CHAPTER

1

How do I investigate a question scientifically?

SCIENCE TOOLKIT

What if?

Yeast reactions

What you need:

Active yeast suspension in warm water, 3 per cent hydrogen peroxide solution, test tube in a rack, measuring cylinder, 2 plastic pipettes, dishwashing detergent

What to do:

1. Use the measuring cylinder to measure 2 mL of hydrogen peroxide. Pour the hydrogen peroxide into the test tube.
2. Add one drop of dishwashing detergent to the test tube.
3. Use the plastic pipette to mix the yeast suspension thoroughly.
4. Add three drops of the yeast suspension to the test tube.
5. Measure the height of the bubbles made from the gas produced by the catalysed reaction.

What if?

- What if more yeast suspension was added?
- What if the hydrogen peroxide solution was diluted with water?
- What if the yeast mixture was put on ice?
- What if the yeast mixture was boiled before it was added to the hydrogen peroxide?

1.1 There are many types of scientific investigations

In this topic, you will learn that:

- types of scientific investigation include case studies, modelling or simulations, quantitative analysis and controlled experiments
- scientists record their research and data in a logbook.

Figure 1 Scientists might ask, 'How did the universe start?' To investigate this, they need to also ask questions that can be tested and measured.

operationalising
a way to break a large science question into smaller measurable questions

methodology
the rationale (why) and approach (how) used by the scientist to investigate the scientific question

Science is a way of asking and answering questions about the biological, chemical, physical and technological worlds. It allows us to explore the unknown and use our knowledge to solve problems.

Questioning and predicting

All scientific investigations start by asking a question. There are many different types of questions that can be asked. Questions can be big (such as 'How did the universe start?') or they can be small (such as 'What will happen if acid is mixed with metal?').

Big questions often need to be broken down into a series of small questions that can be answered over time. For example, the question 'How did the universe start?' could be broken down into these questions:

- What is a universe?
- What makes up our universe?
- What is the state of our current universe?
- How is our universe changing?
- Can we measure these changes?
- Have these changes always occurred?
- What is causing these changes?

Each question may then be broken down into something that is measurable. This is called **operationalising** the question.

Independent variable	IF 6 drops of yeast suspension (instead of 3 drops) was added to 2 mL of hydrogen peroxide
Dependent variable	THEN twice as much gas would be produced in the same time
Possible explanation	BECAUSE increasing the amount of catalyst will increase the rate of a reaction.

Figure 2 A possible hypothesis for the example question

Scientists need to ask specifically how they will test and measure their question.

For example, the question 'What if more yeast was added to hydrogen peroxide?' will need to consider the amount the yeast solution will be increased by. So, an operationalised question for this would be 'What if 6 drops of yeast extract was added to 2 mL of hydrogen peroxide?'

Forming a hypothesis

Once the question is testable, the scientist can predict the outcome of the test and state the reason for their prediction. These things are included in a hypothesis. The easiest hypothesis to use is an 'If … then … because …' statement.

For example, the hypothesis for the previous question could be as shown in Figure 2.

This hypothesis can now be investigated.

Planning and conducting

There are many ways to investigate science. The type of investigation used is called the **methodology**. This is different to a method (the step-by-step procedure of an investigation). The methodology that a scientist uses will depend on the type of question and the equipment that can be used.

Case studies

A case study is a detailed investigation of a real life or hypothetical activity, event or problem. It looks at all the causes or contributing factors involved at the beginning and describes what happened during the event, as well as the outcomes and consequences. The case study will also analyse the data and provide recommendations for the future. An example is a case study of an environment, where all the factors that contributed to a change in the environment (including the motivations of humans) are discussed. It may include a

Figure 3 The Commonwealth Scientific and Industrial Research Organisation (CSIRO) completed a detailed study of Port Phillip Bay and used the data to model the effects of nutrients from sewage and industrial plants, run-offs from agricultural land and run-offs from cities.

detailed description of how the environment changed as well as the short- and long-term consequences of the change.

Modelling or simulations

Many scientific investigations involve constructing a physical or mathematical model or simulation of an object or a change. These models can be used to predict what will happen if something changes. In this year's science classes, you will complete examples of models or simulations, including modelling genetic inheritance and evolution, the properties of alloys, the effects of a carbon sink, and the laws of energy and motion.

Quantitative analysis

Scientists use quantitative analysis to calculate a number or relative amount of a substance. High-technology equipment is usually used in the analysis of samples. For example, chemists may want to calculate the pH in soil, and physicists may want to calculate the amount of dark matter in the universe.

In your science classes this year, you will use quantitative analysis to determine the age of an unknown sample, the amount of acid in a sample, the amount of phosphorus in a detergent, the distance to the sun and the acceleration of a falling object.

Controlled experiments

Experiments investigate the relationship between an independent variable (the variable that is deliberately changed during an experiment) and the dependent variable (the variable that is observed to determine if it is changed by the independent variable). To determine the relationship between the independent variable and dependent variable, all of the remaining factors or variables must be maintained or controlled (Topic 1.3) so they do not influence the results.

Figure 4 Quantitative analysis of pH in soil is important for plant or crop growth.

Using a logbook

All scientists will record their research and data in a logbook. Logbooks can be paper based or computer based (which is regularly backed up). Logbooks should contain your name, address and the name of your school on the front. This is to make sure that if it becomes lost, it can be returned. The first page of your logbook should contain the contents page where you can record the name of each investigation and its page number.

Before you start each investigation, record the name of the investigation and the date at the top of the page. This is to make sure that you will not forget the details of the investigation when you are writing a formal report or studying for your test or exam.

Figure 5 It's important to keep a detailed logbook during scientific investigations.

1.1 Check your learning

Remember and understand

1 **Explain** the purpose of using a simulation in science.

2 **Define** what it means to 'operationalise a question'. Give an example to support your definition.

Apply and analyse

3 **Compare** a quantitative analysis and a controlled experiment.

4 **Contrast** a methodology and a method.

5 A student wanted to demonstrate that heating a chemical reaction will cause it to happen faster. They wanted to test it using a dissolvable Alka-Seltzer tablet.

- **a** Write an operationalised question for this investigation.
- **b** Write a hypothesis for this investigation.
- **c** **Identify** which methodology the student should use.

Evaluate and create

6 Write the method for the experiment described in question 5.

1.2 Scientists communicate using scientific language

In this topic, you will learn that:

- scientific communication requires the author to modify their language to suit the audience.

