Brewarrina fish traps which are thousands of years old and are one of many examples found all across Australia.
- The Brewarrina fish traps were built and maintained by the Ngunnha people and served as a meeting place for approximately 20 nations of Indigenous peoples. As such, they are likely to have supplied food to thousands of people on a seasonal basis as the fish migrated.

- British colonisation resulted in a significant number of Aboriginal and Torres Strait Islander peoples dying of disease. The remaining people were removed and no longer permitted to use or maintain the fish traps. In the 1960s a weir was built upriver which halted the natural flow of the river and caused the traps to run dry.
- The cultural bias of British colonists meant they failed to recognise the purpose of the fish traps or how Indigenous peoples used them. Instead, they imposed their own agricultural practices and denied the Indigenous people the means to obtain their own food via the fish traps. As a result, the health and wellbeing of Indigenous peoples declined and they were displaced from their traditional lands.

CHAPTER REVIEW

Remembering

1 Avoiding unnecessary investigations, to make inferences from the work of other scientists, help develop inquiry questions that can be investigated, learn from research methods of similar investigations and construct hypotheses to test variables identified in the research.

2 Data outlier: an observation or measure that is noticeably different or distant from other observations or measures, likely due to an error in data collection or the introduction of a random variable.

Correlation: the strength of a relationship between two variables; a good correlation is when data points in a scatter plot show a clearly observable pattern while a poor correlation would not show any pattern.

3 Answers will vary. One example is the migration of marine birds from southern Australia to Alaska. Every year the birds migrate south for the Australian summer before heading north for the northern hemisphere's summer. The migration takes a full year.

4 They were able to leach toxins from a number of different plant foods by soaking the plant for an extended period of time in water. The toxins which are soluble in water are reduced enough to make the plant safe to eat.

5 A type II error occurs when a person observes a pattern that is not there. Scientists can make this error by accepting a hypothesis that is not supported by the evidence.

Understanding

6 Answers will vary; one example is spontaneous generation. Spontaneous generation was the assumption that various life forms could arise spontaneously; for example, that maggots would spontaneously appear in meat. Redi disproved this through his experiment involving containers of meat, where one container was covered with gauze to prevent flies accessing the meat. No maggots arose in the covered meat, demonstrating that flies need to be present to lay eggs for life to 'emerge'. Pasteur further disproved spontaneous generation with his swan-neck flasks which demonstrated that microbes in the air spoil the broth in the flask when the neck is broken but do not while the swan neck remains intact. The results of this work finally overturned the assumptions of spontaneous generation and provided the foundations of the new germ theory.

7 A generalisation is when a sample of a particular phenomenon is identified and described, and then used to explain other related or similar phenomena. One possible example is if a scientist observes the mating behaviour of frogs in a pond and finds that the eggs need to be submerged in water to stay alive. From this they may make the generalisation that toads, which are a closely related species, would have a similar mating behaviour and require water to keep their eggs alive as well. This is an example of a generalisation.

8 The similarity is that pareidolia results from a particular type of optical illusion. In both instances the brain uses 'short cuts' and makes assumptions about the information which results in patterns being detected that are not really there. However, they differ in that pareidolia is pattern recognition for seeing faces only, while optical illusions are not restricted only to those that result in 'seeing faces'. In this way pareidolia can be described as arising from a subset of optical illusions.

9 Examples may vary. If one assumes that air has no effect on a falling object then it could be very easy to discount how the shape of an object can influence the rate at which it falls and instead attribute the speed it falls to its mass. This would occur if the investigator's assumptions have blinded them and they haven't taken into account all possible variables in the experiment. A scientist can check that they have not made a false assumption by consulting with others on the possible influencing variables and the design of their investigation.

10 A major part of why this mystery remains unsolved is a lack of data. The first life forms on Earth are recognised as being prokaryotic organisms that are microscopically small and existed very early in Earth's history, approximately 3.5 billion years ago. This means that they and any precursors to life will not have fossilised well. Even if they had formed fossils, the likelihood of any being found is very slim as sedimentary rocks that old are exceptionally rare. For this reason scientists have to rely on trace evidence and inferences based on experimentation and isolated life forms in equivalent environments. However, this evidence and inferences are subject to interpretation and perspective; therefore, until more definitive evidence can be gathered and analysed, the origins of life are a mystery that will remain unsolved.

Applying

11 a The outlier in Figure 4.6.1 is likely to shift the regression line so that it is flatter, or lower, for low values of x. This is because the regression analysis is designed to minimise the distance between the data points and the regression line. Minimising the distance would also result in the line moving left and reduce the strength of the correlation between the variables.

9780170411196

b By removing the outlier in Figure 4.6.1 the regression line will be moved to a position among the remaining data points with approximately half on either side of the line. This is because the outlier is no longer influencing the calculations of the regression analysis. This means the correlation between the variables will be stronger.

12 Answers will vary.

a The burdock leaf has numerous holes in it of various diameter. The margins of the leaf also have sections missing in a number of places. This observation makes no judgement as to what caused the holes and missing sections in the leaf.

b An insect has eaten sections out of the leaf and along its margins; the pattern of sections eaten suggests it was either a caterpillar or a grasshopper.

c If a caterpillar or grasshopper has eaten the leaf then it is very likely they have eaten other leaves and will eat more in the future. There is also likely to be more than one insect. The plant is at risk of more damage from insects.

13 a Answers may vary. One problem is that the sharks are moving over a large distance, making it difficult to follow and track them (even with a satellite tracker). To get this data you would need to go out by boat and take note of all the things in the shark's environment, such as prey species and water temperatures, that may influence the shark's migration. This would need to be done when a shark was in a particular area to collect valid data and it might not be possible to travel the necessary distances in time. Also more than one shark would need to be tracked to build reliable data on which to base conclusions.

b Members of the team can be stationed along the coast so that when sharks come into the area the team can make all the required observations about the environmental conditions (i.e. prey species, water temperature). In this way a more valid and reliable data set can be acquired and used to analyse and then answer the inquiry question more effectively.

14 a Inquiry question: is it possible to break down matter that is a mixture of air, earth, water and fire elements into a pure form?

Hypothesis: If gold is not a pure example of one of the elements of air, earth, water and fire, then it should be possible to break it down into two or more of the elements.

An alternative hypothesis: If air, earth, water and fire are the basic elements, then it will not be possible to break them down into other forms.

b If the air, earth, water and fire assumption was correct then a substance like gold should be able to be broken down into two or more of these elements. However, gold cannot be broken down into simpler elements, unless the atoms are smashed, and even then they do not form air, earth, water or fire. Alternatively, water, earth and air can be broken down into more simple elemental forms. The results of such experiments would disprove the air, earth, water and fire elements assumption.

Analysis

15 a One feature would be the park-like country he saw, as he is noting that this landscape shared a large number of similarities to the carefully managed parks of his homeland. He is perhaps inadvertently acknowledging how Aboriginal and Torres Strait Islander peoples have managed the landscape. He also noted that the 'soil is apparently fitted to produce any kind of grain' yet does not appear to recognise that that is exactly what Indigenous peoples would have been using it for and that it was this way because the soil and grasses had been managed. Finally, the burnt trees may have also given him an indication of just how the Indigenous peoples managed the land.

b When Worgan was confronted with a landscape that was reminiscent of the heavily managed landscape of England (e.g. 'park-like' country), he did not consider that it was the Indigenous peoples that had made it this way, failing to note their possible role in its formation. If he had inquired further or made closer observations of how they managed the land, he may have realised that the landscape was not in its wild state at all. The most likely reason he did not do this was because his cultural bias meant that he saw Aboriginal and Torres Strait Islander peoples as uncivilised and uncultured, and hence incapable of managing the landscape to such a significant degree.

16 Edmond Halley's conclusions were based upon his observations as well as calculations that incorporated Newton's ideas on gravity. However, he understood that the more evidence he gathered the more likely his conclusions would be accepted in the scientific community. By consulting historical literature he was able to make the generalisation that comets orbited the Sun, allowing other scientists to adapt their theories on comet movements immediately instead of waiting for the reappearance of the comet in 75 years for confirmation.

17 a The Tawny frogmouth is using an optical illusion in the form of camouflage to avoid being seen. This is achieved by coloration that makes it difficult to see where the tree ends and the bird begins.

b A type II error is the failure to recognise a pattern that is there. If the ecologist is unaware of the Tawny frogmouth's ability to use the optical illusion to camouflage itself then they may very well underestimate the population in the area. The ecologist would be advised to conduct secondary research on the type of animals likely to be found in the area, and use supplementary count times and methods that are likely to detect the Tawny frogmouth. This may include night counts, photo traps and bird call recordings.

Synthesis

18 a

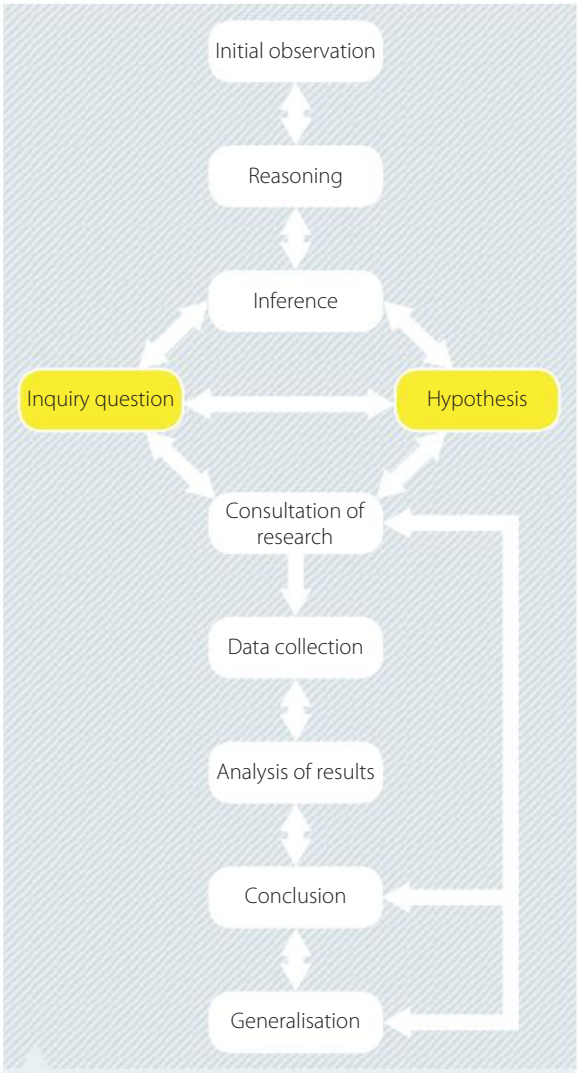


FIGURE A.4.6.1 Concept map

b The first option is to see if the inquiry question she is interested in has been addressed fully by determining if there are flaws in the methods or techniques in any previous studies. If so, she may proceed by conducting a similar investigation that addresses these issues. A second option is to look for related inquiry questions that have not been addressed which are often mentioned in the discussion of a study. She could endeavour to undertake this related study instead of pursuing her initial inquiry question. In this way Emma could still contribute to a field of study that has interest for her.

19 a In conducting the investigation on antibacterial soap it is possible to make a type I or type II error in the laboratory techniques used to prepare or inoculate the agar plates. For example, if the swabs used to take a sample from a person's hand (before and after washing with antibacterial and normal soap) are not sterile then it may result in a type II error occurring and no detectable pattern would be able to be seen.

b Using the example above, a type II error can be prevented by ensuring that the swabs used are sterile and therefore the only microbes that are transferred to the agar plate are the bacteria that were not removed or killed by the different types of soap. Errors can be further reduced by doing repeated plates with numerous participants.

Evaluation

20 a The two ecologists have different life experiences primarily due to their gender, which means that they tend to identify with the perspective of the male and female kangaroos according to their own personal reasoning and stereotypes. The male ecologist has seen competition as the means to gain mating rights to the female kangaroos, while the female ecologist has seen female kangaroo mate choice as motivating the males to fight to prove their fitness.

b A wide diversity of scientists from different backgrounds means that there is a wider range of personal experiences and cultural perspectives, and that there are likely to be different inferences made. By including various inferences it is likely that a more complete understanding and explanation for the phenomena will be developed which is more reliable when applying this knowledge in the real world. In the observations and inferences of the kangaroos, both ecologists are likely to be correct in some way but alone neither would be able to develop a complete understanding of the complexity of kangaroo mating behaviour and evolution.

21 a Scientific knowledge and understanding is built up over time as more evidence is accumulated and different possible theories are presented to explain the observation of a phenomenon like climate change. For this reason having 97.5% of scientists in agreement is actually very significant. It is the job of scientists to question and seek alternative explanations and be sceptical of theories that have an incomplete evidence base. If 97.5% have come to an agreement then it is very likely climate change is happening because of human activity.

b As a part of the peer review process scientists must collectively debate and evaluate the strengths and weaknesses of the various theories presented. This takes time and it is not likely that every scientist will be fully convinced at any given time. It can be expected that 2.5% of scientists may not be convinced that the theory presented adequately explains the observation and want more evidence before coming to a decision.

c Having a diversity of viewpoints is beneficial as each person will bring their own unique perspectives and experiences to the analysis of the data being presented to them. This means that the data can be interpreted in a

9780170411196

number of different ways and promotes debate among the members of the scientific community. Such debate ensures that all voices and opinions are heard and judged against the evidence to get as accurate a picture of the phenomena being studied as possible.