Like all forms of communication, the way we communicate in science depends on the audience. If the audience does not know the key words or concepts that you are discussing, then you will need to use simple pictures, models and language so that they can understand what you are trying to say. For example, two physicists may say 'Potential energy was added to the rubber band', whereas a teacher may explain that 'The rubber band was stretched'.

When writing reports, scientists also avoid using the first person ('I', 'we', 'me', 'you', 'us', etc.). All science is supposed to be unbiased and objective. When the first person is used, it introduces the idea that humans can make mistakes.

Scientists will usually use past tense when they write a report because they are describing something they have already completed. If results were described in present tense (the now) or future tense (the later on), then the listener would not be sure if the experiment was finished.

Some examples showing the differences between scientific language and common language are given in Table 1.

Table 1 Examples showing differences between scientific language and common language

Scientific language	Common language
The equipment was set up.	I set up the equipment.
The mass of the beaker was measured.	We weighed the beaker on the scales.
The beakers were heated to 50 degrees Celsius. (Past tense)	Heat the beakers to 50 degrees Celsius. (Present or future instruction)
The two trolleys were pulled apart. (Past tense)	Pull the two trolleys apart. (Present or future instruction)
The metal was malleable.	The metal could be bent into any shape.
At 6:15 am a single magpie sitting on a protruding tree branch called loudly for 30 seconds.	I think it was a magpie that sang the warbling song that woke me up in the morning.
The mass of the sodium bicarbonate was identified as a possible random error.	We could have improved the experiment if we were more organised and measured the amount of bicarb properly.

Figure 1 When writing reports, it is important to be unbiased and objective.

Writing a scientific report

Scientists write reports so that their experiment and results can be reviewed by their science-trained colleagues or peers. As both the writer and reader are science trained, these reports will contain many terms that have particular meanings. For example, the word 'significant' can mean 'important' when used by a person in the street. But to a scientist, the word 'significant' means that a result is 'not due to chance'. This means that the words in a scientific report need to be carefully chosen.

All scientific reports have common sections and headings. Table 2 explains each section that you will need to include in your scientific reports.

Table 2 Sections of a scientific report

Section	Description
Title	• A statement that includes the independent variable and the dependent variable.
Introduction	• A summary of any previous experiments that you have completed. • A description of the key concepts being examined and how they are related to your hypothesis.
Aim	• A statement of what you are trying to achieve in the experiment.
Hypothesis	• A prediction of how the independent variable will affect the dependent variable and the reason that supports the outcome. • If ... <how the independent variable will change> ... then ... <how the dependent variable will change> ... because ... <reason for the change>.
Method	• A list of the materials, containing the concentrations and brands, should be included in the method. • The method should contain step-by-step instructions or a brief description (in past tense) that would enable someone to repeat the experiment. • Relevant labelled diagrams should be included where necessary.
Results	• The data should be presented in a table, graph or diagram. • A written summary of the results (stating facts without conclusions) should also be included.

Discussion	• This section should analyse the results by:
	  • describing the relevant science concepts that occurred in the results
	  • drawing conclusions from the results
	  • comparing the conclusions to the hypothesis
	  • describing how the results could apply in the real world.

Conclusion	• The conclusion should answer the aim of the experiment by:
	  • comparing the conclusions to the aim
	  • describing the limitations of the experiment (by describing situations where these results would not apply)
	  • describing a possible next experiment that could occur to confirm or extend the conclusions.

References	• Any sources that you used to research the scientific concepts or definitions should be included here. • There are different ways to write a reference. Check which style is preferred by your school. • Most scientific communications use APA Style (American Psychological Association Style). For example: Silvester, H. (2021). *Oxford Science 10 Victorian Curriculum* (2nd ed.). Oxford University Press.

1.2 Check your learning

Remember and understand

1 **Explain** why scientists avoid using the first person to describe the results of an experiment.

2 **Identify** what should be included in the discussion section of a scientific report.

Apply and analyse

3 Rewrite the following statements using scientific communication.

a I measured the speed of a skateboard.

b The acid made lots of bubbles appear on the side of the metal.

c When I put my hand in the water, it felt very cold. I think it was 15 degrees.

4 **Contrast** the common or street meaning and the scientific meaning of the word 'significant'.

5 **Compare** the information that is written in the results and discussion sections.

6 When writing a scientific report, a student used the internet to research the definition of the term 'kinetic energy'. Use an example to **describe** the APA Style of referencing for a website.

1.3 Experiments must be controlled

In this topic, you will learn that:

- experiments must be valid and reliable
- controlled experiments need to have control groups and may have positive and negative controls.

controlled variables
variables that remain unchanged during an experiment

independent variable
a variable (factor) that is changed in an experiment

dependent variable
a variable in an experiment that may change as a result of changes to the independent variable

valid
when the design of the experiment will produce a result that answers the scientific question

reliability
when an experiment can be repeated to produce the same results

repeatable
when an experiment can be repeated by the same scientist using the same materials

reproducible
when the experiment can be repeated by another scientist in another laboratory

control group
a group of organisms, chemical reactions or physical conditions that can be compared to the group that have had the independent variable changed

One of the most important parts of a scientific experiment is identifying all the different variables that affect the outcome of the experiment.

Any experiment will have many different factors or variables that will change the result. For example, an experiment that tests how to improve the growth of a plant will be affected by these variables: type of soil, amount of water, amount of sunlight, temperature of the environment, amount of air, and concentration of different gases in the air. A good experiment will keep all these variables the same, or **controlled**, except for one.

The **independent variable** is the only variable that is deliberately changed by the experimenter. In the example of the plant, the experimenter will keep the same soil, the same temperature, the same sunlight and the same air for all plants. The only thing that may change is the amount of water that the plants receive. Then the experimenter will know if the amount of water causes a change in the **dependent variable**. The dependent variable is the variable that is measured at the end of the experiment and is 'dependent' on any change in the independent variable.

Valid experiments

The dependent variable must be carefully selected to make sure the experiment is **valid**. An experiment is valid if it measures what it is claimed to measure. The scientific validity can be checked by asking three questions.

- Does the experiment relate to what happens in the real world?
- Does the experiment measure a dependent variable that is relevant to the aim?
- Does the experiment control all the other factors that might affect the outcome?

For example, if an experimenter wants to test the growth of the plant, then they need to consider what they mean. Growth can mean the height of the plant, the number of leaves, the size of the leaves, the length of the roots, or the number of roots. A valid experiment would identify which of these dependent variables would apply in the real world and would not be affected by the other factors (such as how tightly packed the soil may be).