CHAPTER 5

SECTION REVIEW 5.1

Remembering

1 A scientific model is a representation of an idea that attempts to make that idea easier to understand, or a model of an idea that cannot be directly observed.

2 Germ theory states that some diseases are spread by pathogens, small particles that invade a host, causing disruptions to the normal functioning of that organism and thus, illness.

3 At one time, approximately 14 billion years ago, all matter and energy in the universe occupied a single point, smaller than an electron. This region began expanding, eventually forming the universe we can observe today. All galaxies in the universe are observed to be moving away from each other.

4 Atoms are made of a dense nucleus of positive protons and neutral neutrons. This nucleus occupies a very small region in the atom. Electrons orbit the nucleus in fixed shells. These shells are formed at areas where electrons have constructive interferences due to their wavelike nature.

5 Climate modelling takes the various interactions in the environment, such as the incoming solar radiation, the movement of air in the atmosphere, the movement of ocean currents, polar ice levels and acid levels in the sea, and develops computer algorithms based on past trends.

Computers run simulations based on these interactions to predict future patterns.

Understanding

6
- Direct contact. Pathogens can live on the skin, such as tinea, or pass through openings, such as your mouth, nose and eyes, and then enter your body.
- Through the air, which can then be breathed in.
- Through water, which is either breathed in as water vapour and enters the lungs, or is swallowed.

7 In the steady state model the universe has always looked the same. Stars come in and out of existence.

In the Big Bang model, all matter and energy in the universe occupied an infinitesimally small region of space approximately 14 billion years ago. This started expanding rapidly and eventually formed the universe as we see it today.

8 The quantum mechanical model describes matter as having a wave nature. In our everyday world waves and particles are two distinct entities. The model also asks students to conceptualise at a level that we cannot see (the sub-atomic level) which may be hard for primary school students.

9 An increase of average temperatures leads to the reduction in the growth of some plants, particularly those that are used for food. This will potentially lead to shortages of food in some regions.

An increase of temperatures may also lead to warmer oceans, which can lead to an increase in storms such as tropical cyclones. The warmer the temperatures, the more violent the storm.

Melting of polar ice caps will lead to an increase of global sea levels. Some Pacific islands are already experiencing these changes, which is threatening their long term survival.

There are more examples.

Applying

10 It allows people to understand how to potentially prevent deadly outbreaks, for example, if there is a variant of the flu spreading.

11 Biological models, such as the model of the torso showing the major organs, show the size and relative positions of those organs in three-dimensional space. They offer an advantage over diagrams as they can be handled and manipulated.

12 The telescope was initially made after developments in the making of lenses and the establishment of optics as a science. The refinement and further study into the way lenses interacted with each other led to people such as Galileo making improvements to the telescope.

Isaac Newton used his knowledge of light and optics to make a new type of telescope using reflecting mirrors which offered better resolution and clarity.

Developments in chemistry led to the development of photographic film, which allowed astronomers to take images that could be studied in detail later. By comparing images at different times, it was possible to analyse minute changes in the sky.

The discovery and development of technology based on the electromagnetic spectrum showed that celestial objects were emitting energies in different parts of the spectrum. Radio astronomy is now a large field of astronomy.

13 Quantum mechanics is utilised in areas such as electronics, which is the backbone of many modern technologies.

For example, the transistor is based on semiconductor technology. In a semiconductor, an electron can jump into what is called the conduction band; this is a quantum effect.

The size of electronic components is limited by quantum effects. If the tiny wires in a circuit are too close, quantum effects may allow an electron to 'jump' from one wire to another.

14 The climate is a large and complex system. While each component can be studied in isolation, such as the atmosphere and the oceans, they also interact with each other. Each individual subsystem (e.g. hydrosphere, atmosphere, lithosphere) can also influence another, and what seems an insignificant change in one subsystem may influence the entire system.

SECTION REVIEW 5.2

Remembering

1 a epidemic: the spread of an infectious agent

b geocentric: Earth centred

c heliocentric: Sun centred

d gravity: an attractive force among all matter

Understanding

2 By understanding how the stars moved across the sky, it was possible to predict when events such as changes in seasons would occur. Ancient people would know when to start storing food for times of bad weather, such as in the winter, or when to hunt for animal skins.

3 Diagrams will vary; some key points to include for each are given below.

a one person may cough, and in doing so eject water from their lungs which contains potential pathogens.

b correct placement of the celestial objects in the two models.

c clearly show where the components of the atom fit.

d illustrate the interaction between solar radiation, reflected radiation and greenhouse gases.

4 The atom is incredibly small, and its individual components infinitesimally small. The neutron being electrically neutral, is not affected by electric or magnetic fields. It took discoveries such as nuclear decay and X-ray crystallography to actually observe them.

5 Developing mathematical systems or algorithms to describe the complex interactions across the Earth, required the development of powerful computers. Even then, it took computers a long time to calculate results. This became faster as the speed and processing power of computers increased.

6 Answers will vary.

7 Answers will vary.

8 Epidemic model: the microscope allowed scientists to directly view microbes and show that the world was filled with life outside our sensory perception. This discovery showed that it was possible for microbes to pass from one organism to another through the air, water or direct contact.

Models of the universe: the telescope made it possible to see into the night sky and observe the movement and structures of objects such as Jupiter and its moons. This established that not everything orbited around the Earth, replacing the idea that the universe was geocentric.

Models of the atom: fluorescent screens allowed scientists such as Rutherford to observe the effects of alpha particles passing through gold leaf. By observing these scintillations (flashes of light) it was possible to deduce that the atom was mostly empty space.

Climate models: the development of satellites allowed scientists to get real-time data on climatic conditions. This data allowed climate scientists to refine their algorithms on the interactions between the different spheres, such as the hydrosphere and biosphere.

Applying

9 Superconductivity is a state where a conductor has zero resistance. This was first discovered by Dutch physicist Heike Onnes in 1911, who was studying resistance in metals at low temperatures. The phenomenon was first seen in mercury, and occurred at a temperature close to absolute zero. In 1957 Bardeen, Cooper and Schrieffer developed the theory that proposed that electrons pair up as the temperature decreases. These Cooper pairs interact with the metallic lattice in such a way that the paired electrons move with no resistance. This greater understanding of the interactions at subatomic levels, and at low temperatures, may revolutionise the electronics industry if room temperature superconductors can be developed.

10 Epidemic models may look at developing vaccines or drugs that directly inhibit the function of individual pathogens. Universe models may discover the nature of dark matter or vacuum energy, leading to possible clean energy sources. Atomic models may lead to computer technology with faster computational power and higher storage capacity. Climate models may more accurately predict long term changes in weather patterns, such as more severe droughts or more severe storms in tropical regions.