Reliable experiments

The **reliability** of a science experiment is dependent on the ability to repeat the experiment with the same scientist and same materials (**repeatable**) or with another scientist in another laboratory (**reproducible**) and achieve the same results. For an experiment to be reliable, all the variables that can affect the dependent variable need to have been identified and controlled for.

Figure 1 Controlled experiments have all variables the same except for the deliberately changed independent variable.

Control groups

Controlled experiments keep all the variables the same except for the independent variable. If the independent variable is changed, then it needs to be compared to a **control group**. The control group is a second group of organisms, chemical reactions or physical conditions for which the independent variable has not been changed.

In a biology experiment investigating the effect of amount of water on plants, the independent variable is the amount of water. The control group and the experiment group would contain identical plants, with the same soil, temperature, sunlight and air conditions. The control group would then receive a standard amount of water while the experiment group receives a different amount of water. In chemistry, a control group might be a set of chemical reactions that occur at a standard temperature, while the experiment group occur at an increased temperature. In physics, an experiment group of model cars might have an added mass. In psychology, the control and experiment groups must contain the same number of people of the same ages and general health. They should differ only in regard to the independent variable being tested.

Positive control

The **positive control** is an individual test that makes sure a positive outcome is possible. For example, in an experiment to determine whether soap will kill bacteria, a positive control would be to test that the original bacteria are alive.

Negative control

A **negative control** is an individual test to check that the different materials will not affect the dependent variable. For example, in a chemical reaction where an indicator changes colour to show the production of the product, a negative control would be to add a reactant to the indicator to check that it does not cause a colour change (a negative reaction) before the experimental reaction.

positive control
an individual test that checks that a positive result is possible in an experiment

negative control
an individual test that checks that a negative result is possible in an experiment

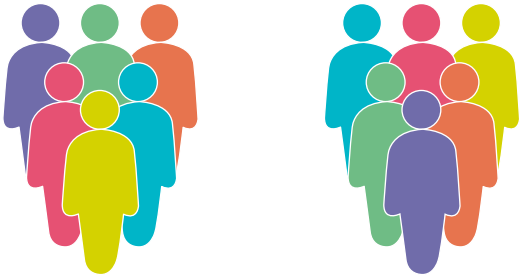

Figure 2 Experiments to determine the effectiveness of dieting require matching participants' ages, sexes, food intake, amount of exercise and general health. Having similar characteristics in each group reduces the number of variables when comparing their results.

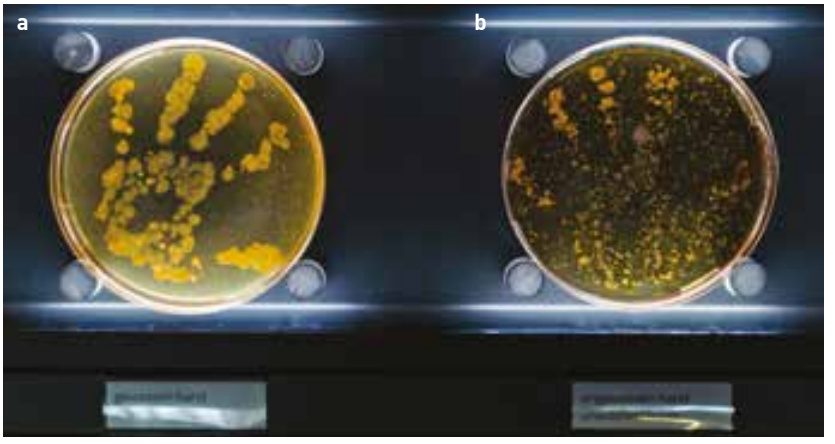

Figure 3 When testing the effectiveness of soap in killing bacteria, **a** the positive control will have bacteria without soap, whereas **b** the negative control will test the soap with no bacteria.

1.3 Check your learning

Remember and understand

1 **Define** the term 'valid'.
2 **Define** the term 'reliable'.
3 **Explain** why a control group should have participants with similar or comparable characteristics to those of the experiment group.

Apply and analyse

4 **Contrast** repeatable experiments and reproducible experiments.
5 **Identify** the variables that need to be controlled in an experiment that tests the following hypothesis. **Describe** how you could control each variable.
If the speed of a car was increased from 60 km/h to 80 km/h, then the distance taken to stop will increase from 27 m to 36 m, because the car will travel further before the driver reacts and the braking distance will also increase.
6 **Describe** a positive control and a negative control for an experiment where an electric circuit was set up to determine whether a crystal was able to conduct electricity.

Evaluate and create

7 Your class is investigating whether adding coffee grounds to soil helps a plant grow faster. One of your classmates suggests adding tea leaves to the soil of a plant as a negative control. **Evaluate** this statement (by defining a negative control and comparing the definition to the student's suggestion, and deciding whether adding tea leaves would act as a negative control).

1.4 Data can be analysed

In this topic, you will learn that:

- bias can affect the design of an experiment or the analysis of data
- graphs can be used to present data
- the mean, median and mode can be used to mathematically analyse data.

first-hand data
data collected by the person writing the report

second-hand data
data collected by someone else

confirmation bias
when a scientist selects a method that will support the outcome they want

There are two types of data that you will examine in science this year: first-hand data and second-hand data. **First-hand data** is data that you collect from your own experiments. This data relies on the careful planning of the experiment to make sure it is a valid experiment that produces reliable results. The second form of data is collected by other people. This data is called **second-hand data**.

When analysing second-hand data, it is important to ask a series of questions. These questions might be as simple as:

- Is the data trustworthy?
- Where did the data come from?
- Why did the person collect the data?
- Is the data unbiased?