SECTION REVIEW 5.3

Remembering

1 Models may include a three-dimensional model of cells or a computer simulation of natural selection.

2 Careful planning allows you to understand the sort of equipment you might need, or the amount of time required to construct your model.

Understanding

3 Access to equipment, particularly if you are building a physical model, can be difficult and expensive. It may also be difficult to transport the materials between home and school.

Applying

4 Responses will vary based on the model chosen.

CHAPTER REVIEW QUESTIONS

Remembering

1 A scientific model is anything that attempts to simplify a scientific concept or show a concept normally outside the range of human perception, such as the scale of the Solar System or the structure of an atom.

2 Some examples include: diagrams of cells, physical representations of the skeleton, formulae governing forces, analogies for the flow of current, and computer simulations of predator–prey relationships.

3 Answers will vary depending on the model chosen. For example, the cells that make up all living things are incredibly small. A microscope is needed to view the individual cells, and an electron microscope is needed to see the organelles that make up the cells. A diagram is a model that allows anyone to identify structures that may not normally be observed.

9780170411196

Understanding

4 Answers will vary.

5 a Diagrams are used to quickly and easily demonstrate a scientific concept. They are commonly used in text books to demonstrate concepts. Examples include force diagrams, where resultant force is determined by analysing multiple forces.

b Physical replicas are models that attempt to replicate aspects of a phenomenon. Examples include replicas of animals or fossilised bones.

c Mathematical representations are formulae that show relationships that are part of a concept. Examples include the formulae used to describe Einstein's special theory of relativity.

d Analogies attempt to help people understand a concept by comparing it to another. Examples include the idea that a biological cell is like a prison.

e Computer simulations take mathematical relationships and calculate possible results. Examples include computer simulations to determine how diseases spread.

6 A simple model is the relationship for speed. Speed is distance divided by time. There are only three variables, and the concepts are easy to understand.

A complex model is a meteorological model, such as one that aims to predict the path of a tropical cyclone. There are multiple factors influencing the cyclone, including ocean temperatures, air speed and air temperature, which influence each other and are influenced by other outside factors.

7 a Epidemic model: infectious diseases are spread by germs.

b Models of the universe: all matter in the universe was found in a singularity which expanded in the Big Bang.

c Atomic models: the quantum atom is not made of definite particles. At the sub-atomic level, protons, neutrons and electrons exhibit wave-like properties. Electron shells are the constructive interference patterns where electrons are most likely found.

d Climate models: the biggest influence on climate is the greenhouse effect. Excess greenhouse gases in the atmosphere, particularly carbon dioxide, trap thermal energy as it attempts to leave the Earth, leading to higher than average temperatures.

8 Timelines should include important dates, relevant scientists, reasons why the model has changed and references to any technological innovations that influenced the change to the model. For example, the Big Bang model takes the observations of scientists such as Hubble, and shows that the universe must have had a definite beginning. Research has been able to describe structures in the universe such as galaxies and galaxy superclusters.

9 When the type of pathogen causing the outbreak has been discovered, its method of contagion can be controlled. For example, in the case of the Cryptosporidium and Giardia outbreak in Sydney in 1998, the source was contamination of part of the water supply. People were advised to boil drinking water, preventing the outbreak from spreading further.

10 Astronomy was constrained as there was not adequate technology to look deeper into the night sky. The development of lenses led to the invention of the telescope, which allowed relatively close astronomical objects such as planets to be viewed in detail. As the magnifying power of telescopes was increased, more detail could be observed.

The discovery of atomic spectra allowed astronomers to determine the chemical composition of stars and nebulae, further building understanding.

The discovery of different parts of the electromagnetic spectrum opened up further study of stars, allowing the complex nuclear reactions occurring in the hearts of stars to be understood.

11 Quantum effects are only noticeable at incredibly small sizes. In our everyday perception, particles and waves are distinctly different entities.

12 In most systems, it is possible to study things in isolation. However, the climate is an incredibly large system, with each part influencing the others. For instance, an increase of heat energy in the oceans in tropical regions may create larger storms leading to the possibility of flooding on land. These influences are subtle and sometimes hard to quantify in algorithms.

13 Answers will vary. For example, diagrams are a simple type of model that can be very effective. Sometimes a diagram may leave out some aspects of the scientific concept it is trying to explain, particularly when it is conveying this concept in a two-dimensional diagram. However, by simplifying the concept, it can be an easy gateway for introducing a scientific concept. This simple concept can then be built upon to allow a student to expand their knowledge.

14 Answers will vary. For example, the epidemic model is influenced by most branches of science. Its basis is in biology and the study of the way organisms interact, and the way pathogens enter host organisms and infect them. The biochemistry of individual pathogens can be studied. Research often focuses on blocking some of the chemistry that occurs in the pathogens to prevent them from being able to invade cells. Aspects of physics are also involved, including the study of fluid dynamics, the way fluids, air and water move around, as many pathogens are carried in air or water. Knowledge may help prevent the disease from spreading further; for example, when people are advised to wear face masks or boil water.

15 Answers will vary. For example, formulae, such as those commonly used in physics and chemistry, give qualitative data. Diagrams are liable to provide quantitative data, as they show positions and parts of the concept.

16 Answers will vary.

17 Answers will vary.

Applying

18 A scientific model should convey meaning to the person studying it. When using models such as those explaining interactions in the climate, it can be difficult to show the essential points without causing confusion.

19 When making a model, a student may become very focused on the task at hand. Peer feedback provides a new point of view. Peers may also provide insight into how effective the model is in conveying the intended meaning.

20 An example may include the double helix model of DNA. It simplifies and explains how genetic information is passed on by organisms. The structure of DNA and the study of the position of genes allows scientists to predict possible genotypes of new organisms.

CHAPTER 6

SECTION REVIEW 6.1

Remembering

1 Theory: an explanation of why phenomena happen.

Law: a description, usually expressed as a mathematical relationship, of what happens in a phenomenon.

2 Law of conservation of mass: mass cannot be destroyed or created, only transformed.

3 The theory of plate tectonics states that the Earth has rigid outer plates that are slowly moving on a molten layer, converging in some places and diverging in others.

Understanding

4 A theory is an explanation of a phenomenon; a law is a description of the events of the phenomenon.

5 The law of conservation of mass describes that in every situation the mass of the reactants and the mass of products in a chemical reaction are equal. This refers to matter not being destroyed or created.

The theory of plate tectonics explains why the continents are in their current positions and the evidence related to the movements of the Earth's plates.

Therefore, the former is a law, because it describes phenomena and the latter is a theory, because it explains phenomena.

Applying

6 The validity of the collection of evidence rests on the assessment of the amount of data collected over time and the procedures followed. The vast amount of data collected was methodically evaluated as to whether each case tested the law of conservation of mass or supported the theory of plate tectonics. Technologies used to collect the evidence, such as empirical measurements for the law of conservation of mass or satellite imaging and surveying techniques for the theory of plate tectonics, were calibrated and verified before any measurements were taken.

7 Answers will vary. Students should identify both the law or theory that is currently being tested and the technology or technologies being used to validate the test. Some examples of laws or theories are string theory, constant speed of light and limited immune system responses.

SECTION REVIEW 6.2

Remembering

1 Evidence includes data that support or disprove a proposition to explain phenomena.

2 The four stages are: speculative, descriptive, constructive and validation.

3

STAGES	GERM THEORY	OXYGEN THEORY OF COMBUSTION
Speculative	Scientists started to question the existence of diseases and suggested that germs are responsible for the spread of disease.	Lavoisier challenged the phlogiston theory with the hypothesis that oxygen was the compound responsible for combustion.
Descriptive	Pasteur and Koch collected evidence that diseases were caused by germs. They injected laboratory rats that were healthy with samples of diseases and those animals displayed the expected disease symptoms.	Lavoisier collected meticulously measured data to prove his theory. He weighed all the compounds with precision before and after chemical reactions took place.
Constructive	Koch's postulates were developed.	The oxygen theory of combustion was stated.
Validation	Other scientists across the world used Koch's postulates as first steps to identify diseases and obtain similar results.	Other scientists obtained similar results when they applied the theory in their experiments.

Understanding

4 It takes a long time to accept or disprove a theory because:

- People have strong ideas at the time the theory is released or presented to the scientific community and usually those ideas are based in strong societal and cultural beliefs.
- Technologies at the time the theory is published may not be good enough to test the hypothesis behind the theory and this leads to speculation rather than facts.
- If the theory is not presented by, or coming from known scientists, the scientific community might not trust the research.
- The theory might challenge the knowledge of that time and it might be difficult to collect evidence for it.

5 The types of evidence used to develop or disprove a theory are similar because data must be collected and observations must be made. Then the data should be rigorously analysed to form a consistent set of evidence.

9780170411196

6 Example: Steady state theory

The steady state theory was once accepted due to the evidence that density of matter is the same across the entire universe. Later, that theory was disproved because new evidence was collected following the development of new technologies. The discovery of microwave radiation across the universe and the redshift of electromagnetic waves demonstrated that density of matter is not the same and that the universe is expanding.

Applying

7 Example:

Formulate a question: why do stars seem to 'turn off' during the day?

Create a hypothesis: stars seem to turn off due to an optical illusion.

Collect evidence: take photographs of the night sky, research the literature about it.

Analyse the data collected.

Create the final hypothesis statement.

SECTION REVIEW 6.3

Remembering

1 The process and procedures undertaken to accept a law are: collect data, apply data to a numerical formula and test the law under different situations.

2 Newton's second law states that the force applied to move an object is directly proportional to its mass and the acceleration needed to move it.

An example could be pulling a truck up a hill compared with pushing a bike up a hill. The force to reach a given acceleration will be greater for the truck than the bike.

3 Avogadro's law states that equal volumes of gases under the same conditions of temperature and pressure contain equal numbers of molecules.

4 In Queensland, the sediments in the soil profile or strata range in age over millions of years. It is common to see index fossils in the Permian sediments such as *Glossopteris* spp. These layers follow the law of superposition, where old sediments are at the bottom of the profile and the youngest sediments are at the top.

5 Ohm's law: the electrical current flowing between two points in a circuit is directly proportional to the voltage. An example of the application of Ohm's law is in dimmed light systems, the higher the current allowed through the light bulbs when manipulating the switches, the higher the voltage those lights will have and therefore the brighter they will be.

Law of conservation of energy: energy cannot be destroyed or created, it can only be transformed. An example is using a toaster: the electrical energy is transformed into heat energy, light energy (filaments in the toaster light up red when hot) and sound (when the toaster pops up or beeps to let you know that the toast is ready).

Understanding

6 a More force is applied to move the big rock compared to the small rock. The force needed to move an object with a given acceleration is proportional to the mass of the object.

b The force from the air released from the balloon is proportional to the acceleration obtained in the balloon car. The more air that is coming out from the balloon (more force), then the more acceleration in the balloon car.

7

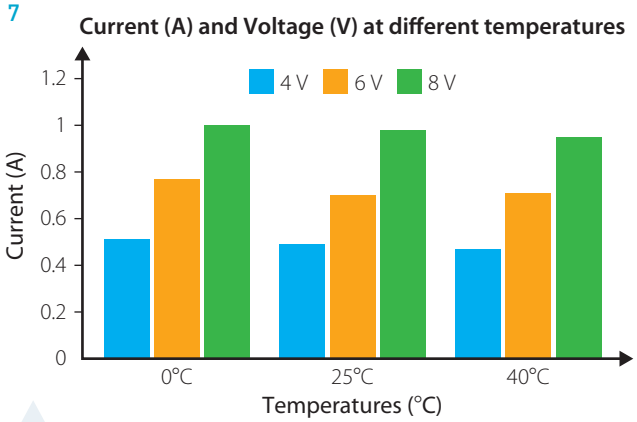


FIGURE A.6.3.1 Graph representing the relationship between current and voltage at different temperatures.

8 The allele for long ears is dominant over the recessive short ears allele. To produce more puppies with long ears, the breeder will select puppies with long ears from each litter and keep reproducing those puppies while also trying to avoid crossbreeding with puppies with short ears.

Applying

9 Topics of interest will vary. The following key points should be in the discussion:

- propose a law
- explain how to collect data and evidence to support the law
- outline a procedure to scientifically test the law
- give an example of how the law is going to reach the scientific community for validation.

10 The validation can be done using simple models and the calculation, force = mass × acceleration.

In the validation, the following points need to be discussed:

- experiment must be designed so that it tests the law
- calculations must use the data gathered
- discussion must show that data supports Newton's second law of motion.

11 Computational models to track seismic waves are programmed using the principles of Snell's law of wave refractions through media (in the case of earthquakes: solid rocks, colloids and liquids). Therefore, the computation model can predict how the waves are going to be transferred throughout the crust of a specific studied area. However,

computational models are not always accurate. This may be because:

- the calculations for the law were not entered correctly in the system.
- the area was not surveyed correctly and the information about what sections were composed of (i.e. solid rock, colloids, liquids or gas reservoirs) was inaccurate.
- the units used in the calculations were mistaken from one step to the other in the system.

SECTION REVIEW 6.4

Remembering

1 Laws and theories are used to represent scientific relationships. They can sometimes be used to predict outcomes and to develop technology for many purposes.