Bias

If a person is biased, it means they have already made a decision about a person or outcome. In science, bias can cause an observer to only notice the information that they expect to occur and to avoid or refuse to acknowledge data that is unexpected. Because biased observations only tell one side of a story, it can sometimes cause inaccurate data and leave a false impression. There are many ways bias can affect a scientific investigation.

sampling bias
a bias where a group of test subjects do not represent the larger sample group

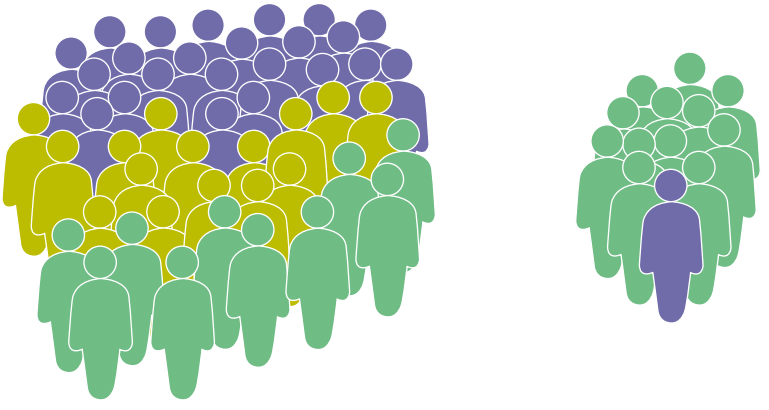

Figure 1 Sampling bias exists when the population of the sample doesn't reflect the actual population.

Confirmation bias

When a researcher has a hypothesis that they are certain is correct, they may shape their investigation so that the data supports the hypothesis. This is known as **confirmation bias**; it involves favouring information that 'confirms' a hypothesis. An example of this occurred in the early 1900s when French scientist Rene Blondlot announced that he had observed a new type of radiation 'glow' called N-rays. He claimed he saw these N-rays released when electricity was passed through particular crystals. Blondlot was so convinced that the N-rays existed, he continued to see them even when an American scientist secretly removed the crystal before a demonstration. Other French scientists also continued to 'see' the glow around crystals for several years because they were convinced that the rays existed.

Sampling bias

When discussing experiment methodology, a sample refers to the people or objects tested in an experiment. The people or objects chosen to be part of a sample should represent the population being studied.

Sampling bias occurs when an experiment tests a small group of subjects (either people or objects) that do not properly represent the larger group. This has been seen most recently during pre-election surveys where people are asked who they will vote for via landline phone surveys in city regions. These surveys often miss people who are not home during the day or who do not have a landline phone because they only use their mobile phones. This means the predictions of who will win an election can be biased because the sample only represents people who own landline phones.

Channelling bias

When scientists want to test the effectiveness of a new drug, they will carefully select a large

group of people and divide them into two smaller groups. When selecting which person will be placed into each group, it is tempting for the scientist to place or 'channel' the people most affected by a condition into the group that will receive the treatment and the people who are least affected into the non-treatment group. But this can affect the outcome of the trial.

Instead, the two groups should be **randomised** (randomly assigned to a group), and both groups should appear to receive the same treatment. This can be done by giving both groups a pill to take at the same time each day. One group will have the new drug in the pill, while the control group will be given a placebo.

A **placebo** is a substance or treatment that is designed to have no effect; for example, a sugar pill. Some people can be so convinced that the treatment will work that a placebo will make them feel better. In one experiment, a group of patients with osteoarthritis of the knee underwent a placebo operation instead of receiving the real procedure. These patients reported feeling less pain as a result of the fake procedure. When participants do not know if they are receiving the real treatment or a placebo, it is called a randomised **blind study**.

Although a blind study is useful, the doctors treating the participants might also behave differently towards a patient if they know the patient is receiving treatment or a placebo. To avoid this, sometimes the treating doctors are not told which treatment the patient is being given. In these tests, only the scientists know the outcome and can decode which group received the treatment. When there are two layers of people who do not know who received the treatment until it is over, this is called a randomised **double-blind study**.

Processing data

There are a variety of tools that can be used to analyse the data of an experiment. One important way is to draw an appropriate graph of the data. All graphs should have:

- the independent variable on the horizontal *x*-axis
- the dependent variable on the vertical *y*-axis
- a descriptive title.

The type of graph you can use will vary according to the type of data. Continuous data can have any value including decimals or fractions, whereas discrete data can only have certain values or names. For example, height (… 1.67 m, 1.68 m …) is continuous data. Colours, categories or types are discrete data.

Line graphs are used when both the independent variable and the dependent variable are continuous data.

Scatter graphs are used when both the independent variable and the dependent variable are continuous and may not be connected by a line. Occasionally a line of best fit can be used to show the trend or direction of the relationship. A line of best fit is a straight line drawn through a group of data points, and it can show the positive or negative relationship (correlation) between two variables.

randomised
when people or objects are selected at random

placebo
a substance or treatment that is designed to have no effect

blind study
when the participants do not know if they are receiving the treatment or a placebo

double-blind study
when neither the participants nor the treating doctors know if they are receiving the treatment or a placebo

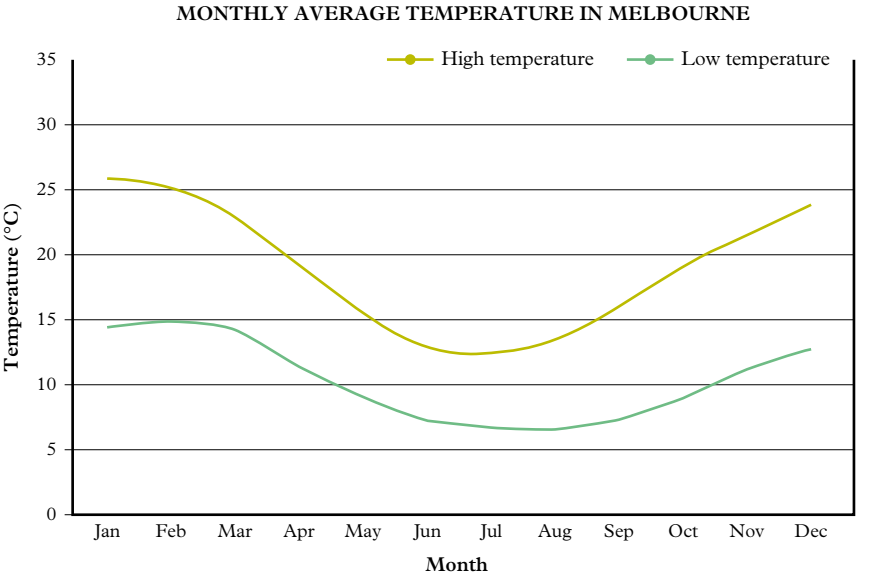

Figure 2 A line graph plots continuous data. In this graph, two data sets are included and are represented by different colours to make it clearer to read.