2 The law of conservation of energy states that energy is not created or destroyed, it can only be transformed.

3 Einstein's formula states that energy created/destroyed/transformed is equal to the mass multiplied by the speed of light squared. This means that energy and mass are interconvertible, and when mass is converted it produces huge amounts of energy.

Understanding

4 a The law of conservation of energy in physics applies to a situation where the energy in the system is transformed to another type of energy; for example, in a Newton's cradle. The potential energy of the bob at rest is transformed into kinetic energy, which is transferred to the other bobs in the cradle and finally to the last bob, which will then move. If the potential and the kinetic energy are measured the net energy will be zero. No energy is created or destroyed, it is all transformed from potential to kinetic energy.

b In chemistry, the law of conservation of energy applies when elements are rearranged from the reactants to the products of the chemical reaction, and energy to break the chemical bonds to form new bonds in the products is released in the form of heat or light. No new energy is created in the products, it is just transformed from the reaction between the initial compounds. For example, when an acid reacts with a carbonate (e.g. bicarbonate) the bonds in the acid and the bonds in the carbonate are broken and new bonds are formed to create a salt, water and carbon dioxide.

c In biology, the law of conservation of energy applies in the flow of energy in food webs. Energy from the Sun is transformed into sugars in plants. Herbivores eat those plants, sugars are transformed by cellular respiration into energy in the herbivore and when they are eaten by a carnivore the energy moves to the next level. Energy is not destroyed or created, it is always transformed across organisms at different trophic levels.

Applying

5 The energy in our planet should be balanced between the energy coming in (i.e. the Sun and cosmic rays) and the energy released from the planet (i.e. reflected natural heat and human activities). Therefore, it follows the law of conservation of energy. Since the Industrial Revolution, more greenhouse gases have been released from human activities into the atmosphere, trapping and retaining the heat. As the law of conservation of energy states that energy is not created or destroyed, the increase in human activities creates an unbalanced amount of net energy.

6 Einstein proposed the law of mass–energy equivalence. This means that mass can be created by destroying energy and that energy can be produced from mass. This is clearly seen at the atomic level. The nucleus of the atom can be bombarded with other particles and the atom can be split (sacrificing mass), releasing large amounts of energy. An example is what happens in nuclear reactors to generate energy or to create isotopes for medical purposes and radiometric dating.

CHAPTER REVIEW

Remembering

1 A theory is an explanation of why a phenomenon or event happens. Examples: theory of evolution, theory of plate tectonics.

2 A law is a description, usually expressed in a mathematical equation, about phenomena. Examples: law of conservation of mass, Newton's laws of motion.

3 A theory explains why an event is happening but a law describes the event. For example, the law of conservation of mass states that the mass of the reactants is equal to the mass of the products in a reaction. The law does not explain why that is happening. The atomic theory will explain the arrangement of atoms and how they interact to create the new products.

4 Theories are developed following four main steps:

Speculative: questions and hypotheses are formulated after observing and inquiring about a phenomenon.

Descriptive: data is collected following a valid procedure.

Constructive: once the data is analysed, theory statements are developed to explain the phenomenon.

Validation: the theory is presented to the scientific community in conferences and published journals to be supported or not supported by other scientists.

5 Laws are developed following the steps of the scientific method. At the end of the collection of empirical data and analysis a statement is formulated which is usually expressed in a mathematical equation. The development of a law is based in the quantitative collection of data.

Understanding

6 The theory of plate tectonics is not a law because it explains why the movement of continents happens and the geomorphology of the planet. For example, the theory explains that continental plates move past each other, diverge from each other or collide with each other. These interactions create zones which are areas of high levels of volcanic activity and earthquakes.

9780170411196

7

THEORIES	EVIDENCE
Plate tectonics	• Convection currents • Common fossils across continents • Mid-ocean ridges and crust formation
Big Bang	• Redshift • Cosmic microwave radiation • Same elements across the universe
Law of conservation of mass and energy	• The amount of mass in the reactants is equal to the amount of mass of the products • The energy is always conserved in a pendulum

8 Dr Smith needs to analyse the data collected, and repeat the experiments to increase the reliability and validity of the procedure. Once all the data is analysed, a mathematical formula might be created to describe the phenomenon observed, and then he can publish the law for further discussion and tests by the scientific community.

9 To disprove a theory, new evidence must be collected. For example, the geocentric model of the Solar System was replaced by the heliocentric model. The evidence collected over the years included new measurements of the movement of the planets and later observations from powerful telescopes.

10 Ohm's law states that the electric current is proportional to the voltage and inversely proportional to the resistance in an electrical circuit. Therefore, the more voltage in the system, the more electric current will go through the system but if the resistance is higher, the current will be lower.

Applying

11 The snail has adapted to live in small burrows and its shape has evolved to fit inside those burrows.

Following the theory of evolution, the population of snails has shell shape variations within the species. Snails with shapes that 'fit better' in the holes and burrows are better adapted to their environment, survive, reproduce and pass on those favourable genes to the next generation.

12 The carts do not have enough kinetic energy to finish the first loop and continue the ride. This is because the amount of potential energy they acquire is not enough to be transformed (using the law of conservation of energy) into the kinetic energy needed.

Designers should increase the height of the hill to give the carts enough potential energy to be transformed into kinetic energy.

13 The introduction of a new species into an ecosystem creates an imbalance in the transfer of energy. It takes some time for an ecosystem to come back to a balanced energy flow.

The introduced beetle has created a new energy source for the frogs.

14 Example experiments include:

- Vinegar and bicarbonate, collecting the gas in a balloon.
- Liver catalase and hydrogen peroxide.

Whatever experiment is chosen, follow the experiment scaffold below:

INQUIRY QUESTION	
HYPOTHESIS	
AIM	
EQUIPMENT	DIAGRAM
EXPERIMENTAL DESIGN	
Independent variable Dependent variable Controlled variable	
PROCEDURE	
Risk assessment	
RESULTS (TABLES, GRAPHS, OBSERVATIONS IN SENTENCES)	
Validity and reliability	
DISCUSSION AND CONCLUSION	

15 Energy from the Sun, continental drift and human activities.

Analysing

16

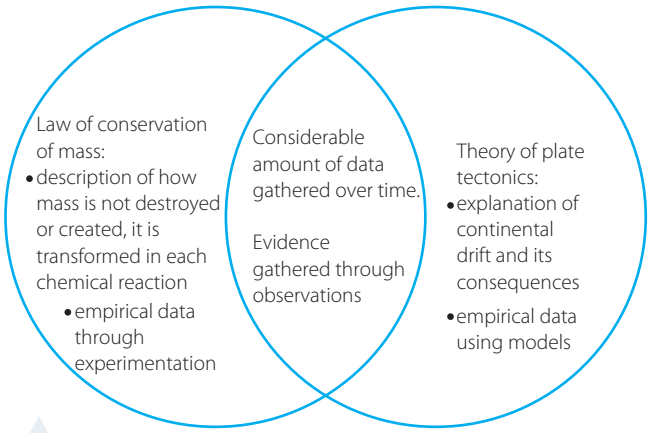


FIGURE A.6.5.1 Comparison of the law of conservation of energy and the theory of plate tectonics

17 It was previously thought that a common ancestor of the emu, ostrich and rhea populated Gondwana, and that the three species evolved some time after the supercontinent broke up into Africa, South America and Australia. This theory made sense because of the many physical characteristics shared between the three animals. However, according to DNA evidence, the common ancestor was most likely a common flying bird that populated the different continents and then lost the ability of flight. The analogous body forms of ostriches, emus and rheas are the result of convergent evolution, in which species independently evolve similar features in response to similar selection pressures in their new environments.

18 Steps taken to disprove the steady state theory of the universe:

- collect evidence to disprove the steady state theory
- gather sufficient data to test the new theory: Big Bang theory and the expansion of the universe
- analyse the data collected
- publish the findings that support the new theory so the scientific community can review and discuss the findings

The steady state theory is replaced by the Big Bang theory. The evidence to support the Big Bang theory includes:

- redshift
- microwave background
- abundance of hydrogen, helium and common elements across the universe

19 Keep in mind that this survey can have ethical issues for people of different beliefs, so be cautious and respectful with your questions, and do not judge people because of their beliefs.

Suggested questions and structure for the survey:

	STRONGLY AGREE	AGREE	NEUTRAL	DISAGREE	STRONGLY DISAGREE
All the living things on the planet appeared spontaneously.	○	○	○	○	○
Living things have evolved over time.	○	○	○	○	○
Living things survive under pressures in their environment, reproduce and pass genes on to the next generation.	○	○	○	○	○
Living things adapt and evolve spontaneously	○	○	○	○	○

20 Most of the population before the 20th century was not well educated or had little access to education. Only a minority had access to higher education and, therefore, very few people were exposed to different ideas and points of view. New (and challenging) laws and theories in the major branches of science took time to be accepted by the scientific community and then to reach the general population.

Synthesising

21 Suggested procedure:

1. Set up the equipment as per Figure 6.5.1.
2. Place 5 mL of water in syringe 1 and press down to fill the tube.
3. Record the height that the car is lifted.
4. Repeat steps 2 and 3 first with 10 mL and then 15 mL of water.
5. Repeat the entire experiment three more times to increase its reliability.

Possible results:

If more pressure is added in the system more movement will be observed. The difference between the pressure in the two syringes will determine the type of movement observed.

22 In the essay (no more than a page long) you should:

- explain the theories and laws that we currently have about the universe
- compare these with the ideas at the time of Aristotle
- describe evidence for the new theories and laws.

Evaluation

23 The evidence that the theory of evolution is accepted as a unified theory is related to how it merges other theories. For example, the theory of plate tectonics explains that the continents are drifting apart over millions of years leading to the isolation of land masses and consequently new climates which create a selection pressure for the species living in those areas. Consequently, it creates the conditions for speciation because those organisms need to adapt, survive and reproduce in a new environment. Mendel's theory of inheritance is related to theory of evolution because it explains how different traits are passed from one generation to the next.

24 Einstein unified the law of conservation of mass and energy into the mass–energy equivalence when he presented his famous equation $E = mc^2$. With this equation, Einstein explained that energy can be converted to mass and vice versa, in accordance with the relationship given. His contributions had positive and negative impacts in society. On the one hand, nuclear research has led to the development of nuclear medicine which has seen improvements in medical outcomes. On the other hand, nuclear research was used to create weapons such as the atomic bombs used at the end of World War II.

9780170411196

GLOSSARY

A

abdomen the section of the body of an insect located just behind the thorax

accuracy level to which a measurement, calculation, or specification conforms to the true value

adaptation process of change over time by which an organism or species becomes better suited to its environment

adenosine triphosphate (ATP) high energy molecule present in every cell

agriculture cultivation of the soil for growing crops, and the rearing and management of animals for food and other useful products

aim purpose of the investigation

alpha particle helium nucleus emitted by radioactive substances

anthrax bacterial disease, originally from sheep and cows, that affects the skin and lungs

assumption idea in the form of an inference that was established in the past and is used to inform another inference

atmosphere layer of gases surrounding the Earth

atom from the Greek word 'atomos' meaning cannot be divided

autotrophic when an organism produces its own energy (sugars) by the process of photosynthesis

B

beta particle fast moving electron emitted by radioactive decay

bias when personal opinion affects how a person weighs the validity of evidence

binding energy energy required to completely separate the atomic nucleus into its components (protons, neutrons and electrons)

C

calx oxide that remains after a substance has been burned or gone through combustion

cell organelle cell structure that has a specific function

chemical bond electrical attraction between the atoms of elements that enables the formation of molecules and compounds

chemical reaction chemical process that involves the rearrangement of the elements of the reactants into new products

chloroplast cell found in green plants, containing the green pigment chlorophyll, which is crucial in converting sunlight into sugar through photosynthesis

combustion rapid chemical combination of a substance with oxygen

comet small celestial object composed primarily of dirt, gas and ice that travels on an elliptical (oval-shaped) path on its orbit around the Sun

compound substance that is made of more than one element

control experimental set-up where the independent variable is not applied

controlled variable factor that is kept constant during the investigation

correlation relationship or connection between two or more variables

cosmic microwave radiation electromagnetic wave radiation in the range between 0.3 and 300 GHz

cultural bias interpreting and judging phenomena from a particular cultural viewpoint

current flow of electrons around a circuit

D

data numerical or observational facts collected together as evidence for analysis

data logger electronic or digital device that records data either with a sensor or digital aid

data outlier data point distant from other observations and measurements that may indicate an error

dependent variable factor measured in the investigation

E

ecosystem area where living things interact with non-living things

electron negatively charged particle in the atom spinning around the energy shells of the atomic nucleus

element substance that cannot be separated into smaller substances by chemical means

empirical data information collected by observations or measurements during an investigation

Enlightenment European intellectual movement of the 17th and 18th century emphasising reason as a means to advance science and society

error measure of the estimated difference between the observed or calculated value of a quantity and its true value

ethical relating to moral principles and values

extrapolation extension from a range of plotted data to infer new values from the known ones

F

false premise incorrect proposition or assumption that is used to form the basis of an argument or conclusion

feynmanium possible last element of the periodic table as proposed by Richard Feynman

fieldwork investigation conducted outside the laboratory

fission nuclear reaction when a heavy atomic nucleus is split into smaller ones

fixity of species notion that species, once created, can never change; an idea diametrically opposed to theories of biological evolution

fossil remains or impression of a prehistoric plant or animal preserved in petrified form

fractal mathematically related repeating pattern that exists at different scales

friable easily crumbled

fusion nuclear reaction when smaller nuclei fuse to form heavier ones releasing energy in the process