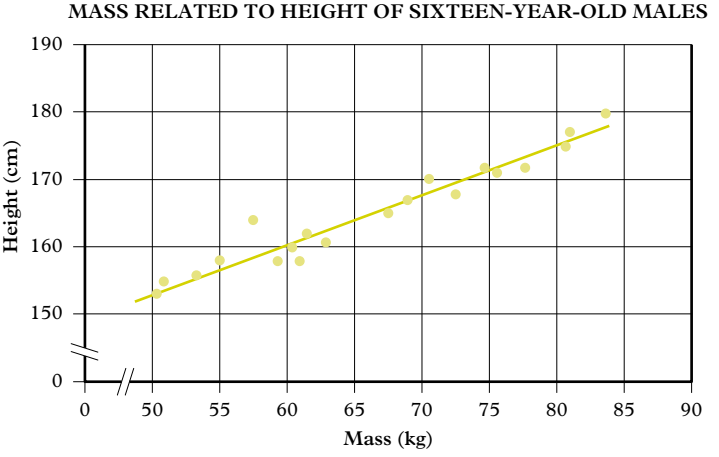

Figure 3 A scatter graph with a line of best fit

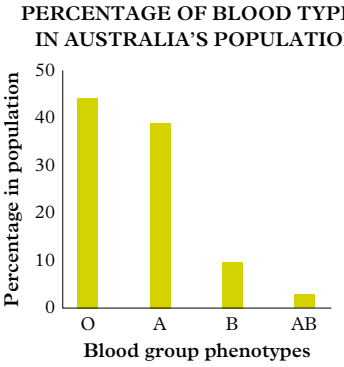

Figure 4 A column graph is used to represent discrete data.

Column graphs are used when either the independent variable or the dependent variable has discrete data.

Analysing numerical data

There are many different ways to use mathematics to represent the data. The average of the data set can be found in a number of ways (outlined in Table 1). Worked example 1.4 shows how to find the average of a data set.

Table 1 Ways to measure the 'average' of a data set

Measure	Description
Mean	• The expected or average value of a data set. • It is calculated by the formula: $\text{Mean} = \frac{\text{Sum of all values}}{\text{The number of values}}$
Median	• The middle value of the data. • It is calculated by placing all the values in order from lowest to highest and then selecting the value in the middle.
Mode	• The most common value in the set of data. • It is calculated by tallying how many times each number appears. The number that appears most often is the mode.

Worked example 1.4: Calculating mean, median and mode

Calculate a the mean, b the median and c the mode for the following times taken for a car to travel 100 m.

278 seconds, 167 seconds, 180 seconds, 208 seconds, 3 minutes

Solution

a Mean: To calculate the mean, all values must be in the same units (seconds).

The data should therefore be: 278 seconds, 167 seconds, 180 seconds, 208 seconds, 180 seconds.

$$\text{Mean} = \frac{\text{Sum of all values}}{\text{The number of values}}$$

$$= \frac{278 + 167 + 180 + 208 + 180}{5}$$

$$= \frac{1013}{5}$$

$$= 202.6 \text{ seconds}$$

As all values have three significant figures, the answer should also have three significant figures.

202.6 seconds should be rounded up to 203 seconds.

Therefore, the mean is 203 seconds.

b Median: To calculate the median, all the values must be placed in increasing order.

167 seconds, 180 seconds, 180 seconds, 208 seconds, 278 seconds

The median value is the middle number, which is 180 seconds.

c Mode: The mode is the most common number in the data set.

The mode value is 180 seconds.

Uncertainties in data

There are many different variables that can affect the outcome of an experiment. Something as simple as measuring the mass of an object on scales can change if someone breathes on the scales, or if a person generates a small breeze by quickly walking past. These small unpredictable variations in measurements are called **random errors**. Random errors can be reduced if the measurements or experiments are repeated.

Another error that can occur is a **systematic error**. These errors occur when there is an error in the equipment that is used (such as scales that constantly measure the wrong mass) or in the way the experiment is completed. Repeating the experiment will not remove these errors. Instead, checking the accuracy of the scales with a known weight or carefully checking that there are no other variables in the method that will affect the outcome will minimise these errors.

Figure 5 Checking the accuracy of scales will minimise errors in data.

random error
when an unpredictable variation in measurement occurs, resulting in an outlier result

systematic error
a repetitive error that occurs when equipment has not been calibrated

1.4 Check your learning

Remember and understand

1 **Define** the term 'bias'.
2 **Define** the term 'placebo'.
3 **Compare** (the similarities and differences between) a blind study and a double-blind study.
4 **Explain** how a blind study or double-blind study can be used to control variables in an investigation.
5 **Contrast** (the differences between) random errors and systematic errors.

Apply and analyse

6 A student measured the amount of hydrogen gas produced from an acid and metal reaction. They repeated the experiment five times to make sure the experiment was reliable. The amount of gas collected in each attempt is shown in Table 2.

Calculate the mean, median and mode for the hydrogen gas produced.

Table 2 The amount of gas produced from an acid and metal reaction

Attempt	Amount of hydrogen gas (mL^3)
1	1.68
2	2.54
3	2.05
4	1.69
5	2.05

7 **Explain** how a scientist can avoid confirmation bias when designing an experiment to test the effectiveness of adding phosphorus to soil to improve plant growth.

Figure 6 Does adding phosphorus to soil improve plant growth?

1.5 Clinical testing uses the scientific method

In this topic, you will learn that:

- all drugs and vaccines must be tested before they are approved by the Therapeutic Goods Administration in Australia
- clinical testing on humans is part of the testing procedure.

The Covid-19 pandemic began in 2019 and caused major disruptions across the world. As a result, there was renewed interest in the importance of science and the scientific method, especially in relation to the rapid development of vaccines.

Vaccines are a way of warning the body's immune system to watch for a particular molecule called an **antigen**. Antigens trigger our body's immune response to fight infection. Most vaccines contain a copy of the antigen, either individually or on the surface of an inactive virus. A few new vaccines contain a copy of special genetic material (mRNA; messenger ribonucleic acid) that allows the body's own cells to make the antigen that warns the immune system.

antigen
a molecule that will cause the body's immune system to react

informed consent
a decision that is made by a person who has had the procedure and possible effects explained to them

Figure 1 During the first phase of clinical trials, the vaccine is tested on a small number of adults.

All new vaccines must go through the same five-stage development cycle.

Stage 1: Exploratory stage

This stage of vaccine development involves basic laboratory research to identify and produce copies of the appropriate antigen molecule. Like a 'wanted' poster, the antigen is used to warn the immune system to watch for the agent that causes the disease. The antigen molecule may also need to be placed on the surface of the inactive virus. This exploratory stage can last 2–4 years and depends on the number of researchers involved and the funding requirements of the laboratory.