G

gamma radiation penetrating radiation released from an atomic nucleus during radioactive decay

gene sequence of DNA that is considered the unit of heredity, as it is transferred to the next generation

generalisation idea or conclusion that can be applied more broadly to related phenomena

germ theory theory that infectious diseases are caused by the presence and actions of specific micro-organisms (germs)

Gondwana supercontinent thought to have existed in the southern hemisphere after the Mesozoic era, now Australia, South America, Africa, Antarctica and India

H

heterotrophic when an organism gathers its energy from external sources of food

hexagonal symmetry repeating pattern that forms a shape that can be cut into six identical wedges

hydrosphere water layer of Earth, including oceans, seas, lakes and rivers

hypothesis educated guess tested through experimentation to answer the inquiry question; states the relationship between the independent and dependent variables

I

independent variable factor deliberately changed during an investigation to obtain data

index fossil fossil that is common across the same layers of strata for a specific period of geological time

inference conclusion that is rationally and logically made based on observations and available information

inquiry question driving force of the research and can be investigated scientifically

interpolation estimating new data points within the range of data points

L

Large Hadron Collider particle accelerator that propels subatomic particles (hadrons) at high speed

Laurasia supercontinent thought to have existed in the northern hemisphere, now North America, Greenland, Europe and Asia

law description, usually expressed as a mathematical relationship, of what happens in a phenomenon

leaching process in which water-soluble substances are dissolved into surrounding water, allowing the substances to be transported and removed from their source material

line of best fit trendline that best fits the plotted data; it goes through the centre of the plotted data

log book journal taken during the investigation where all data, observations, results, inquiries and conclusions are registered

lore tradition and knowledge held by a cultural group passed down through the generations

M

magnetic stripe area of newly formed crust that aligns with the magnetic field of the planet

mass amount of matter in a solid, liquid or gas

mass defect mass of the whole atom is less than the total mass of its components (protons, neutrons and electrons)

method experimental steps to follow to collect data and test the hypothesis of an investigation

migrating process of moving from one region to another according to the seasons

model two- or three-dimensional representation or description of a process, system or idea

molecule group of atoms bonded together, representing the smallest fundamental unit of a chemical compound that can take part in a chemical reaction

N

nuclear decay process by which an unstable atomic nucleus loses energy by emitting radiation in the form of gamma rays or particles in the form of alpha and beta radiation

O

ocean ridge underwater mountain system formed by plate tectonics

optical illusion image that deceives the visual system

P

***p*-value** statistical measure of the probability of making a type I error

Pangaea from the Greek 'pan' meaning all and 'gaea' meaning Earth; therefore, 'all of the Earth'

parallax scientific error caused by a change in line of sight by the observer

pareidolia psychological priming effect whereby a familiar pattern is perceived from random stimuli

pathogen organism or particle that disrupts the normal function of another organism (i.e. causes disease)

peer review process in which experts review and critique the work and research of others in the same field

periodic table organisational structure in which the atomic elements are arranged to highlight elements with similar properties

periodicity tendency to repeat at regular intervals

perspective way of seeing or interpreting something

pH scale scale ranging from 1–14 that describes the acidity or alkalinity of a substance

phenotype observable characteristic that results from the interaction between genetics and the environment

philosopher person who studies all the truths related to knowledge

phlogiston chemical that was thought to be released during combustion prior to the discovery of oxygen

psychologically primed effect where exposure to a particular stimulus unconsciously influences a person's response and understanding of the stimuli

Q

qualitative data descriptive data collected as evidence during an investigation (e.g. images, observational sentences)

quanta (quantum) discrete amount of energy

quantitative data numerical values collected as evidence during an investigation (e.g. calculations, measurements)

R

radiometric dating technique used to date rocks and minerals based on the decay rate of radioactive isotopes

redshift displacement of spectral radiation towards longer wavelengths

regression analysis statistical process of establishing the relationship between variables

reliable extent to which an observation and/or measurement can be repeated under the same circumstances and produce similar results

9780170411196

research literature accumulated written knowledge based on investigations and thoughts of scientists that have been published

resistance amount by which a circuit tries to stop the flow of electrons

risk assessment evaluation of the risks of an investigation

S

safety hazard expected risk during an investigation

sample size number of observations or replications in an experiment

scientific consensus collective judgement of a community of scientists in a particular scientific field

scientific process systematic process whereby questions are answered and hypotheses tested to generate empirical evidence

sediment solid fragmented material that is transported and deposited by water, ice or wind, forming layers on the Earth's surface

selective pressure change in the environment that causes organisms to adapt to that change with the aim to survive

species group of living organisms with similar characteristics that can interbreed

stippling technique used in scientific drawing to show detail and shading using small dots

stratigraphy branch of geology which studies the position of layers of sediments

T

theory explanation of why phenomena happen

trait physical or chemical characteristic that is genetically determined

treatment variation of the independent variable

trend general pattern

true value measurement with no errors

type I error when a hypothesis is incorrectly accepted

type II error when a hypothesis is incorrectly rejected

U

uncertainty interval (±) around the measured value compared to the true value

V

valid extent to which a report or investigation contains accurate data, inferences and conclusions

variable measurable factor that can be changed or maintained in an experiment

voltage force pushing electrons around the circuit

W

wonky hole submarine freshwater spring found along the Great Barrier Reef

INDEX

9780170411196

9780170411196

9780170411196

INVESTIGATING SCIENCE IN FOCUS

YEAR 11

nelsonnet

Register online at:

www.nelsonnet.com.au

to access digital resources to support improved learning & teaching*

9780170407281
Biology in Focus 11

9780170408929
Chemistry in Focus 11

9780170409063
Physics in Focus 11

9780170411196
Investigating Science in Focus 11

9780170408851
Biology in Focus 12

9780170408998
Chemistry in Focus 12

9780170409131
Physics in Focus 12

9780170411264
Investigating Science in Focus 12

OVERVIEW

- Completely aligned to the new NSW Investigating Science Syllabus
- Suitable for students studying Investigating Science as a stand-alone course or a companion course
- A student-focused approach to teaching and learning
- Detailed scaffolds for a range of depth studies at the end of each module
- Contains a flexible approach to depth studies, enabling teachers to engage with students' areas of interest.

NELSON
A Cengage Company

*Please note that complimentary access to NelsonNet is only available to teachers who use the accompanying student textbook as a core educational resource in their classroom. Contact your Education Consultant for information about access codes and conditions.

ISBN 978-0170411196