Stage 2: Pre-clinical stage

During this stage, the vaccine antigen will be tested on groups of cells in the laboratory or in animal subjects such as mice or monkeys. These tests allow researchers to test how effective the antigen is at warning the immune system and to check that the antigen will not harm the organisms receiving the vaccine. This stage usually lasts 1–2 years due to the costs involved. Most vaccines fail at this point.

Stage 3: Clinical development stage

This stage involves testing the vaccine on humans who have given their **informed consent**. (They understand what is going to happen and the possible side effects and agree to take part.) Three phases of trials must be completed as part of the clinical development process. The scientific method is most obvious during the clinical development trials.

Phase I

The first phase of clinical trials involves the vaccine being tested on a small number of adults (usually adult males) to determine how their immune systems will react. Females are usually not included, to prevent the possibility of a woman undergoing the trial treatment without realising that she is pregnant. The trials take place over several days and start with very small doses before increasing the dose. The participants are carefully monitored to make sure their bodies do not over-react to the vaccine. These trials may be un-blinded (meaning the patients know whether they are receiving a placebo or the real vaccine).

Phase II

In this phase of the vaccine trial, a larger group of several hundred people are treated with different doses, schedules and methods of delivery. These trials are randomised to different adult age groups and different sexes, and these trials always include a placebo group. Pregnant women, children or people with pre-existing conditions are not included in these trials. These trials may also be un-blinded.

Phase III

Vaccines that pass phase II are then tested on groups of thousands to tens of thousands of people. These tests are randomised and double blind. This means the participants and the doctors or nurses injecting the participants do not know whether the treatment is the vaccine or the placebo (either saline or an unrelated safe vaccine). This phase is to test for possible rare side effects that may still occur in healthy people. This stage is designed to test the following:

- Will the participant be protected from the disease's symptoms?
- Will the participant be protected from becoming infected?
- Will the participant produce an immune response?

Stage 4: Regulatory review stage

If a vaccine is shown to be successful during the clinical testing stage, the vaccine company will provide all its data to the Therapeutic Goods Administration (TGA) for a regulatory review and approval. The data is equivalent to a peer review to ensure that the scientific method had been correctly followed. The TGA must also approve the method of manufacturing.

Stage 5: Manufacturing and quality control

Before vaccines can be administered, the manufacturing process must produce a pure, sterile antigen. Most vaccines contain a mixture of substances including the important antigen, an adjuvant (an ingredient to strengthen the body's immune response), preservatives (to prevent bacteria from growing), sugars or oils to stabilise the vaccine, and a solution to dilute the vaccine. Each batch of vaccine needs to be tested to make sure that the manufacturing process is safe.

Fast tracking the process

During 2020, the Covid-19 vaccine approval process was fast-tracked by checking the vaccine manufacturing process while the phase III trials were still being conducted.

The University of Oxford and AstraZeneca vaccine was one of the first vaccines that went through this process. This vaccine was shown to be highly effective when two doses were given 12 weeks apart. This vaccine passed the first two stages of the clinical trials without any difficulties.

However, an error occurred during the phase III trial. Some of the volunteers (all under 55 years of age) received a half dose in the first injection as a result of an error in the concentration of antigen in the manufacturing process. Although the use of a half dose was found to be more effective than the expected full dose, this meant that the phase III trial needed to be repeated because the control group was no longer matched to the test group. Review by the regulatory authorities suggested that the small number of people who received the half dose first (2741) could not be effectively compared to those who received the full dose first (8895). Any differences in participants being resistant to the symptoms of the disease could be due to the statistical effects rather than the effectiveness of the vaccine.

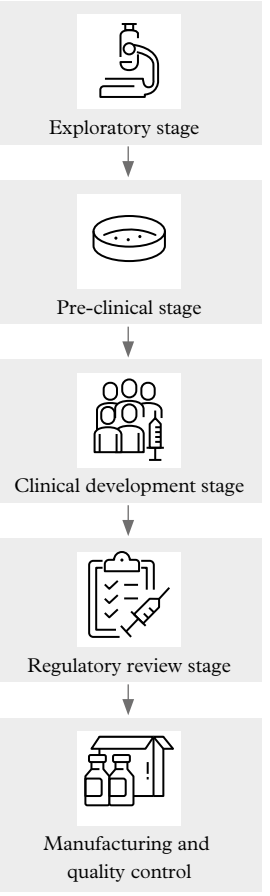

Figure 2 The stages for developing a vaccine

Figure 3 The University of Oxford and AstraZeneca vaccine for Covid-19

1.5 Check your learning

Remember and understand

1 **Describe** how a vaccine works.
2 **Identify** the regulatory body that is responsible for approving drugs for use in Australia.
3 **Identify** what could be used as a placebo in a vaccine trial.

Apply and analyse

4 **Explain** why double-blind studies must be used in the final stage of clinical testing.
5 Use the example of the University of Oxford and AstraZeneca vaccine to **explain** why a control group must match the age and health of the test group.

Evaluate and create

6 **Discuss** the importance of 'informed consent' in drug or vaccine trials.
7 **Evaluate** the ethics of not including female participants in vaccine trials. **Describe** the benefits and consequences of this.

1.6 Scientific investigations must be ethical

Ethics is a set of principles that provide a way to think when making decisions. There are different frameworks for thinking about ethics. For example, consequentialism ethics considers the consequences of an action. Deontological ethics considers duties or rules when making a decision. These approaches can be used to help us make decisions about what is the right course of action, when the answer might otherwise be unclear.

cultural norm
the expectation that you should behave according to the values of the people around you

Science does not always answer questions. Sometimes the study of science can cause many more questions to be asked. An example of this is the invention of dynamite.

Alfred Nobel was a scientist who worked with the highly explosive nitroglycerine. Because of an accident in his laboratory, he experimented on ways to make the nitroglycerine safer so that it could be used in blasting rock and drilling tunnels to build a railroad. He patented this method in 1866. As a pacifist, he was horrified when his invention was used in wars. As a result, he used the wealth that was generated from his invention to set up the most important prize in science (and literature, peace, economics, etc.): the Nobel Prize. Although this might sound like a happy ending, there were many ethical questions raised by this research.

Figure 1 Nobel Prizes are awarded to people who have contributed greatly to the benefit of humankind.

Ethics

Ethics is a set of principles that provide a way to think when making decisions. Sometimes when you make a decision, you use the rules that are written down, such as the school rules or the laws of the government. Other times you use the rules that are not written down. Some rules are set according to what is normal to the people around you. For example, the unwritten rules in your science classroom may be different to the rules in a physical education class. When playing sport, it might be normal to yell to a team member, whereas yelling in a science classroom is not normal. Neither of these rules are written down; however, everyone in the class will know them and behave accordingly. The expectation that you should behave according to the values of those around you is called the **cultural norm**.

The cultural norm in the study of science has traditionally led scientists to ask and answer questions. It is only recently that scientists have started to ask, 'Even though we can, should we?'

Ethical approaches

When answering the question 'Should we?', scientists can use a variety of ethical approaches. Two of the most common approaches are consequentialism ethics and deontological ethics.

CONSEQUENTIALISM ETHICS

The consequentialist approach to ethics considers the consequences of an action in order to decide whether an action is good or bad. This approach can also be described as 'the end justifies the means'.

If this approach was used by Alfred Nobel, he might have considered that his 'invention' was bad, because it had been used to kill many people, and that the science should therefore not have been investigated. Alternatively, if the consequence was setting up the Nobel Prize that led to increased recognition of science and scientists, and the promotion of peace, then the overall action could be considered good.

DEONTOLOGICAL ETHICS

In contrast, the deontological approach to ethics considers each action taken according to a set of rules or duties. If an individual did the 'right thing' at the time, then ethically it is 'good' despite the outcome. Using this approach, Alfred Nobel did the ethically right thing because he wanted to stop people becoming hurt by unstable nitroglycerine. The consequences of this decision are not as important when using this approach.

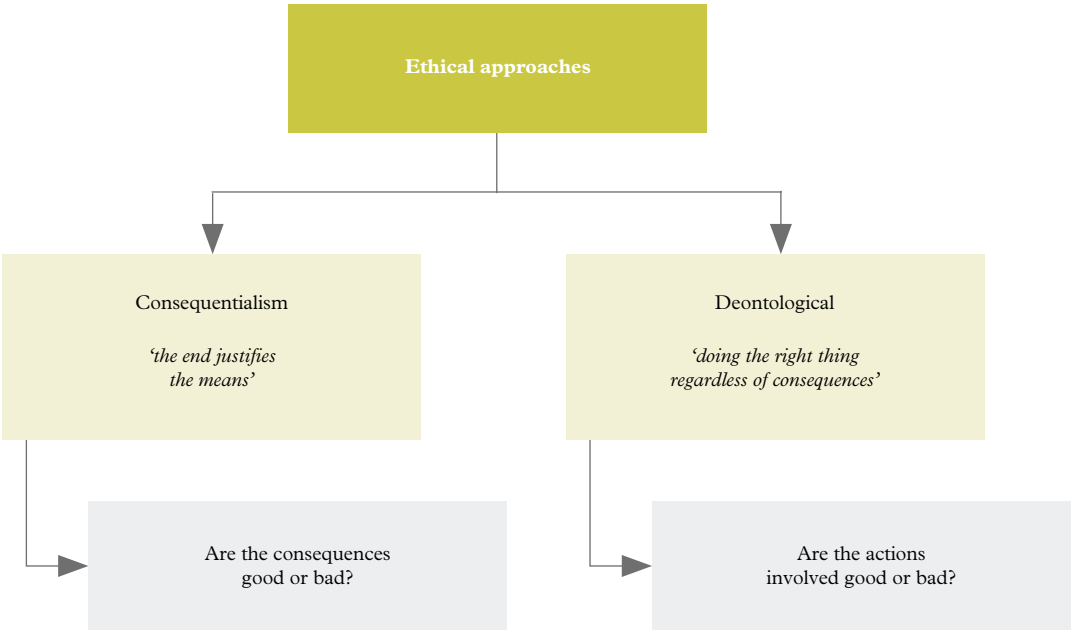

Figure 2 Deontological approaches to ethics consider duties and rules. Consequentialism considers the consequences.

1.6 Develop your abilities

Applying ethics

Using the different ethical approaches can lead to different opinions about what is right or wrong. When this occurs, there is not always a single correct answer to the ethical dilemma. Instead, the consequentialism and deontological approaches can be used to understand the reasons for the different opinions and to provide a common base to discuss the ethical decision that each person would make.

1 **Consider** six ethical problems that occur in science (see the following list). For each problem:
   - use consequentialism ethics to **identify** the issue
   - use deontological ethics to **describe** the issue
   - **identify** any conflicts between the two approaches
   - **describe** the decision you would make
   - **explain** the reasons for the decision.

Is it ethical to:

a dissect humans post-mortem to determine the cause of their death

b test vaccines on animals to determine the safety of the vaccines

c test new drugs on humans to determine the safety of the drugs

d use foetal cell lines in the development of vaccines

e dissect animals in science classes

f develop new flexible plastic moulds (to make ceramic false teeth) that do not degrade?

REVIEW 1

Multiple choice questions

1 **Identify** the section of a written report that contains the analysis of data.
   - **A** method
   - **B** results
   - **C** discussion
   - **D** conclusion

2 A double-blind study occurs when:
   - **A** neither the patient nor the treating doctor knows if the treatment is the placebo
   - **B** the patient does not know if they are receiving the placebo
   - **C** a placebo is used on test animals
   - **D** a placebo is being used.

3 **Identify** which of the following could be used to describe deontological ethics.
   - **A** survival of the fittest
   - **B** the end justifies the means
   - **C** a rules-based approach
   - **D** a common good approach

Short answer questions

Remember and understand

4 **Describe** how a vaccine protects a person from becoming sick from a disease.

5 **Explain** why a placebo may be used in a clinical study.

6 **Describe** the three phases of the clinical trial for drugs or vaccines.

7 **Define** the term 'unconscious bias'.

8 **Identify** and **describe** three different types of bias that can occur in scientific investigations.

9 **Define** the term 'ethics'.

10 Use an example to **explain** the term 'cultural norm' (by defining the term, describing an example and comparing the example to the definition).

11 **Define** the terms 'independent variable' and 'dependent variable'.

12 **Explain** what is meant by the term 'valid experiment' (by defining 'valid experiment' and describing the factors that affect the validity of an experiment).

Apply and analyse

13 **Calculate** the mean, median and mode for the following values. (Express your answers in significant figures.)
14.0, 19.76, 33.1, 26.187, 105.7, 59.0, 73.97

14 **Compare** (the similarities and differences between) consequentialism ethics and deontological ethics (by defining both terms, describing their similarities and describing their differences).

15 **Contrast** (the differences between) methodology and method (by defining both terms and emphasising how they are different).

16 **Compare** the methodologies of modelling and case studies.

17 **Describe** how the selection of people for a sports team could be randomised (by defining 'randomisation' and describing how it can be used to select people for the team).

18 A scientist wanted to investigate if the angle of a ramp affected the time it took for a ball to reach the bottom of the ramp. **Identify** the independent variable and the dependent variable for this experiment.

19 Final VCE exams must be marked by someone who does not know the student. Use your knowledge of bias to **explain** the purpose of this rule.

20 A manufacturer claimed that their antibacterial wash killed 99 per cent of all bacteria.
   - **a** Rewrite this claim as an operationalised question.
   - **b** Write a hypothesis for this question.
   - **c** **Identify** the methodology that could be used to test this hypothesis.
   - **d** **Identify** the independent variable and the dependent variable for this investigation.
   - **e** **Identify** three variables that you will need to control in this experiment.
   - **f** **Describe** a negative control and a positive control that you will need to use in this experiment.
   - **g** **Describe** the method you will use for this investigation.

Figure 1 It is important to check a manufacturer's claims.

Evaluate

21 A consumer scientist wanted to test the effect of a lotion for treating acne. At first, they tested the lotion on a group of 20 teenagers, all aged 15 years old, but then they decided to conduct some more tests on 100 14-year-old teenagers. **Explain** one way to improve the reliability of this experiment (by defining 'reliability', identifying one way the experiment is not reliable and describing how this can be improved).

22 **Identify** a potential random error and a systematic error for the investigation you designed in question 20. **Explain** how you could minimise these errors.

23 A scientist set up an experiment that had seven samples from a control group and seven samples from a treatment group. There are two possible ways to measure the samples:

- Method A: in a random order
- Method B: alternating the control group and the treatment group.

Evaluate which method would be the most appropriate to avoid bias (by describing the way the scientist could be affected by bias in each method and deciding which method would have the least bias).

Social and ethical thinking

24 ClassDojo is a popular online tool that allows a teacher to record what occurs in the classroom. This can include the students' marks, how they behave and what they are currently doing. This information is then converted into a ranking that is shared with the students and parents. The schools and teachers that use this tool claim that it improves the classroom environment by providing feedback to students and parents. Use two ethical approaches to **evaluate** this online tool (by defining both ethical approaches, using each approach to identify and explain the key ethical issues in the online tool, and deciding which ethical approach is similar to your values).

25 A scientist wanted to test whether a particular drug was effective in preventing Alzheimer's disease. He recruited a series of volunteers who had just been diagnosed with the disease and compared them to a control group of volunteers who had no family history of Alzheimer's disease. **Describe** how the scientist should modify this experiment to prevent bias in the test.

26 **Describe** what is meant by 'informed consent'. Use a deontological approach to ethics to **explain** why it is considered unethical to include people who have limited capacity to understand the information provided to them, in medical drug trials.

Critical and creative thinking

27 A new vegetarian dog food claims to give improved coat condition within two weeks. **Describe** how you would evaluate this claim.

Figure 2 Can vegetarian dog food improve coat condition within two weeks?

28 Draw a mind map that identifies the links between each of the glossary terms that are used in this chapter.

29 A customer wrote the following review on a restaurant's website.

'The food was excellent, and the atmosphere was amazing. Our chef is the best in town.'

Identify who might have written the review. **Explain** what feature of the review suggests that the person who wrote it might be biased.

Research

30 Choose one of the following topics for a research project. Some questions have been included to help you begin your research. Present your report in a format of your own choosing.

» Causation versus correlation

The terms 'causation' and 'correlation' can seem very similar. If the independent variable increases when the dependent variable also increases, then the two variables are described as positively correlated. This does not necessarily mean that the independent variable causes the change in the dependent variable. Define the terms 'causation' and 'correlation'. Compare the two terms. Describe an example where a positive correlation does not mean one factor causes the other to change. Describe one example of causation.

» Pharmaceutical bias

Some pharmaceutical companies sponsor medical conferences in exotic locations around the world. They may pay for doctors' flights, accommodation and food during the conference. Explain why some doctors may refuse to attend these conferences. Explain how attendance at these conferences could affect the care of a patient. Describe one way a pharmaceutical company could promote their product without causing bias.

» Ethical machines

Quantum computers use quantum circuits that are based on qubits. These circuits are enabling computers to learn from data and to make decisions based on this data. These decisions can include deciding the diagnosis and treatment of diseases in a hospital and deciding whether a criminal is guilty and how long they should spend in jail. One of the difficulties of this machine learning is the type of data that should be used to teach the machine. Identify and describe the ways machine learning is used to make decisions. Identify the possible bias that could be entered into the quantum computer with the data. Explain how each bias would affect the decisions made. Use the different ethical approaches to discuss the advantages and disadvantages of using machine learning for these decisions.

Reflect

The table below outlines a list of things you should be able to do by the end of Chapter 1 'Science toolkit'. Once you've completed the chapter, use the table to reflect on your ability to complete each task.

	I can do this.	I cannot do this yet.	
Explain how to predict, plan and conduct a scientific investigation. Describe what a logbook is and how to use it.	☐	☐	Go back to Topic 1.1 'There are many types of scientific investigations' Page 2
Explain how scientists communicate when writing reports for different audiences.	☐	☐	Go back to Topic 1.2 'Scientists communicate using scientific language' Page 4
Define independent variables, dependent variables and controlled variables. Describe valid experiments, reliable experiments and control groups.	☐	☐	Go back to Topic 1.3 'Experiments must be controlled' Page 6
Recognise that bias can affect the design of an experiment and the analysis of data. Explain how graphs can be used to present and analyse data.	☐	☐	Go back to Topic 1.4 'Data can be analysed' Page 8
Identify and explain the five stages of developing a new vaccine.	☐	☐	Go back to Topic 1.5 'Clinical testing uses the scientific method' Page 12
Describe the deontological and consequentialism approaches to ethics. Apply ethical approaches to practices in science.	☐	☐	Go back to Topic 1.6 'Science as a human endeavour: Scientific investigations must be ethical' Page 14

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